Geographic Determinants of Human Schistosomiasis Transmission in the Sourou Valley, Burkina Faso

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"Our vision at Schistosomiasis Control Initiative (SCI) is a world free of Neglected Tropical Diseases (NTDs). This would allow the world's poorest populations to be healthier, develop fully, learn effectively, raise families, and be productive members of their communities, thereby helping to realise the Millennium Development Goals of sustainable poverty reduction."[1]

[1] SCI; accessed on : http://www3.imperial.ac.uk/schisto

Dedication

To my beloved wife and children

To my beloved mother

To my brothers and sisters

To my deceased father for inspiring me

Acknowledgements

Thanks to the almighty God: my dream came into reality.

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List of abbreviations

AICc	Akaike Information Criterion
AIS	Agent Itinérent de Santé
AMVS	Autorité de Mise en Valeur de la Vallée du Sourou
AOI	Area of interest
BDOT	Base de Données de l´Occupation des Terres
BNDT	Base National de Données du Territoire
BNWDI	Banlanced Normallized Water Demand Index
CHR	Centre Hospitalier Régional
CHU/N	Centre Hospitalier Universitaire/National
CISSE	Centre d´Information Sanitaire et de Surveillance Epidémiologique
CLW	Laundry
CM	Centre Médical
CRS	Children Recreational Swimming
CRSN	Centre de Recherche en Santé de Nouna
CSPS	Centre de Santé et de Promotion Social
CV	Cross Validation
DEFCON	DEFence CONdition
DGISS	Direction Générale de l'Information et des Statistiques Sanitaires
DRS	Direction Régionale de Santé
DS	District Sanitaire
DWCI	Daily Water Contact Index
EC	Environmental Contamination
FDB	Fixed Distance Band
GEO	Group on Earth Observations
GIRE	Gestion Intégrée des Ressources en Eau
GIS	Geographic Information Systems

GPS	Global Positionning System
GWR	Geographic Weighted Regression
HD	Hôpital de District
HD	Hot Day
HI	Human Infestation
HP	Hand Pump
HW	Hydraulic Works
I.D.E	Infirmier Diplomé d´Etat
IB	Infirmier Brevété
IGB	Institut Geographique du Burkina
INSD	Institut National de la Statistique et de la Démographie
IRR	Irrigation
IWCI	Individual Water Contact Index
MAT	Mean Air Temperature
MCC	Millennium Challenge Cooporetion
MDA	Mass Drogue Administration
MDG	Millennium Developement Goals
MW	Modern Well
MWP	Modern Water Point
NNCD	Nearest Neighbor Compounds Distance
NNSD	Nearest Neighbor Settlements Distance
NTA	Non-Targeted Activity
NTD	Neglected Tropical Disease
ON	Office du Niger
PN-AEPA	Programme National d´Aprovisionnement en Eau Potable et Assainissement
RS	Remote Sensing
SD	Standard Distance

SDE	Standard Deviational Ellipse
SSA	Sub Sahara Africa
TEAR	Theoretical Effective Average Radius
TFP	Traditional Fishing in Ponds
TW	Traditional Well
WBG	Water lily Bulbs Gathering
WDI	Water Demand Index
WF	Water Fountain
WHO	World Health Organization

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Chapter 1. Introduction

1.1. The relevance of studying geographic determinants

1.1.1. Background

Throughout her work "*Influences of Geographical Environment*" Semple (1911, cited, Haggett, 1968, p. 22) has decisively contributed to spreading the idea that study of geographical determinants is an essential goal of the geographical research. Geography is an exciting and dynamic subject, concerned with issues which affect us all no matter where we live. We are all to a greater or lesser extent concerned with environmental quality and social well-being (Daniel & Hopkinson, 1989). Given that disease is a multiple phenomenon occurring only if various factors coincide in time and space, the focus of interest widens to include the relationship between these various factors and their respective geographical components (May, 1950, cited, Koch, 2005, p. 216). Geographical studies of disease are valuable for two major reasons (Mayer, 1983). The first reason is that they suggest possible causal factors in pathogenesis. The second reason is more subtle. Spatial patterns of disease may serve as useful indicators of how regions are structured, and of how individuals and groups exist in mutual interaction with the environment. Elements of this interaction may be adaptive, while other elements may be maladaptive (Mayer, 1983).

The pre-eminence of places as object of geography compared with the disease, affirms clearly the specificity of the geographical field compared with others sciences dealing with disease (Dory, 1995; Fromageot et *al.*, 2005). Situating schistosomiasis at the inter-face environment-health, the geographer finds here a field of application particularly fecund and has in this way a long history (Dory, 1995; Grisorio et *al.*, 2005). Moreover by associating with its spatial analysis, the physical and human dimensions, the geographer responds to the new understanding of relations between the health and the environment, building an eco-health system (Amat-Roze, 1998; Grisorio et *al.*, 2005; Fromageot, 2005).

The central place of the geography was recognized since 1772 by Finke (a medicine professor) (Garrison, 1932) throughout his work: "*Essay on General Medico-Practical Geography*":

"Firstly, he [Finke] has indicated that topography, chorography, and geography have all a common basis. […] Together they study the nature and the relations between places. That distinguishes them is the scale. […] Secondly, by using these three levels at a comparative scale he has used the fundamental geographical approach. He has applied geographical criteria, non-medical, in order to demarcate the extent of medical problems because he was suspected that the causalities were geographic and not medical." (Barrett, 1993, cited Brillet, 1995, p. 22-23).

This implies that geographical methods have long been used as aetiological tools to provide clues about the reasons for occurring diseases (McGlashan, 1972, cited, Ali et *al.*, 2001, p.100). The essence of geography remains in the description, analysis, and explanation of spatial patterns of health, disease and health care, as well as the application of normative concepts of location within particular social, economic, and institutional contexts (Pyle, 1979, cited, Mayer, 1990, p.176).

Sorre (1933) argued that the extended area of an endemic or epidemic disease is that of a pathogenic complex. His concept firstly addressed the contraction and expansion movements of the extended area to the ecological problem, whom explanation is an essential goal in physical geography (Le Bras & Malvy, 2004). It also encompassed the external circumstances that favour or obstruct the constitution or maintenance of the complex such as population density, migration and lifestyles; which circumstances deal with human geography (Le Bras & Malvy, 2004). Picheral (1983, cited, Handschlimacher et *al.*, 2003, p. 298) has introduced the term "pathogenic system" instead of "pathogenic complexes" (naturalist concept) for making the Sorre's concept more globalist and holistic. Renewing Sorre pathogenic complex approach, May (1950, cited, Koch 2005, p. 216) launched the modern geography of health which goal is clearly to understand the interrelations between physical geography, social context, and disease pathology.

1.1.2. Traditions in geography

1.1.2.1. Spatial tradition

The first concern in geography is the location that means a fixed point or geographical area on the earth's surface, somewhere that can be pinpointed by using a pair of locational co-ordinates (latitude and longitude) (Gatrell, 2002). This tradition is well caricatured by Emmanuel Kant's words cited by Barry (1963): "As History encompasses the unifying element of time, so Geography provides the unifying element of space". In other words geography deals with man, plus his environment, in his distribution through space. The spatial tradition, therefore, emphasizes on space, spatial form, spatial structure, distance, direction and position (Mayer, 1990).

1.1.2.2. Regional tradition

It consists largely of place description and characterization and includes the application of spatial and ecological concepts and principles in particular regional settings (Pattison, 1964; Mayer, 1990). Gatrell (2002) stated that our "health" and our "geographies" are inextricably linked, because we occupy localities and move from place to place in the course of our lives. This means that each region is unique (Hartshorne, 1939, cited, Haggett, 1968, p. 13). Alfred Hettner must be cited in this tradition (Barry, 1963, p. 118): "Geography is the chorological science of the earth or the science of earth areas and places in terms of their differences and their spatial relations. The goal of the chorological point of view is to know the character of regions and places through comprehension of the existence together and interrelations among the different realms of reality and their varied manifestations, and to comprehend the earth surface as a whole in its actual arrangement in continents, larger and smaller regions, and places."

1.1.2.3. Man-land tradition

Also known as the human-environment tradition, it is concerned with the knowledge of the relations between culture and physical environment, and human ecology (Pattison, 1964; Mayer, 1990). Sauer (1925, cited, Haggett, 1968, p. 21) distinguished the natural landscape, anterior to the intervention of human from cultural landscape, modified or transformed by human. Where you live affects your risk of diseases or ill-health, the treatment you get, and your access basic resources (Gatrell, 2002). For Woolridge & Gordan (Barry, 1963, p. 119): "Geography seeks to discover the spatial relationships of the manifold features, physical and human, which diversify the earth's surface." In other words the main concern of the geographer is with the distribution of man and his material works, and with the unravelling of the causes and consequences of inequalities in that distribution (Barry, 1963).

1.1.3. Geography of health

1.1.3.1. A geographic discipline

The geographic study of human schistosomiasis comes within the framework of geography of health with the target of putting into perspective the natural and social determinants of the states of health in some given areas (Salem, 1995; Gatrell 2002). Hunter (1974, cited, Mayer, 1990), referred to geography of health as the application of geographical concepts and techniques to health-related problems; thus bringing out the close relationship between geography of health and geography (Mayer & Meade, 1994). According to Menard (2002), geography of health is endowed with a particular profile with multiple facets including and dealing with all geographical specialities, for physical as much as for human (Figure 1). Therefore, this means that questions which are central to geography of health inquiries are questions which are central to geography itself (Mayer, 1990).

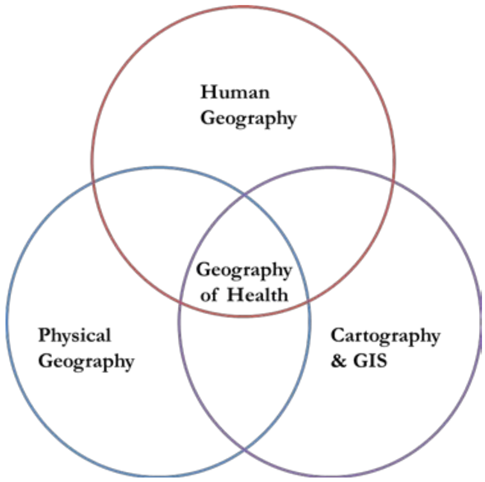


Figure 1: Internal dialogue between geographic disciplines

1.1.3.2. Geography of health's subdisciplines

The geography of heath can be divided into three subdisciplines: medical geography, health geography and geographic medicine (Figure 2).

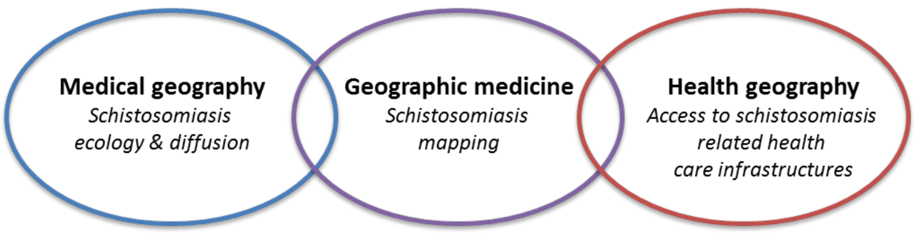


Figure 2: Geography of health intra-related streams

- Medical geography

Also termed as geography of pathologies, medical geography is the approach of geography of health to schistosomiasis ecology and diffusion (Figure 2) based on the landscape concept (Pyle, 1976; Meade, 1977; Bimal, 1985; Kearns & Alun, 1993; Rosenberg, 1998; Barrett, 2000; Gatrell, 2002; Menard, 2002). The knowledge of patterns of human movements and transportation, in particular forms of social organization in society, are essential in terms of disease spread (Meade, 1997; Mayer, 2000). Particularly concerned with the influence of the physical environment, the background of medical geography could be rooted in physical geography.

- Health geography

Also known as ethnomedicine or geography of health care systems, health geography deals with the spatial properties of delivery systems, and the access, utilization and planning of health care services (Figure 2) (Pyle, 1976; Meade, 1977; Bimal, 1985; Kearns & Alun, 1993; Rosenberg, 1998; Menard, 2002; Gatrell, 2002). It also makes manifest social inequalities emerge face to the disease and to the death, for lack of access to care and to preventive measures (Meade, 1977). From the mid-1960s particular attention has been paid by geographers to approaches of health-care planning, health-seeking behaviour and health service provision, which are deeply rooted in location theory, transport, and public service provision (Bimal, 1985). The knowledge of different perceptions of disease and concepts of causality and appropriate treatment is useful to geographical concern for the utilization of health care services (Meade, 1977). A recent interest is given to traditional medicine systems particularly in developing countries. This emerging approach is called ethnomedicine and medical pluralism first recognized by Good (1997) as a major field for basic and applied research in health geography. He proposed a rational for involving geographers in the field of traditional medicine and suggested possible lines of geographic research. Therefore, the background of health geography could be linked to human geography.

- Geographic medicine

Also termed geomedicine, geographic medicine aims to map out not only the distribution and peculiarities of disease, but also the status of medicine and sanitation over given areas, within the same time-interval (Garrison, 1932; Barrett, 2000). Mapping is like storytelling and mapmaking is like story writing; two distinct things but related and interdependent: there is no mapmaking without map thinking (Koch, 2005). Disease ecology visualization on maps dates from the first third of the 19th century, and was conceptualized by naturalists, such as Humboldt, based on the technique of isotherms (Brömer, 2000). Medical mapping, which is a way of showing abstract things in a graphic and practical way, materializes geographers shift from static and deterministic to dynamic and probabilistic enterprises (Koch, 2005; Haggett, 1968). This means that the background of geographic medicine is rooted in cartography & geographic information systems (GIS). Coupled with GIS, geography is helping us to better understand the earth and apply geographic knowledge to a host of human activities. Geographic medicine is viewed by Rosenberg (1998) as the hyphen between medical geography and health geography (Figure 2).

1.2. Human schistosomiasis

Human schistosomiasis (also known as Bilharzia) is a disease caused by infection with blood flukes of the genus *Schistosoma*. Most cases of the disease result from infection with *Schistosoma japonicum* and *S. mansoni* both of which cause intestinal schistosomiasis and *S. haematobium,* the causative agent of urinary schistosomiasis. The larvae of the organism (cercariae) are released into water by infected snails. Human contact with water inhabited by the snails is the source of the persistence of schistosomiasis (World Health Organazition (WHO), 2013).

1.2.1. Historical information

1.2.1.1. Discoveries

Until the identification of its causative agent in 1851 in Egypt by Bilharz (Tan & Ahana, 2007), urinary schistosomiasis was vaguely recognized under names like "Tropical hematuria" or "menstruating males of Egypt" because the chronic form leads to the discharge of blood in urine. Bilharz was the first to describe in detail, from careful observation of autopsy specimens, the *Schistosoma* organism as well as the macro- and microscopical pathological changes they caused. Bilharz named his discovery *Distomum haematobium*. In 1856, the terms "Bilharzias" and "Bilharziasis" were given to the disease and published in his honour by Hemsbach (Shousha, 1949). In 1858, Weinland introduced the terms "schistosoma" and "schistosomiasis" as being synonymous with the disease Bilharziasis (Tan & Ahana, 2007). The term comes from the Greek *skhistos* (split) and *soma* (body). In 1907, Sambon discovered in Egypt a second species of *Schistosoma*. He named the parasite *S. mansoni* because Manson had noted this peculiarity few years earlier in a specimen from a West Indian case of the intestinal disease (Carmichael, 1929; Garnham, 1970). In 1915, in Egypt, Leiper demonstrated, using monkeys as experimental mammalian hosts, that *S. haematobium* and *S. mansoni* were two distinct species and that they required different snails of the genus *Bulinus* and *Biomphalaria*, respectively, as intermediate hosts (Sandbach, 1976). Katsurada discovered *Schistosoma japonicum* in 1904 in Central Japan which was the first report of the intestinal schistosomiasis outside Egypt (Carmichael, 1929).

1.2.1.2. Parasites origin and spread

The scientific proofs found in Egypt such as the discoveries of the parasites and its life cycle, the earlier view that the Egyptian medical papyri contained description of the symptoms of *S. haematobium*, and its first diagnostic in Egyptian mummies (Ruffer, 1910; Kloos & David, 2002; Harter-Lailheugue & Bouchet, 2006), strongly contributed to the view that schistosomiasis (and several other infectious diseases) originated in Egypt. But several studies of the paleoecology of the parasite, the snail intermediate hosts and humans demonstrated that schistosomiasis existed together with their human host around the headwaters of the Nile much earlier, at least as early as the Paleolithic era (Wright, 1970, cited Kloos & David, 2002, p. 15). In addition, the earlier view that Egyptian medical papyri contained descriptions about *S. haematobium* infection has been recently rejected (Nunn, 1996; Westendorf, 1992, cited Kloos & David, 2002, p. 15). From 1961, according to the same authors, Egyptologists have finally accepted that the determinative *âââ* instead of haematuria meant semen or poison. Therefore, opinions are divided on the origin of schistosomiasis between Africa and Asia.

According to Davis (1982), based on a biogeographical scenario, schistosomiasis originated in Gondwanaland or supercontinent (South America, Africa, Antarctica, Australia, India and Arabia) (Figure 3a). From Africa *Schistosoma* and associated snail faunas reached Asia via the India Plate 70-148 million years ago (Kloos & David, 2002). South America was colonized 80-120 million years ago by African strains before the breakup of the supercontinent (Morgan et *al.*, 2001). Running counter to Davis' ideas, the hypothesis in favour of the Asian origin was suggested by Snyder & Loker (2000) and based on a phylogenetic study (Figure 3b). They concluded that the African strain originated from Asia. After diversification, the African *Schistosoma* strain was reintroduced into India. However, the scenarios explaining the invasion of South America by the African strain through slave trade (Davis, 1982; Snyder & Loker, 2000; Morgan et *al.*, 2001).

Bearing in mind that the australopithecines and their successors lived in close proximity to freshwater in East Africa (Fenwick, 1969, cited Kloos & David, 2002, p. 15), that from there, the human species amply diversified itself and spread through the world (Templeton, 2002, cited Cox, 2002, p. 595); we agree with Davis' opinion that schistosomiasis originated from Africa (Figure 3a). The region of the African great lakes is assumed to be the "cradle" of schistosomiasis where parasites and their intermediate hosts are in an active state of evolution (Adamson, 1976; Sandbach, 1976). In addition, the presence to date of a rich snail fauna about half a dozen species each of *Biomphalaria* and *Bulinus* in Ethiopia strongly suggests that schistosomiasis evolved in East Africa (Kloos & David, 2002).

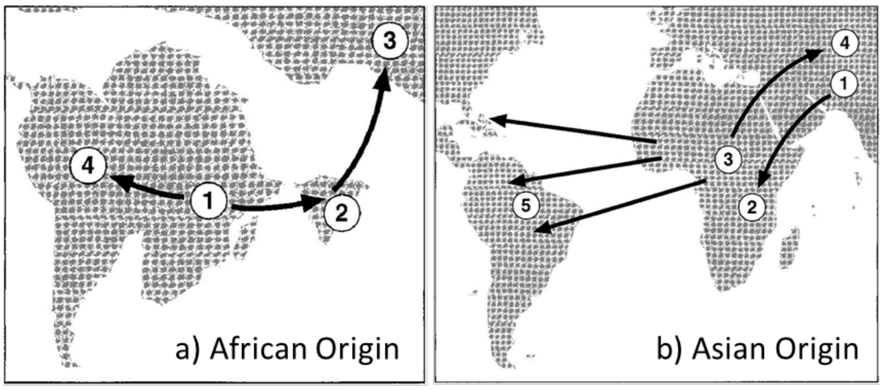
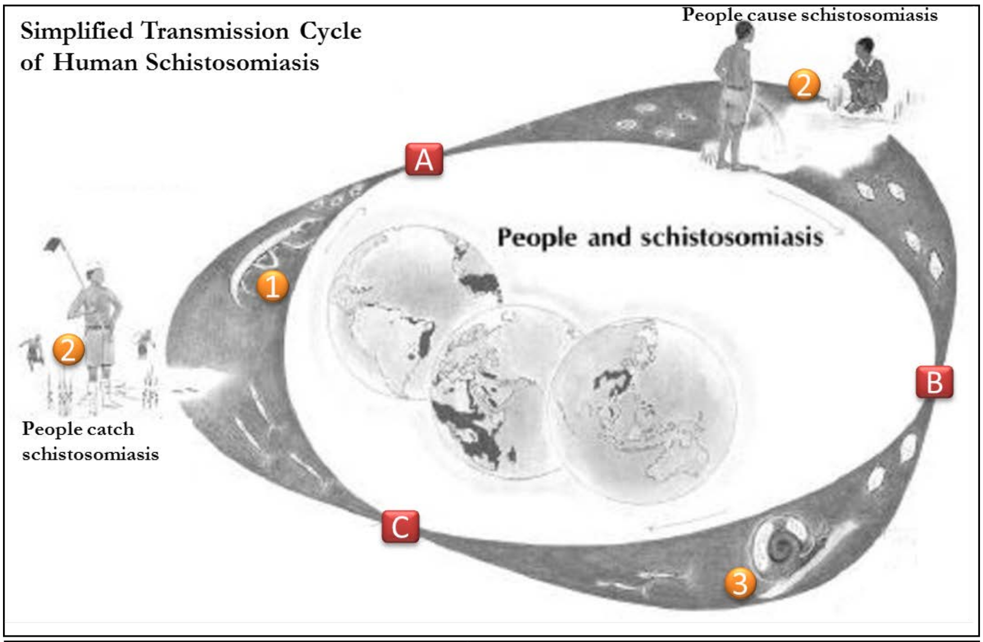


Figure 3: Scenarios about origins of schistosomiasis (Source: Snyder & Loker, 2000)

1.2.2. Human Schistosomiasis: A typical water-based transmitted disease

To complete their life cycle, schistosomes need two different hosts, human-beings and snails (Figure 4). Human is qualified as the definitive host of schistosome worms because humans support the sexual development of the parasite. The snail stands as the intermediate host because it supports only the asexual development of the parasite. However, these three actors (schistosomes – human – snail) are linked by complex inter-connections that are achieved in the water body which is the environment common to the three actors and necessary for transmission to take place (Gentilini, 1993; Grisorio et *al.*, 2005; Gryseels, et *al.*, 2006; King 2009). The transmission cycle also depends on three inter-dependent stages (Figure 4). The production of eggs after copulation (A) is a prerequisite for environmental contamination (B) which is the transmission of parasites from humans to the snail intermediate host. Parasites spend part of their life cycle in the snail. The transmission of parasites from snail to the human (C) is called human infestation stage. Once into the human body, parasites copulate in order to produce eggs (A).

The human-being plays an active role by causing schistosomiasis (B) and catch (C) schistosomiasis. The afore-mentioned represent the two main important transmission stages.



Schistosomiasis transmission actors			Schistosomiasis transmission stages		
Schistosome	Human	Snail	Eggs production	Environmental contamination	Human infestation
1	2	3	A	B	C

Figure 4: Simplified human schistosomiasis transmission cycle (Adapted from WHO, 1990 in Utzinger, 1999, p.13)

1.2.2.1. Parasite lifecycle

- In human host: sexual reproduction

The penetration of the cercariae through human skin remains the commonest and well documented way by which one gets infested by schistosomiasis (Gentilini, 1993; Gryseels et *al.*, 2006, King, 2009). This form of infection occurs during swimming, bathing, irrigation, fishing, laundries and all other activities leading humans to get into contact with contaminated water. As a rule, parasite needs no injury to enter the human skin. The complete process of cercariae penetration into human skin needs a relatively short time of about 10 minutes (Oliver, 1949; Gentilini, 1993).

Once having penetrated the human skin, the cercariae migrate passively into the blood via the lungs and heart to the liver and become schistosomulae (young worms). Schistosomulae develop to reach differentiation and sexual maturity. After 4 to 6 weeks, the schistosomes (adult worms) appear in the portal vein and migrate to their final perivascular (*S. heamatobium*) or mesenteric (*S. mansoni*) destination where male and female worms copulate (Gentilini, 1993; Gryseels et *al.*, 2006; King, 2009). The female produce hundreds of eggs daily (about 3500 for *S. haematobium* and 400 eggs for *S. mansoni* per female/day) which drop into the lumen of bladder or the intestine from where they will be excreted into the urine (urinary schistosomiasis) or feces (intestinal schistosomiasis). Eggs do not automatically become worms in the infested person's organs. Laid in the environment, the eggs can stay viable for up to 7 days (Gentilini, 1993; Gryseels et *al.*, 2006; King, 2009). To keep evolving, eggs must fall (directly or indirectly) into water in which they have to find and penetrate their respective snail intermediate hosts. The development of the parasite in humans is not influenced by environmental variables.

- In snail intermediate host: asexual reproduction

Upon reaching the water, each egg hatches to release a tiny parasite called miracidium (first larval living stage). If, after 8-12 hours, the miracidium do not find and penetrate the suitable snail intermediate host then it dies (Gentilini, 1993; Gryseels et al., 2006, King, 2009). Once in the appropriate snail host, the miracidium proliferates asexually into sporocysts and develops into thousands of cercariae (second larva living stage) which start leaving the snail about 4 to 6 week later. One snail infested by one miracidium can shed thousands of cercariae every day for months. The fork-tailed cercariae can live up to 72 hours outside the snail, within which time they must penetrate the skin of a human-being (Gentilini, 1993; Gryseels et *al.*, 2006; King, 2009). Then, a new cycle starts again.

Water temperature of between 10 and 30 °C is a prerequisite for egg hatching (Allison et *al.*, 1974, cited, Weil & Kvale, 1985, p. 197). The ability of the miracidia to penetrate snails is also influenced by the water temperature which ranges from an optimum of 26 to 28 °C. Below 10 °C miracidia are very inactive (DeWitt, 1955; Chu et *al.*, 1966). The parasites within the snail intermediate host are profoundly influenced by habitat temperatures (DeWitt, 1955), particularly the length of the pre-patent period in snails (Stirewalt, 1954). Gordon et al. (1934, cited, Stirewalt, 1954, p. 510) obtained similar results with the Egyptian *S. mansoni* in *Planorbis pfeifleri*, where the pre-patent period lasted 15 days at 32 to 33 °C; 19 to 22 days at 26 to 28 °C; and 33 to 37 days at 20 to 22 °C. Comparable periods for *S. haematobium* in *Physopsis globosa* were 22 to 23 days at 32 to 33 °C; 36 days at 26 to 28 °C and 66 to 68 days at 20 to 22 °C (Stirewalt, 1954). The infectivity rate or the cercariae capacity to penetrate the skin depends on temperature with an optimum of 26 °C to 28 °C (Stirewalt, 1954).

1.2.2.2. Life cycle of snail intermediate host

All species of *Bulinus* and *Biomphalaria* are hermaphrodites (Wright, 1970, cited, Weil & Kvale, 1985, p.198). It means that they possess both male and female organs and being capable of self-fertilization, but cross-fertilization between individuals is possible. A snail can lay eggs at intervals in batches of 5-40, each batch being enclosed in a mass of jelly-like material. After 6-8 days, the young snails hatch and reach maturity in 4-7 weeks, depending on the genus and environmental conditions. Within 5 months, a single snail can have about 50,000 snailets. The lifespan may last more than a year. The parasites multiply in the snail and not in man (Nelson, 1990).

Although, they have distinct ecological niche preferences, both *Biomphalaria* and *Bulinus* are aquatic that live under water and cannot usually survive elsewhere. They are most common in water moderately polluted with organic matter, such as feces and urine (Lévêque, 1980; Weil & Kvale, 1985; Poda, 1996). *Biomphalaria* prefers deeper water with less vegetation while *Bulinus* which tolerates high temperatures occupies shallower water with abundant aquatic vegetation (Appleton & Bruton, 1979, cited, Weil & Kvale, 1985, p. 199). The water quality and quantity also matter. According to Webbe (1966) and Shiff (1969) (cited, Sukhdeo & Sukhdeo, 2004, p. 298), water flow is considered to be of critical importance because flow rates >15 cm per second prevent miracidia of *S. haematobium* from finding and penetrating *B. globosus* at the bottom of the ponds while flow rates as high as 105 cm per second do not affect the miracidia of *S. mansoni* from finding *B. glabrata* on the surface.

Temperature and food availability are among the most important limiting factors. The optimal temperature (Sturrock, 1993, cited Brooker, 2007, p. 3) for snail development and survival is around 25-26 °C. Snails tolerate water temperature range from 12.5 to 35 °C for *Biomphalaria* and 10 to 37° C for *Bulinus* (Moussa & El-Hassan, 1972, cited, Weil & Kvale, 1985, p. 197). They do not usually lay eggs in temperatures below 18° C. Egg laying behaviour increases proportionally with temperatures up to 30-35 °C. Above this level, snail and egg mortality rise dramatically (Sturrock, 1993, cited Brooker, 2007, p. 3). However, exposure to 40 °C for 2 hours resulted in high death rates among all snail strains (DeWitt, 1955).

The food quantity and/or quality are the main limiting factor to the enormous reproductive capacity of snails. The number and mass of eggs in the spawn, and the number of free-living offsprings increased with high nutrient loading (Slootweg et *al.*, 1994; Brönmark, 1990; Jones et *al.*, 1992; Madsen, 1992).

1.2.2.3. Symptoms – manifestations – Diagnosis of the disease

Primary itching is the first sign of penetration of cercariae into the human skin (Oliver, 1949). Acute schistosomiasis leads to fever, urticaria, cough, neck pain and headache (Grandière-Pérez et al., 2006). In invasive infectious cases, about half of the eggs do not leave the body but embedded in the body tissues where they cause damage to organs (Gentilini, 1993; Gryseels et *al.*, 2006; King, 2009). The severity of symptoms depends on the number of male and female schistosome worms in a particular patient and location of the eggs. In urinary schistosomiasis, the eggs cause damage to the urinary tract and blood appears in the urine (hematuria). Urination becomes painful and there is progressive damage to the bladder, ureters and kidneys. Bladder cancer is a common complication (van der Werf et *al.*, 2003; Gryseels et *al.*, 2006; Steinmann et *al.*, 2006; Utzinger et *al.*, 2009; WHO, 2013). In intestinal schistosomiasis, the eggs lead to a progressive enlargement of the liver and spleen as well as damage to the intestine and hypertension of the abdominal blood vessels. Symptoms such as bloody diarrhoea, abdominal pains and fatigue are commonly reported (Gryseels & Nkulikyinka, 1990; Tanabe et *al.*, 1997). Some subjects may be infested by both urinary and intestinal forms. These co-infested individuals often harbour heavier infections than individuals infected with a single species. Symptoms such as fever, anemia, malaise and glucose intolerance have been reported by patients with schistosomiasis; however, these are not diagnostic of the disease because they can be experienced by patients with other diseases (Hotez et *al.*, 2008; Utzinger et *al.*, 2009). The clinical diagnosis of schistosomiasis is commonly based on the presence of schistosomes eggs in urine (*S. haematobium*) or in stools (*S. mansoni*) (Katz et al., 1972; Gentilini, 1993; Chitsulo et al., 1995; Gryseels et al., 2006, King, 2009).

1.2.3. Human schistosomiasi: A world problem

1.2.3.1. Overview of the current global distribution of schistosomiasis

Table 1 summarizes types of diseases and parasites, snail intermediate host genus and their geographic distribution, and codes of the international classification of diseases (ICD version 10). According to the WHO Weekly Epidemiological Record (WHO, 2012a), 77 countries were reported to be endemic areas in which one or more *Schistosoma* species are transmitted.

Table 1: Overview of human schistosomiasis

Type of disease	Symptom	Diagnostic	Type of parasite	Snail genus	Snail Geographic distribution	ICD-10 code
Urinary	Hematuria	Eggs in urine	*S. haematobium* (Bilharz, 1851)	*Bulinus*	Africa, the Middle East	B65.0
Intestinal	Bloody diarrhoea	Eggs in stool	*S. mansoni* (Sambon, 1907)	*Biomphalaria*	Africa, the Middle East, the Caribbean, Brazil, Venezuela, Suriname	B65.1
			S. japonicum (Katsurada, 1904)	*Oncomelania*	China, Indonesia, the Philippines	B65.2
			S. intercalatum (Fischer, 1934)	*Bulinus*	Rain forest areas of central Africa	B65.8
			S. mekongi (Vic-Dupont, 1957)	*Neotricula*	Cambodia and the Lao	B65.8

Source: Carmichael, 1929; Shousha, 1949; Deschiens & Delas, 1969; Garnham, 1970; Gryseels & Nkulikyinka, 1990; Tanabe et *al*., 1997; Matsumoto et al., 2002; Tan & Ahana, 2007; Katz, 2008; Machado-Silva et *al*., 2010; WHO, 2012a.

1.2.3.2. Human Schistosomiasis: A typical endemic tropical disease

Schistosomiasis transmission occur in endemic areas which are limited to tropical areas (Figure 5) that contain more than half the population of the earth (Engels et *al*., 2002; Kloss & David, 2002; Gryseels et *al*., 2006). The geographic distribution of snail intermediate hosts is the most important factor accounting for the endemicity of the diseases and transmission of the parasites. For example, *S. mansoni,* introduced into South America through the slave trade, has become established because of the presence of suitable *Biomphalaria* snail intermediate hosts. On the other hand, *S. haematobium* is not found in South America because there is no susceptible *Bulinus* snail host (Sandbach, 1976). The snail refractoriness was tested by Dewitt (1955) using two different strains. The Puerto Rican *S. mansoni* miracidia were able to penetrate the Brazilian *A. glabratus*, but the parasite was destroyed and removed within 24 to 48 hours after penetration. According to Newton (1953, cited, DeWett, 1955, p. 275), the refractoriness of this snail to Puerto Rican *S. mansoni* was under genetic control. Although distribution of the parasites and intermediate hosts is geographically limited, schistosomiasis remains one of the most widespread and important human disease and is considered a world problem (Shousha, 1949).

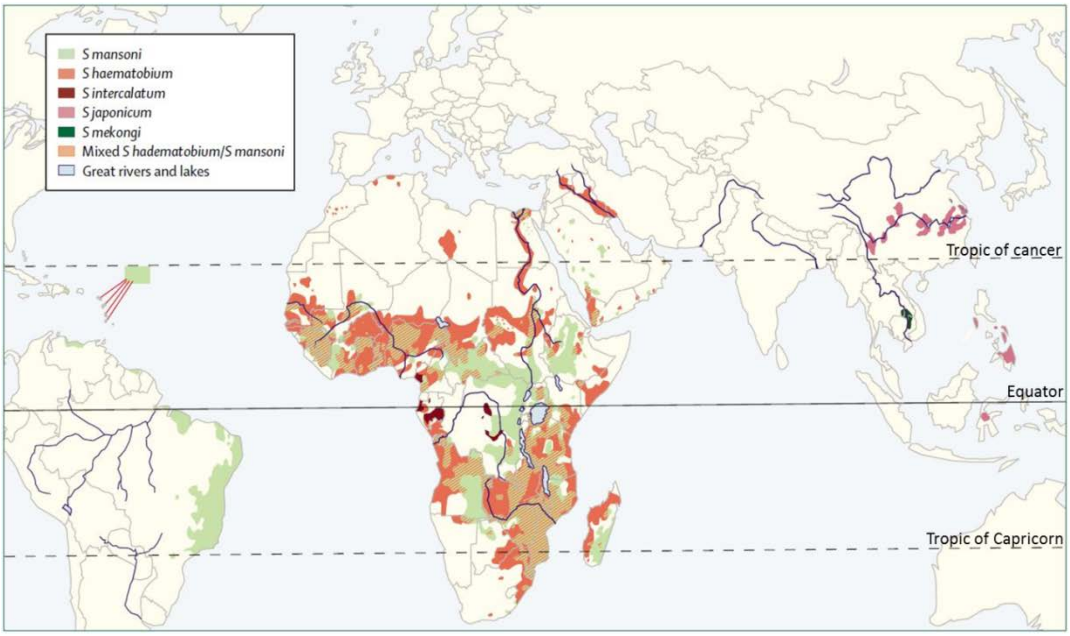


Figure 5: Geographic Distribution of Schistosomiasis Endemic Areas (After: Gryseels et al., 2006)

Due to the ease of travel between continents, schistosomiasis spread could be readily enhanced. The increase in ecotourism and adventure tourism in schistosomiasis endemic areas has resulted in an increased number of imported cases in nonendemic areas (Cooke et *al.*, 1999; Corachan, 2002). Other travel purposes such as visiting relatives and friends, business, immigration or seeking refuge, research or education and humanitarian mission are among the contributing factors to the better understanding of the spread of the disease in nonendemic areas (Grobusch et *al.*, 2003; Outwater & Mpangala, 2005). According to Grobusch et *al.* (2003), majority of schistosomiasis infections in people engaged in the afore-mentioned endeavours were contracted in Sub-Saharan Africa (SSA).

1.2.3.3. Epidemiology of schistosomiasis in Sub-Saharan Africa (SSA)

More than 85% of the estimated 779 million people at risk worldwide are concentrated in Sub-Saharan Africa (SSA). Of the 207 million infested persons worldwide, more than 97% are concentrated in SSA. (Van der Werf et *al.*, 2003; Gryseels et *al.*, 2006; Steinmann et *al.*, 2006; Utzinger et *al.*, 2009; WHO, 1993; WHO, 2012a; WHO, 2013). *S. haematobium* produces bladder wall pathology in approximately 18 million people in SSA and 10 million people suffer from hydronephrosis (van der Werf et al., 2003; Hotez & Kamath, 2009). An estimated 4.4 million people with *S. mansoni* have bloody diarrhea and bowel ulceration and 8.5 million develop hepatomegaly and/or associated periportal liver fibrosis, portal hypertension, and hematemesis (van der Werf et al., 2003; King & Dangerfield-Cha, 2008; Hotez et Kamath, 2009). In addition, the parasite egg-related ulcerative processes in the vaginal and cervical mucosa are thought to increase risk for transmission of HIV and other sexually transmitted diseases (Hotez, 2007; Hotez et al., 2008; King & Dangerfield-Cha, 2008; King, 2009). The bulk of death due to schistosomiasis is concentrated in SSA (Figure 6). Approximately, there are 150000 deaths from urinary schistosomiasis yearly and 130000 from *S. mansoni* infection in SSA (van der Werf et al., 2003; King & Dangerfield-Cha, 2008; Hotez et Kamath, 2009).

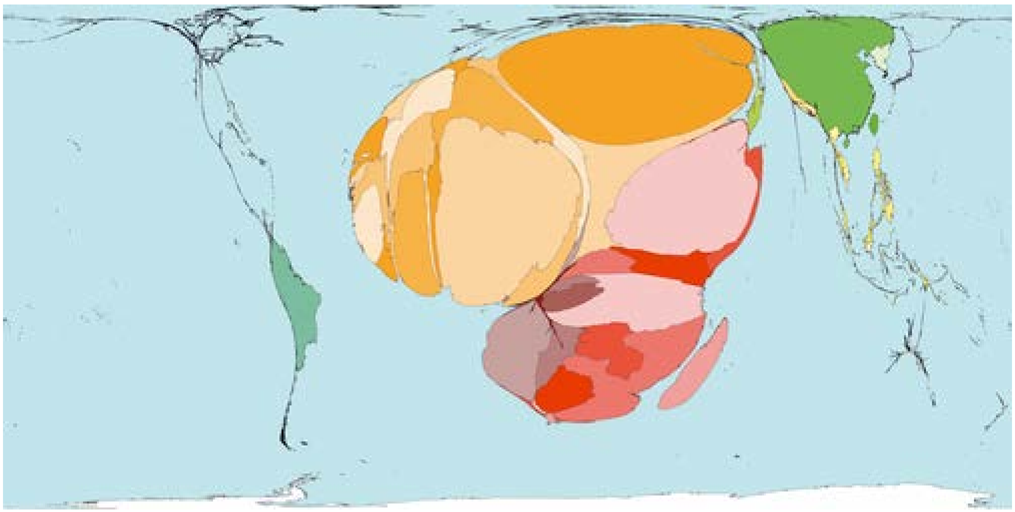


Figure 6: Cartogram of schistosomiasis deaths

(source: http://www.worldmapper.org/display_extra.php?selected=393)

Note: Territories are sized in proportion to the absolute number of people who died from schistosomiasis in one year. The colours used on the map allow for easier visual comparison between the maps than would otherwise be possible. Therefore, colours do not reflect the importance of deaths

1.2.3.4. Epidemiology of schistosomiasis in children

Although the reasons are still not well understood, compared with any other age group, children tend to harbor the greatest number of schistosomes (Hotez et al., 2008). The relationship between age and the intensity and prevalence of schistosomiasis infection is similar in endemic areas, where patterns of infection and reinfection reveal that children are more heavily infected and are more susceptible to reinfection than are adults in most communities (Figure 7). Changes with age in the average intensity of infection tend to be convex, rising in childhood and declining in adulthood (McMahon, 1976; Wilkins et al., 1984; Butterworth & Hagan, 1987; Hagan et al., 1998; Kabaterine et al., 1999; Hotez et al., 2008; Kapito-Tembo et al., 2009). Physiological factors like skin thickness, lipid content and hormone levels, depending on age of the subject, might modify innate or acquired resistance to infection. The precise nature of these interactions and their relative importance in determining levels of infection are still yet to be elucidated (Hagan et al., 1998). The decline in the older age groups was attributed to a spontaneous death of adult worms accompanied by either immunity to superinfection or reduced levels of exposure in adults (Wilkins et *al.*, 1979; Wilkins et *al.*, 1984; Butterworth & Hagan, 1987; Fulford et *al.*, 1998; Kabatereine et *al.*, 1999).

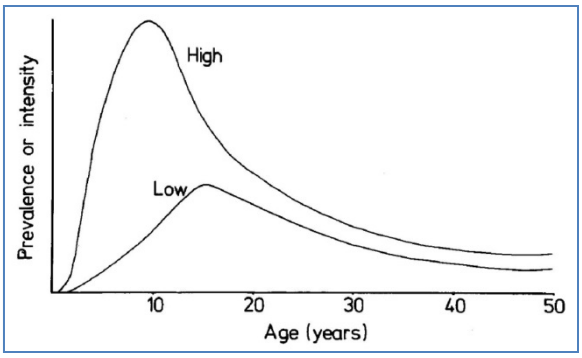


Figure 7: Prevalence by age in areas of high and low transmission (Source: Butterworth & Hagan, 1987)

1.2.4. Human Schistosomiasis: A typical neglected tropical disease (NTD)

Largely confined to the unseen rural areas of the developing world, the NTDs were for centuries the forgotten diseases of forgotten people (Hotez, 2007; Hotez, 2009). According to WHO (2013), schistosomiasis has been on the list of neglected tropical diseases in Africa and other parts of the developing world since 1950. Schistosomiasis has been neglected for decades due to many interrelated factors. The occurrence of schistosomiasis is confined to the tropics and subtropics and primarily affecting the poor segment of a population and hence the distribution of the disease is focal (Lengeler et *al.*, 2002; Hotez & Fenwick, 2009; Utzinger et *al.*, 2009). Medical reviews and public health appraisals have frequently stated that 'the majority of schistosome worm infections are asymptomatic and have concluded that the disease has 'no effect' on general health, but this assessment overlooks many realities of parasite-associated disease and that the lack of statistical significance does not mean absence of a clinically relevant effect (King & Dangerfield-Cha, 2008). Poor rural and urban communities are usually neglected and marginalized; hence, their non-inclusion in the national political agenda, especially with respect to policies on diseases affecting them even though they represent the grassroot level in the politics of every developing nation. (Schistosomiasis infections are so common that its chronic manifestations are often mistaken as normal in endemic areas (King & Dangerfield-Cha, 2008). National health budgets are chronically underfunded and governments have to target interventions and prioritize among many competing diseases (Utzinger et *al.*, 2009). Schistosomiasis is a chronic and debilitating disease causing mainly subtle morbidities. Hence, schistosomiasis features much less prominently on national strategic plans and on global health initiatives, which still tend to focus on mortality outcomes and consequently focus on malaria, tuberculosis and HIV/AIDS (Hotez, 2007; King & Dangerfield-Cha, 2008; Utzinger et *al.*, 2009). The global burden of schistosomiasis as expressed in disability-adjusted life years (DALYs) lost has been seriously underestimated. Hence, insufficient resources have been allocated for research and control (King & Dangerfield-Cha, 2008; Hotez & Fenwick, 2009; Utzinger et *al.*, 2009). Schistosomiasis together with other helminths is considered as NTD with study of these diseases receiving less than 1% of global research funding (Hotez et *al.*, 2008).

1.2.5. Schistosomiasis control strategies according to WHO

There are many reasons for eliminating schistosomiasis. According to Audibert & Etard (1998) a decrease of 10% of urinary schistosomiasis prevalence rate among rice farmers might allow an increase of paddy production of about 2% in Mali. According to Cohen (1974), the elimination of mortality due to schistosomiasis would have increased the expectation of life at birth of Zanzibar males in 1960 by approximately 1.8 years and would have extended the life of the average male in Zanzibar in 1960 by 2.3 years.

Efforts to control schistosomiasis are based on a combination of snail control, chemotherapy and educational and sanitary measures (WHO, 1998). In Figure 8, the decrease in shading from arrow one to arrow three points out priorities in eliminating schistosomiasis. Therefore, parasites remain the main target in the control strategy. Upstream, the destruction of parasite (A) in the system will, downstream, directly impact on the non-contamination of the environment (B). In the case of absence of treatment, the focus turns on human-beings through the improvement of latrine sanitation (Figure 8). Upstream, the utilization of latrines for defecation will directly impact on infection in snail intermediate host. This means that eggs cannot reach water bodies colonized by snail intermediate host. It also implies that there shall be no miracidium, no infected snail, no cercariae emission and consequently, no human infestation (C).

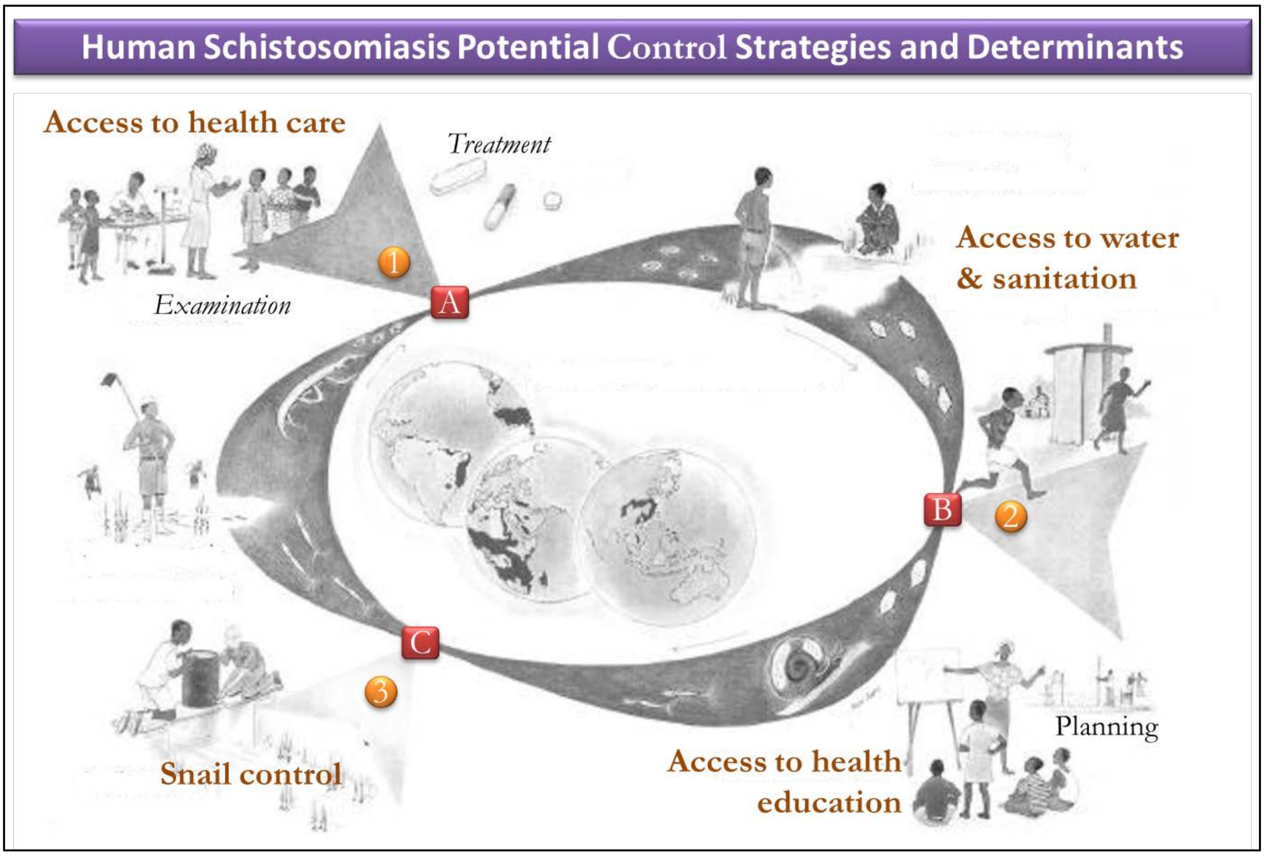


Figure 8: Schistosomiasis control opportunities (Adapted from WHO, 1990 in Utzinger, 1999, p.13)

1.2.5.1. Preventive strategies

- Access to water, sanitation and education

Human exposure to schistosomiasis infection can be eliminated by providing alternative source of water. In the case of human schistosomiasis, improvement in access to clean water will stop the use of contaminated freshwater colonized by snail intermediate hosts; hence, a break in the transmission cycle. (Nelson, 1990; Cairncross & Valdmanis, 2006). In fact, a combined improvement of water supply and proper excreta disposal will affect human schistosomiasis general morbidity by a median reduction of prevalenece between 59% and 87 % (Esrey et *al*., 1990).

Primary schools are ideal for determination of schistosomiasis prevalence rates for four reasons: 1) schools are accessible and receptive; 2) the highest prevalence levels of urinary schistosomiasis infection are found among school-age children; 3) data collected in this age range may be used to evaluate not only if schistosomiasis threatens the health of school-age children, but also if there is need for intervention in the community as a whole; 4) children in intermediate grades (generally between ages 9–12) allow for the accompaniment of treatment impact over one to two years before they leave school (Savioli et al., 2005, cited Koukounari et al., 2011, p. 11).

- Snail control

The importance of controlling snail is to provide healthy work and play environment to the community. Much effort has been directed towards snail control strategies as a means of reducing the prevalence of schistosomiasis (Lardans & Dissous, 1998). Essentially, these efforts have been based upon elimination of snail intermediate hosts by molluscicides (chemical control) (Meyer-Lassen et al., 1994) and/or by the use of competitor species and plants (biological control) (Lemma, 1970; Slootweg et al., 1994; Turner et al., 1999). All employed molluscicides have a negative impact on the non-targeted fauna (Sellin et al., 1995). Therefore, this control strategy is almost abandoned.

1.2.5.2. Curative strategy

- Chemotherapy

With the introduction of praziquantel, a powerful single-dose drug became available. This has changed the emphasis in schistosomiasis control in favour of large-scale chemotherapy with the primary aim of reducing morbidity (WHO, 1998). Then, World Health Assembly (WHA) urged member states to follow these examples to scale-up control of the disease and to attain a target of regular treatment of "at least 75% and up to 100% of all school-age children at risk by 2010" (Utzinger et *al.*, 2009; Savioli et *al.*, 2009). The mass treatment of human populations with anthelminthic drugs, known as mass drug administration (MDA), has been a major approach to controlling human helminthiases in developing countries (Hotez et *al.*, 2008). Since 2006, several partnerships committed to MDA have formed an alliance, which is known as the Global Network for Neglected Tropical Diseases (GNNTDC) and aim to increase efficiencies and produce economies of scale by delivering a package of drugs that simultaneously targets schistosomiasis and most common human helminthiases (Hotez et *al.*, 2008, Savioli et *al.*, 2009).

- Schistosomiasis National Control Programs

Because of its low cost and cost savings, integrated helminth control has become highly attractive to both global policy makers and donors such as the Schistosomiasis Control Initiative (SCI) and the Partnership for Parasite Control (PPC) (Hotez et *al.*, 2008). SCI, sponsored by grants from Bill and Melinda Gates Foundation, assisted six African countries in establishing and implementing their national schistosomiasis control programmes. Burkina Faso, Mali, Niger, Uganda, United Republic of Tanzania and Zambia have an estimated population of 26 million school-age children and a treatment coverage varying between 31% and 49% (Savioli et *al.*, 2009; Utzinger et *al.*, 2009). Consequently, the number of schistosomiasis treatments increased in these countries from 530 000 to 12.84 million between 2003 and 2005 (Frost & Reich, 2008 cited Savioli et *al.*, 2009) and 8.17 to 10.72 million from 2006 to 2008 (Fenwick et *al.*, 2009, cited Savioli et *al.*, 2009). Burkina Faso and Uganda were judged to be good examples following their attainment of the 2010 WHA target (Toure et *al.* 2008; Savioli et *al.*, 2009). In fact in mid-2003, just before the launch of the national control program, Burkina Faso was classified as high prevalent setting (Steinmann et al., 2006). The country made a substantial progress and was classified as moderate prevalent setting in the second WHO report on NTDs (WHO, 2013). The new target for eliminating schistosomiasis is to attain at least 75% national coverage with preventive chemotherapy by 2020 (WHO, 2013).

1.2.6. Importance of geographic information system (GIS), remote sensing (RS) in schistosomiasis control

1.2.6.1. Cartography

Disease mapping is the specific contribution of the geographer to medical sciences. Upstream, the spatialized data favour the formulation of etiological hypotheses in epidemiology and, downstream, maps are tools used in public health for program appraisal and their monitoring on contrasted fields (Fromageot et *al.*, 2005). The incidence and prevalence rates of specific diseases tend to vary regularly and the techniques of spatial analysis, including cartographic techniques, are essential for the identification of the patterns of spatial variation (Mayer, 1990; Czernichow et *al.*, 2001; Brooker, 2007). However, United States' physicians seem to be the first to attempt to produce a disease map (Bimal, 1985). It is possible that the first Global Map of the Distribution of Human Diseases was produced by Schnurrer (1827) *'Charte Uber die geographische Ausbreitung der Krankheiten'* (Brömer, 2000). These unknown works could help to explain the myth of John Snow in medical geography related to his map of the 1853-54 Broad Street cholera outbreak in London, which has put geographical research tool into the spotlight, made him a hero, and commonly cited in disciplines with a health-related focus (Vandenbroucke et *al.*, 1991; McLeod, 2000; Koch, 2005). According to Monmonier (1997, cited, McLeod, 2000, p. 929), most epidemiologist and geographers refer to John Snow's 1854 map when asked about disease maps. Viewed by medical geographers, Snow's map meaningfully illustrates the power of cartography and was qualified as achieving the highest use of cartography to find out by mapping things that cannot be discovered by other means , or at least, not with so much precision (McLeod, 2000; Koch, 2005). Meanwhile, under the direction of May "The World Atlas of Disease", was published by the American Geographical Society around the period of the Second

World War and marked the "renaissance of medical cartography" in the 20th century. Rodenwaldt & Jusatz (1952, cited, Bimal, 1985) completed their monumental three-volume "World Atlas of Epidemic Diseases" by attempting to define environmentally-oriented diseases. Doumenge et *al.* (1987) published the first African schistosomiasis atlas. Nearly 20 year ago these authors first comprehensively mapped the geographical distribution of schistosomiasis across Africa based on historical records, documents and published reports, including hospital-based data (Brooker, 2007). But the main problem and limitation of this atlas are the fact that the derived maps cannot be updated easily and therefore might not be able to reflect recent epidemiological trends (Brooker, 2007).

1.2.6.2. Geographic information system (GIS) and remote sensing (RS)

The use of GIS and RS has enhanced the scientific study of the spatial heterogeneity of human schistosomiasis over the past 20 years (Hugh-Jones, 1989; Hay et al., 1997; Kristensen et al., 2001; Brooker, 2007). GIS-RS applications lend themselves for schistosomiasis spatial and temporal risk mapping, since the climatic data (temperatures, rainfall), environmental data (water bodies, topography, vegetation) and human data (settlements, water resources development) are readily available from RS sources (Hay et al., 1997; Simoonga et *al.*, 2009; Beck et *al.*, 2000; Kristensen et al., 2001); and since the geographical distribution of schistosomiasis is a function of the interaction between these biotic and abiotic factors that determine the fulfilment of the parasite transmission cycle (Bavia et *al.*, 2001). The concepts and uses of medical geographic information system implemented by Ali et *al.* (2001) facilitated spatial data analysis and modelling of disease, environment and healthcare systems based on methods and theories of geography of health. Cross et al. (1984, cited, Brooker, 2007; Simoonga et al., 2009) had the original idea of applying GIS-RS to schistosomiasis study. In the Philippines and the Caribbeans, they employed, for the first time, the Landsat TM satellite data to predict the occurrence of schistosomiasis. Following their experience, several authors have used GIS-RS to predict the distribution of the disease. According to Simoonga et al. (2009), the first successful application of GIS-RS for prediction of human schistosomiasis, ten years after Cross et al.(1984), was implemented by Malone et *al.* (1994) in the Nile delta areas in Egypt. GIS-RS application with focus on Africa remains a big challenge for risk mapping and prediction of human schistosomiasis infection patterns and distribution of intermediate snail hosts.

1.3. Rational for the study

The need for this study becomes increasingly apparent since we acknowledged that most people living in the developing world are vulnerable to a great variety of chronic diseases throughout the course of their lives. Because of the adverse effects of these diseases on child development and cognitive capacity, pregnancy outcome and agricultural worker productivity, NTD represent a major reason why the "bottom 500 million" people in SSA cannot escape poverty. Therefore, efforts to control and eliminate the NTDs represent key elements for achieving Africa's Millennium Development Goals (MDGs) for 1) sustainable poverty reduction, including its eradication, 2) promote education, 4) reduce child mortality, 5) improve maternal health, and 6) to combat "other diseases" (Hotez et al., 2008; Hotez, 2009; Hotez & Kamath, 2009).

Human schistosomiasis transmission depends on the active role of the human-being in the transmission process through direct contact with infective water and excretory contamination of snail intermediate host habitats (Ernould, 2000; Kloos & David, 2002). The settlement, being a place where people inhabit and where they carry out a variety of activities, becomes the "center of gravity" on continuous movements of the population and, therefore, constitutes an essential element of the landscape (physical geography) and its study is at the heart of the human geography (Haggett, 1968; Daniel & Hopkinson, 1989).

A key issue of schistosomiasis control identified by Utzinger et al. (2003, cited, Brooker et *al*., 2004, p. 659) was the rapid and accurate identification of schistosomiasis susceptible-areas and of populations at risk. The complexity and multiplicity of factors contributing to the well-known focality of human schistosomiasis suggests that patterns are readily predicted at regional and national scales and that more complex models are required to predict patterns at local scales (Simoonga et *al*., 2009). Yet, during a period roughly dating from the end of the Second World War to the early 1990s, neither epidemiology nor medical geography and medical sociology tended directly to study the impact of the local social or physical environment on human health (Macintyre et *al.,* 2002). Services provided either publicly or privately to support people in their daily lives include health and welfare services, education and transport. Health personnel and facilities must be readily available where people live and work and people must have the means and know-how to get to these services and make use of them (Andersen, 1995; Macintyre et *al*., 2002). Reis et *al.* (2010) have stressed the urgent need for information on access to and utilization of schistosomiasis-related health services in poor rural, geographically isolated areas where health services are weakest and economic, social, cultural and logistic barriers facing patients are usually the most problematic. Very little is known about the problems faced by people who are battling with schistosomiasis infection and access to health services in the Sourou Valley.

Therefore, the present study aimed to collect useful ground information for analysing human schistosomiasis ecology and diffusion as well as access to health care services and associated infrastructures at the community level. The local fine scale approach adopted in this research to assess schistosomiasis risk at the community level through integration of natural and social geographic determinants is newly applied in Burkina Faso in general and in the Sourou Valley in particular.

1.4. Questions – Hypotheses – Objectives of the study

1.4.1. Study questions

1.4.1.1. General question

What do we know about natural and social geographic determinants of human schistosomiasis transmission at the community level in the Sourou Valley in Burkina Faso?

1.4.1.2. Specific questions

1. What are the natural and social geographic determinants and how do they interact in terms infestation of the local population?
2. How do the natural and social geographic determinants interact in terms of the local environmental contamination?
3. Could natural and social geographic determinants be integrated to geographically map high schistosomiasis-susceptible communities in the Sourou Valley in Burkina Faso?

1.4.2. Underlying hypotheses

1.4.2.1. General hypothesis

In Burkina Faso in general and in the Sourou Valley in particular, human schistosomiasis transmission strongly depends on natural and social geographic determinants.

1.4.2.2. Specific hypotheses

1. Human infestation depends on diverse natural and social geographic determinants occurring through a multi-factorial and complex interaction.
2. Local environmental contamination depends on diverse natural and social geographic determinants through a multi-factorial and complex interaction.

3. The comprehensive mapping of high schistosomiasis-susceptible communities and sub-communities in the Sourou Valley is conditioned by the integration of diverse natural and social geographic determinants collected at the community level.

1.4.3. Study objectives

1.4.3.1. Global objective

Assess natural and social geographic elements for explaining human schistosomiasis transmission at the community level in the Sourou Valley.

1.4.3.2. Specific objective

1. Identify natural and social geographic elements at the local community level for understanding their complex inter-action in keeping with the human infestation.

2. Identify natural and social geographic elements at the local community level for understanding their complex inter-action in keeping with the environment contamination.

3. Integrate identified local natural and social geographic elements for comprehensively mapping schistosomiasis-susceptible communities in the Sourou Valley.

1.5. Thesis organization

The rest of the thesis is structured as followed. Chapter 2 deals with the geographic fundaments of human schistosomiasis study in the Sourou Valley. Its highlights through literature review the role and place of geographic elements in schistosomiasis transmission in Burkina Faso in general and in the Sourou Valley in particular. Chapter 3 deals with the central concept of the study, materials and methods employed to collect and analyze data. Results of the study were spread onto four chapters. Chapter 4 presents outcomes of settlements categorizing according to 16 geographic parameters. Chapter 5 presents key circumstances and ways through which local populations enter into contact with contaminated water bobies. Chapter 6 presents key circumstances and ways through which local populations contaminate the environment. Chapter 7 deals with the integration of identified local geographic parameters for mapping schistosomiasis-susceptible settlements and populations. Finally, in Chapter 8 outcomes of the study are discussed and recommendations made for future studies.

Chapter 2. Risk Factors of Human Schistosomiasis in the Sourou Valley in Burkina Faso

2.1. Priority factors

The report of the Group on Earth Observations (GEO, 2010) categorized four main priortity factors for infectious diseases (Figure 9). The GEO is an intergovernmental organization working to establish and conduct a process to identify the critical Earth observation priorities within each Societal Benefit Area: agriculture, biodiversity, climate disasters, ecosystems, energy, human health, water and weather. Climate, environment and human remain the most important risk factors of human schistosomiasis transmission which are very familiar to geographers (Mayer, 1989; Kloss & David, 2002). Physical elements which tend to predispose populations to being susceptible to specific diseases may include climatic variation and environmental constraints on where pathogens themselves may survive. Diseases are not just physiological or pathological entities, but are also linked strongly to individual and collective behavior (social, economic and cultural factors). When enough individuals behave in ways which predispose them to particular diseases, then the population of which these individuals are members will have an increased risk of developing disease. Cultural and social constraints may sometimes expose individuals to disease vectors, or to physical agents in the environment, which might result in disease.

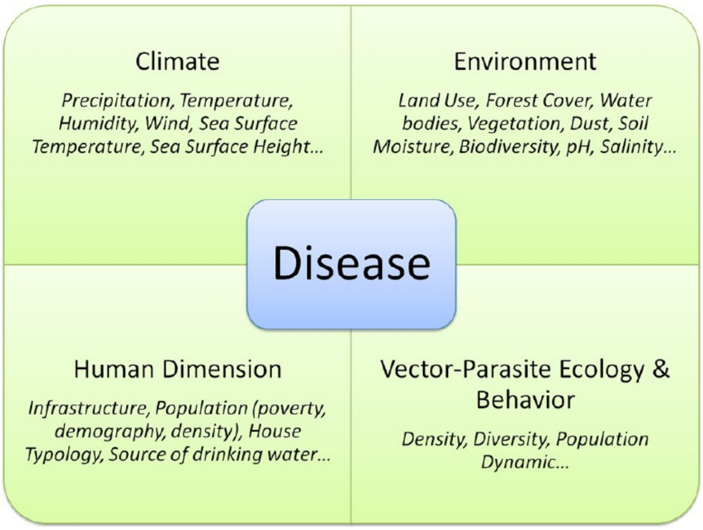


Figure 9: Disease main risk factors (GEO, 2010, p. 22)

2.2. Physical data

2.2.1. Geographic Location of the Sourou Valley in Burkina Faso, West Africa

Burkina Faso is located in western SSA in the North hemisphere between 9° and 16° of latitude, and crossed by the Greenwich meridian (Figure 10a). With 274200 km^2, the country is limited North-West by Mali, East by Niger and South by Côte d´Ivoire, Ghana, Togo and Benin (Figure 10b). The Sourou Valley is located in north-western Burkina Faso (Figure 10b). Using a pair of geographic co-ordinates the study area is located at 3° 27´ W and 13° N.

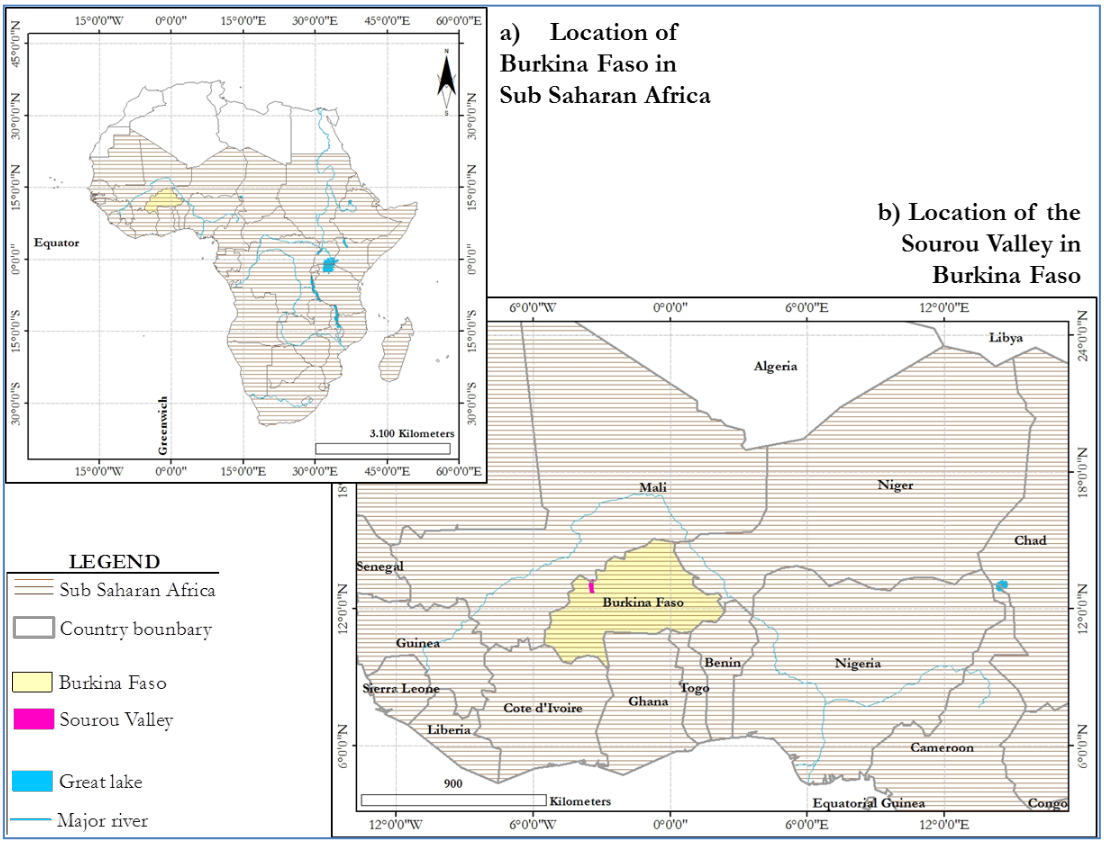


Figure 10: Location of the Study Area in wertern Burkina Faso in wertern SSA

2.2.2. Climatic data

2.2.2.1. Sudano-sahelian climate

The major tropical bioclimatic domains are defined by the combination of temperatures and their ranges, annual rainfalls and the alternation, more or less longer, between dry seasons and wet seasons. The common feature to tropical areas is that the mean temperature during the coolest month hardly ever goes down 18°C. Therefore, annual rainfalls were used to define 5 main climatic areas: equatorial (>2000 mm), sub-equatorial (1500-2000 mm), guinean (1100-1500 mm), sudanian (600-1100 mm) and sahelian (200-600 mm). Only the last two are observed in Burkina Faso. Using data of Dori, Ouagadougou (airport) and Bobo-Dioulasso as referential weather stations, the National Meteorology distinguishes three main climatic areas as indicated in Figure 11. From North to South as one goes through:

- The sahelian area: northern part of the country with Dori as referential weather station, this area covers 22.19% of the country's area,
- The north-sudanian area: central part of the country with Ouagadougou being the station of reference, it covers 52.92% of the national area, and
- The nouth-sudanian area: southern part of the country with Bobo-Dioulasso as basis weather station, the area covers 24.83% of the national territory.

Di-Sourou is the weather station located in the Sourou Valley, north-sudanian.

From Figure 11a and Figure 11c, the values of annual mean air temperatures and physical evaporation decrease southward. Conversely Figure 11b and Figure 11d show that values of annual mean rainfall and moisture decrease northward. Thirty years monthly distribution in Figure 12a shows that mean air temperatures varied between 23 °C and 35 °C at Dori whiles Bobo-Dioulasso recorded 26 °C and 31 °C. Curves of Di-Sourou and Ouagadougou evolved between those representing Dori and Bobo-Dioulasso. However, Figure 12a shows that the curve of temperature representing Dori overtooak others during seven months (April – October). This indicates an extreme variability of temperatures in the sahelian zone and explains the higher seasonal temperature ranges in Figure 12d. The opposite Figure 12b showed a net pre-dominance of Bobo-Dioulasso's rainfall curve. Its lowest rainfall fitted to the highest ones for Dori. The raining season duration as well as the number of raining days decreases considerably from the south-sudanian zone to the sahelian one (Figure 12d). In fact, the existence of higher continental and oceanic pressures and their alternation explains the decreasing trend of rainfall northward as indicated in Figure 13. The country and similar wertern SSA countries are connected to the Atlantic by the gulf of Guinea.

The monsoon (maritime air) from the south-west meets with the Harmattan (continental air) from the north-east. Rains fit to the arrival of the monsoon and to the moving of the intertropical front (FIT) northward during which the cloudy masse runs out progressively. This alternation creates two contrasted seasons. During the raining season the totality of the country is under the influence of the monsoon which reaches latitude 21° N in August (Figure 13). This explains why August remains the rainiest month of the year whatever the station (Figure 12b). During the dry season the Harmattan replaces the monsoon which goes down to 8° N in November (Figure 13). This means that the monsoon arrives earlier in the

South and leaves it later while it arrives in the sahel later and leaves it earlier. The short stay of the monsoon explains the very short raining season attributed to Dori and the longer stay in Bobo-Dioulasso results in a very long raining season.

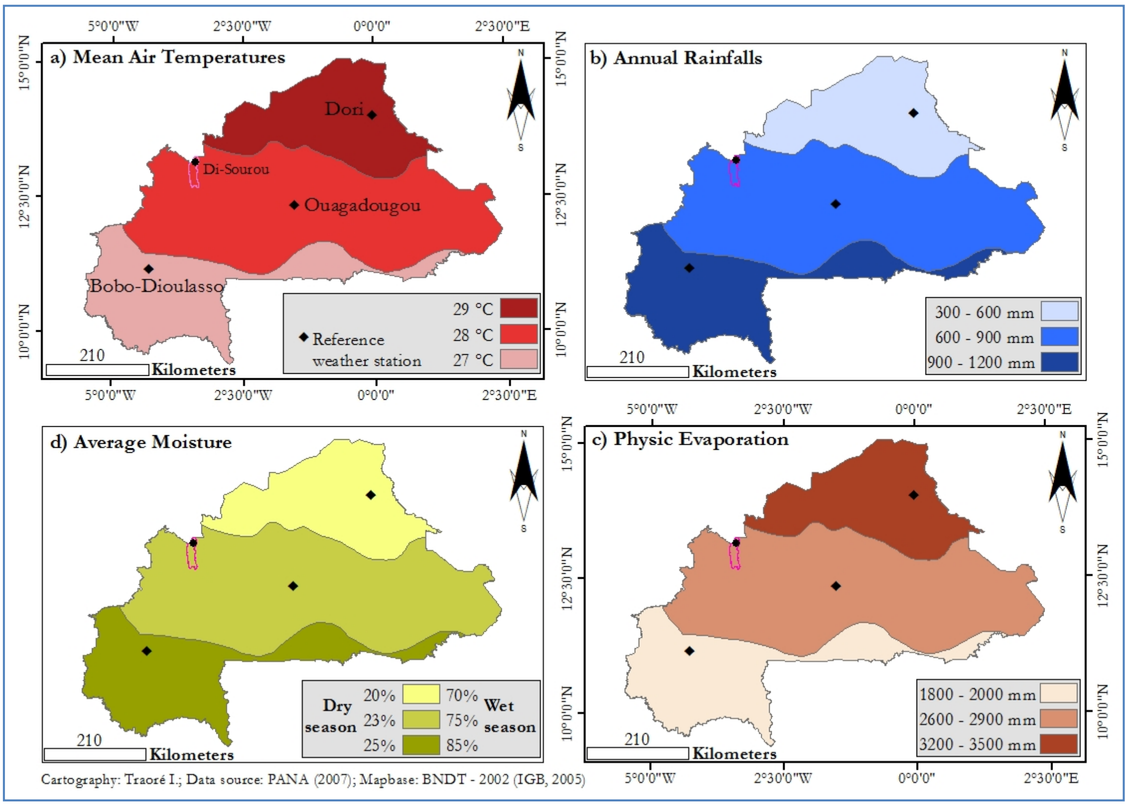


Figure 11: Spatial Variability of Climatic variables in Burkina Faso

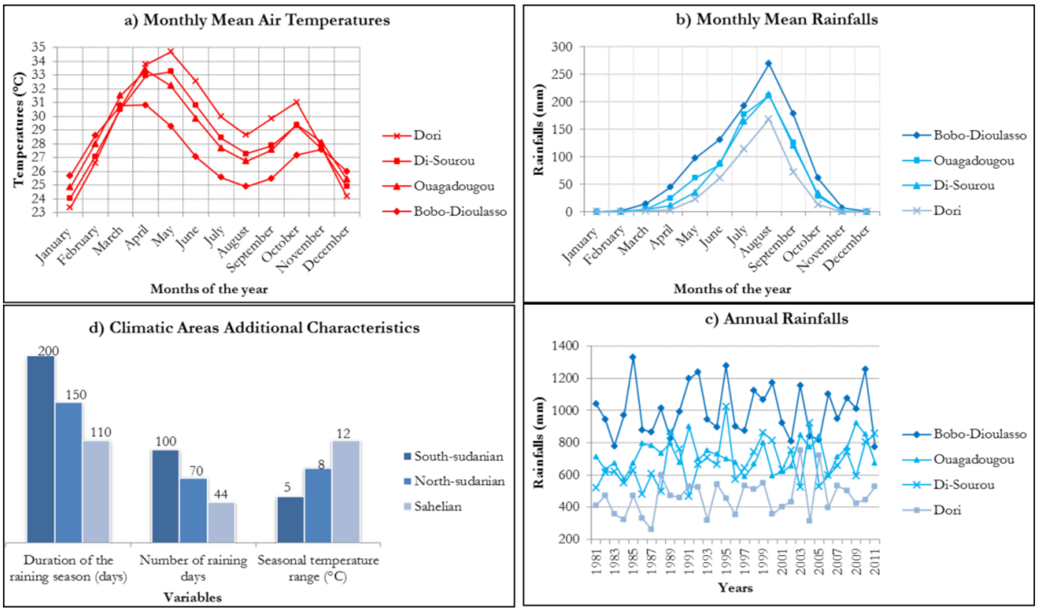


Figure 12: Spatio-temporal variability of Climatic variables in Burkina Faso (Direction Général de la Météorologie, Burkina Faso)

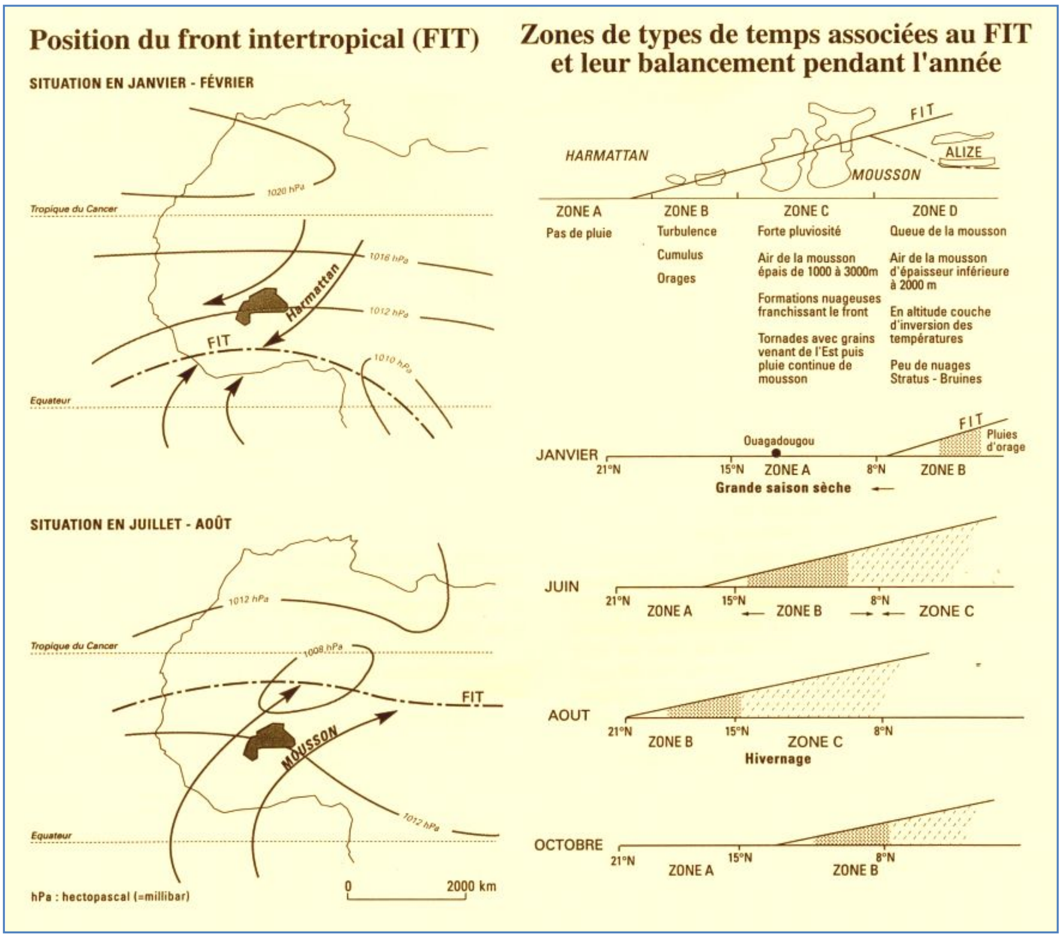


Figure 13 Explanation of the Spatio-temporal Variability of Climate in Burkina Faso (Pigeonnière & Ménager, 2001)

2.2.2.2. Climate trend in Burkina Faso

Both precipitations and temperatures are subject of great change in Burkina Faso since 1970s. This change is manifested by the apparition of the isohyet 400 mm at the North and the disruption of the isohyet 1300 mm at the South. In addition, isohyets 600mm and 900 mm migrated southydraulic worksards [Pigeonnière & Ménager, 2001; SPCNEDD (*Secrétariat Permanent du Conseil National pour l'Environnement et le Développement Durable*), 2007].

Concerning temperatures, Figure 14 shows the pattern of annual mean values for a 31-years period. Linear regression statistics calculated on a period of 13 years (1981-1994) in Table 2 showed weak correlation coefficients, except for Di-Sourou (p-values >0.03). Conversely, strong correlation coefficients were obtained for the period from 1994 to 2011 (17 years) which also shows better determination coefficients compared to 1981-1994 (p-values ≤0.006. Therefore, Figure 14 and Table 2 demonstrated that annual mean temperatures are rising up in all four weather stations.

Using MAGICC/SCENGEN, a coupled gas-cycle/climate model (MAGICC; Model for the Assessment of Greenhouse-gas Induced Climate Change) that drives a spatial climate-change SCENario GENerator (SCENGEN), the SPCNEDD (2007) predicted at the country scale an increase in mean temperatures of about 0.8 °C in 2025 and 1.7 °C by the horizon 2050. At the opposite the model predicted a slight decreasing in rainfall amount corresponding to -3.4% in 2025 and to -7.3% in 2050.

Table 2: Linear Regression Statistics of Temperatures Change in Burkina Faso

Annual Mean Air Temperatures Rising				
Time interval	Weather station	Linear regression statistics		
		R	*R^2 (%)*	*p-value*
1981 - 1994	Dori	-0.03	0	0.454
	Di-Sourou	0.51	26	0.032
	Ouagadougou	0.12	1	0.344
	Bobo-Dioulasso	0.02	0	0.474
1994 - 2011	Dori	0.65	42	0.002
	Di-Sourou	0.81	65	0.000
	Ouagadougou	0.58	33	0.006
	Bobo-Dioulasso	0.66	43	0.002
1981 - 2011	Dori	0.68	46	0.000
	Di-Sourou	0.83	68	0.000
	Ouagadougou	0.64	40	0.000
	Bobo-Dioulasso	0.67	45	0.000

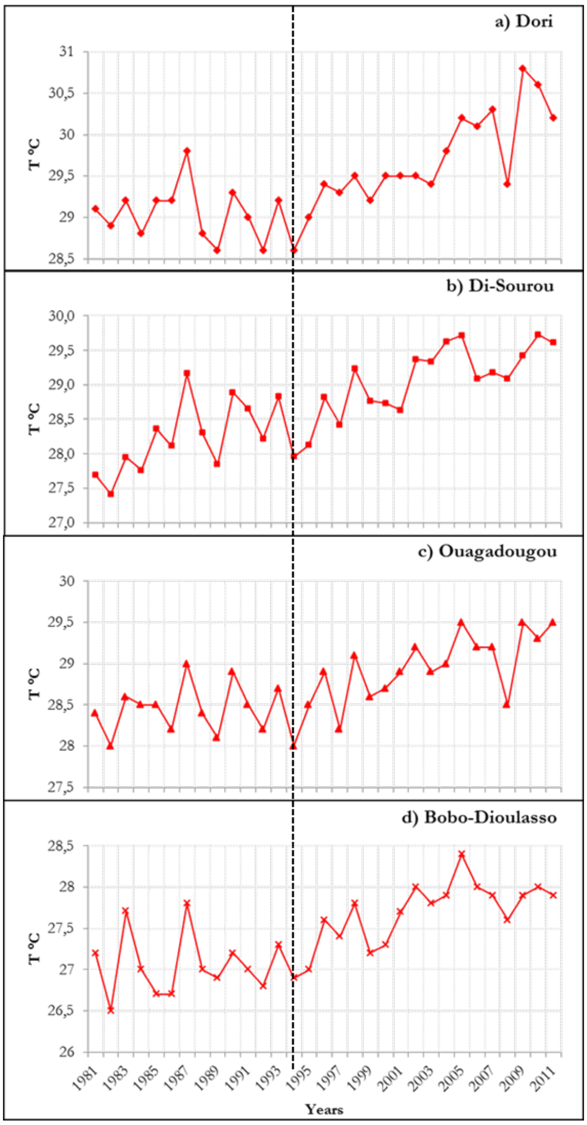


Figure 14: 31 years period annual mean temperatures profiles in Burkina Faso (Direction Générale de la Météorologie, Di-Sourou weather Station)

2.2.3. Environmental data

2.2.3.1. Hydrology

- Watersheds and water roads

Burkina Faso is a continental locked-land country shared by three international watersheds as indicated in Figure 15: the Comoé (6.42% of the national area), the Volta (63.13%) and the Niger (30.45%). On the national plan, four national watersheds are distinguished with the subdivision of the Volta into the mouhoun (33.22%) and the nakanbé (29.90%). At their turn, national watersheds are subdivided into 17 sub-watersheds (Figure 15). Then, the Sourou is a sub-watershed of the Mouhoun and accounts for 16.76% of the area of this national watershed while the Mouhoun supérieur alone represents 60.20%. The Sourou River is a tributary of the Mouhoun which is the main water flow in the country. The

Nakanbé River and Nazinon River are secondary in terms of importance. These three rivers flow down southward and meet each other at the center of Ghana to form the Lake Volta.

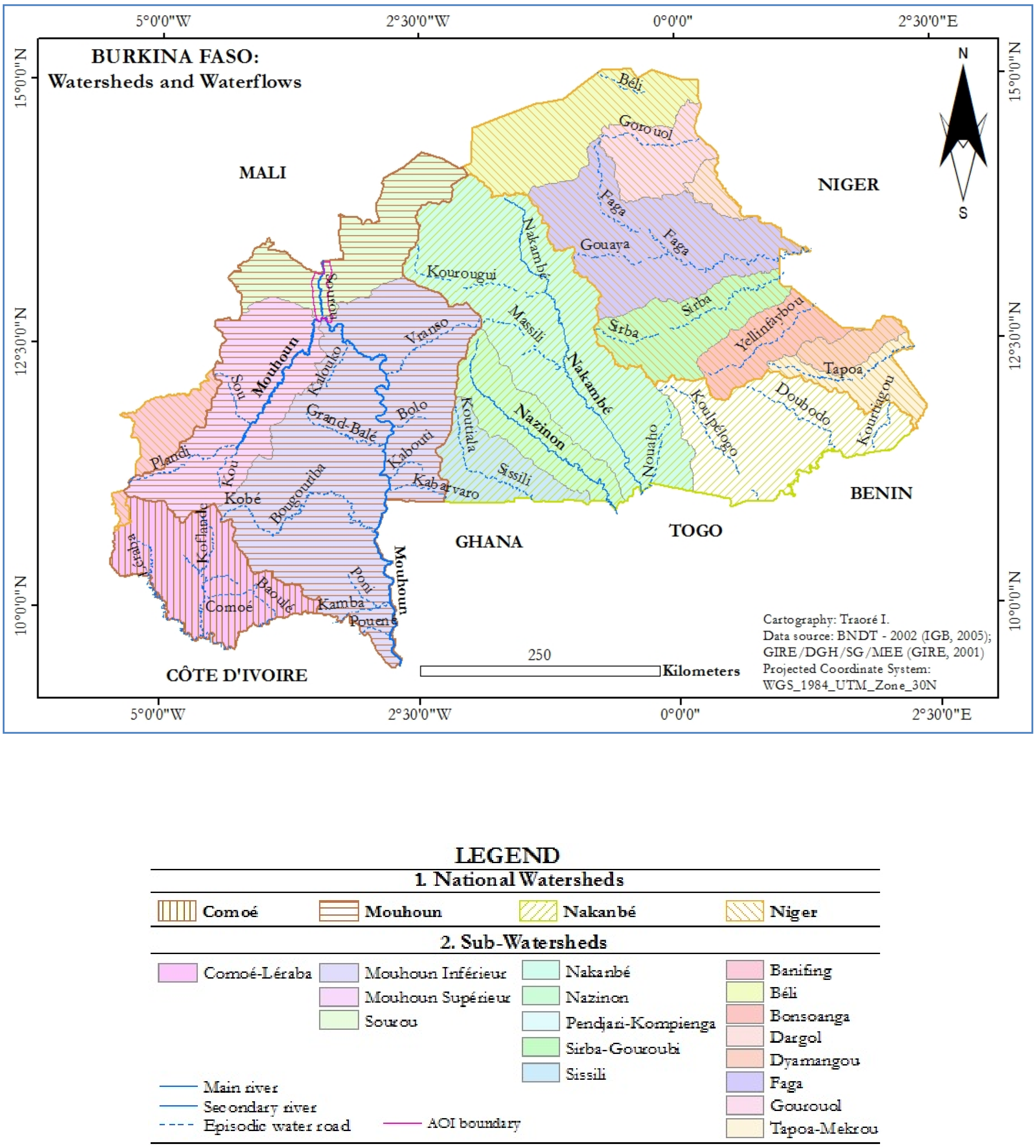


Figure 15: National and Sub- Wathersheds and Water Roads in Burkina Faso

- Wetlands and water bodies

Figure 16 shows the potential of water bodies and wetlands in the country for 2002. The Sourou Valley was classified as Ramsar site in October 2009. The Convention on Wetlands of International Importance, called the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. Negotiated through the 1960s by countries and non-governmental organizations that were concerned at the increasing loss and degradation of wetland habitat for migratory waterbirds, the treaty was adopted in the Iranian city of Ramsar in 1971 and came into force in 1975. It is the only global environmental treaty that deals with a particular ecosystem, and the Convention's member countries cover all geographic regions of the planet. Figure 16 shows the spatial distribution of the 15 Ramsar sites identified through the country from 1990 till 2009 per sub-watershed.

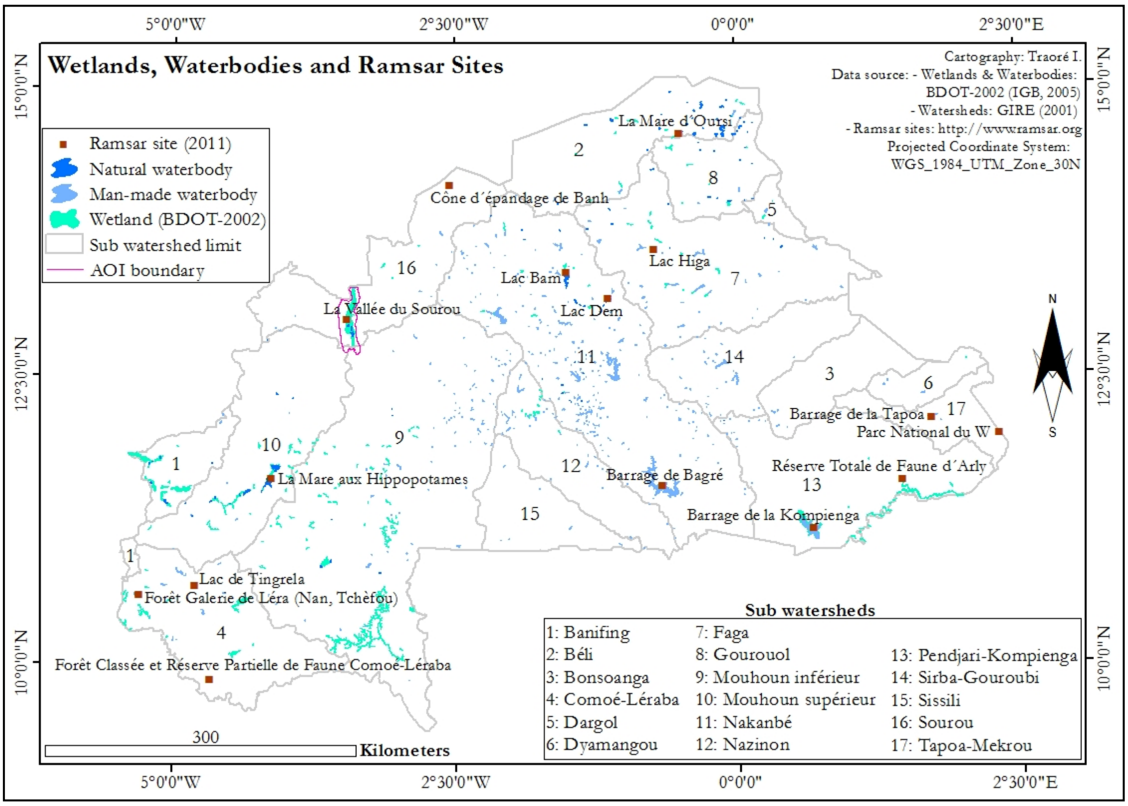


Figure 16: Water bodies and Ramsar sites distribution per sub-watershed

2.2.3.2. Vegetation cover data

- Bioclimatic areas

The bio-climatic division proposed by Guinko (1984) distinguishes five different areas. From North to South, he distinguished: 1) the sahelian area: above 14° of latitude and covers 9.77% of the national area , 2) the sub-sahelian area: between 13° and 14° of latitude, covering 18.75% of the territory, 3) the north-sudanian area: between 11° 30´and 13° of latitude accounting for 36.23% of the national area, 4) the south-sudanian area: between 10° and 11° 30´of latitude, covering 29.76% of the country area, and 5) the sub-sudanian area: below 10° of latitude which covers 5.50% of the national territory. Then, our study area spread into two bio-climatic areas, mainly north-sudanian.

- Overlapping of vegetation cover data on bioclimatic areas

The overlapping of these bio-climatic areas on vegetation data is shown in Figure 17. Figure 17a shows the densification of forests southydraulic worksards and similarly for savannas indicated in Figure 17b. Conversely, the empty space in the sahelian area in Figure 17b is replaced by a concentration of steppes in Figure 17c and by dunes and sands and, bare rocks in Figure 17d.

Figure 18a shows the pre-dominance of savanna at the country scale with 65.51% while's dunes and sands, bare rocks and soils together represented only 2.75%. In Figure 18b, we compared the pre-dominance of variables, ones to others, within each bio-climatic area. Therefore, proportions represented the area covered by the variable divided by the sum of variables within the bio-climatic area multiplied by 100. In accordance with Figure 17d, Figure 18b confirms the pre-dominance of steppe in the sahelian groups. At the opposite, the savanna represented more than 80% of land cover data within sudanian groups.

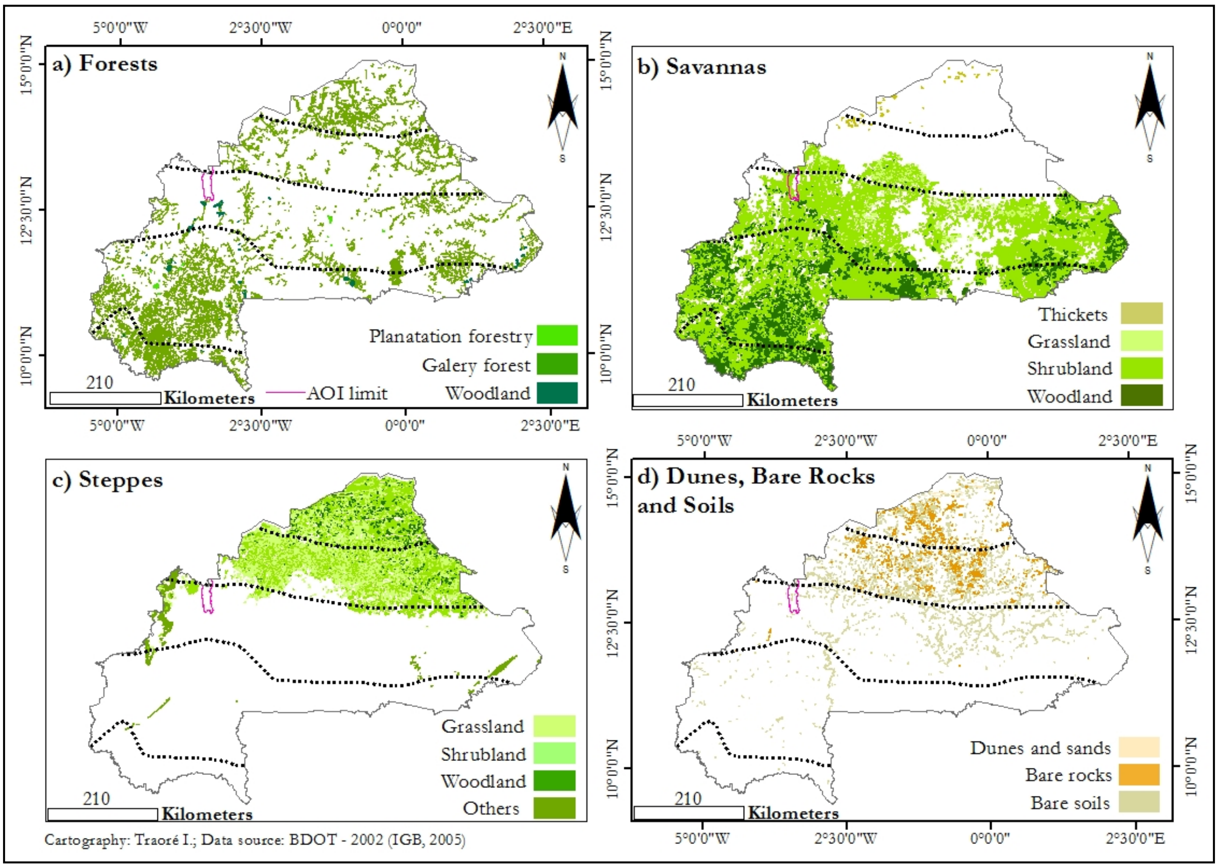


Figure 17: Land cover data spatial distribution by bioclimatic area

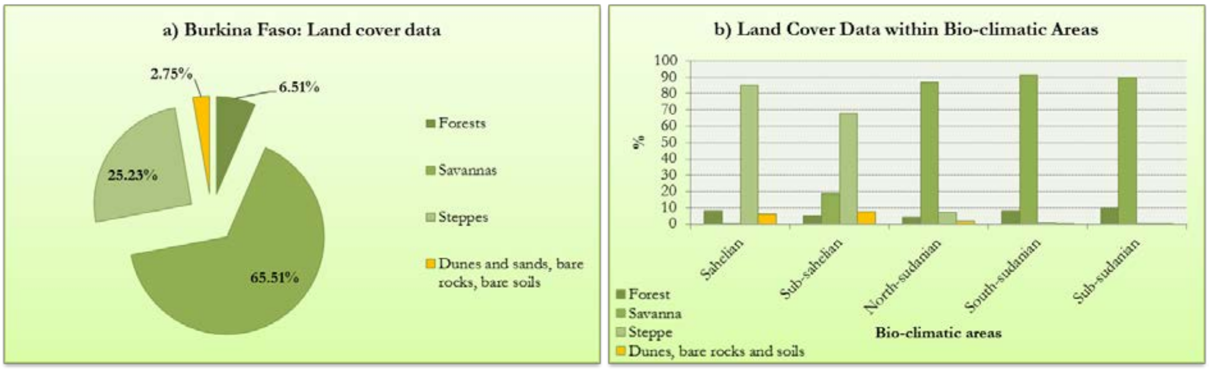


Figure 18: Land cover data: a) Pre-dominance by type; b) Pre-dominance by bio-climatic area

2.2.3.3. Combined impact of climate and environment on snail intermediate host distribution in Burkina Faso

- Snail intermediate hosts of schistosomiasis in Burkina Faso

Results of the malacological prospection from 546 habitats done by Poda (1996) through the country showed 90.84% of positive biotopes where six snail species were identified to be intermediate hosts of schistosomiasis in Burkina Faso as shown in Table 3. According to Figure 19, *B. truncatus* (32.66% of positive biotopes) occupied the first place while, *B. pfeifferi* (15.12%) and *B. umbilicatus* (1.21%) came at the third and last positions, respectively. Associations of snail species within the same habitat or biotope co-colonization were also observed (Poda, 1996). In accordance with Table 3, only *B. pfeifferi* is responsible for *S. mansoni* transmission in the county while, *S. haematobium* is transmitted by *Bulinus sp*ecies except *B. forskalii* whose role in the natural transmission of *S. haematobium* was never been demonstrated so far (Poda, 1996).

Table 3: Snail intermediate hosts of schistosmes endemic to Burkina Faso (Poda, 1996)

Zoologic classification of snail intermediate hosts of schistosomiasis in Burkina Faso	
Class: *Gastropoda* (Cuvier, 1798)	
Sub-class: *Pulmonata* (Cuvier, 1917)	
Order: *Basommatophora* (Schmidt)	
Families	
Planorboidea (Rafinesque, 1815)	*Bulinidae* (Cross and Fisher, 1880)
Sub-family: *Planorbinae* (Rafinesque, 1815)	**Sub-family:** *Bulininae* (Cross and Fisher, 1880)
Genus: *Biomphalaria* (Preston, 1910)	**Genus:** *Bulinus* (Muller, 1781)
Specie: - *Biomphalaria pfeifferi* (Krauss, 1948)	**Species:** - *Bulinus senegalensis* (Muller, 1781) - *Bulinus forskalii* (Ehrenberg, 1831) - *Bulinus globosus* (Morelet, 1866) - *Bulinus truncatus* rohlfsi (Clessin, 1886) - *Bulinus umbilicatus* (Mandahl-Barth, 1973)

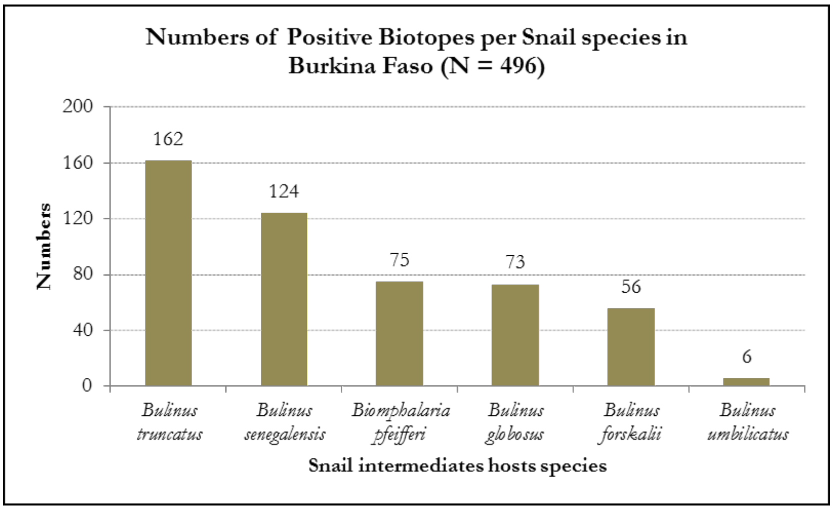


Figure 19: Pre-dominance of snail species in Burkina Faso (Poda, 1996)

- Biotope preference typology

To measure the preference of biotope, Poda (1996) divided the prospected habitats into five types: ponds (17.77% of prospected biotopes), streams (30.59%), dams (46.52%), lakes (2.01%) and irrigation canals (3.11%). For each snail intermediate host, Figure 20 shows its pre-dominance per type of biotope. *B. pfeifferi* and *B. umbilicatus* were mostly found in permanent water such as streams and dams. *B. truncates* and *B. senegalensis* are adapted to temporal ponds.

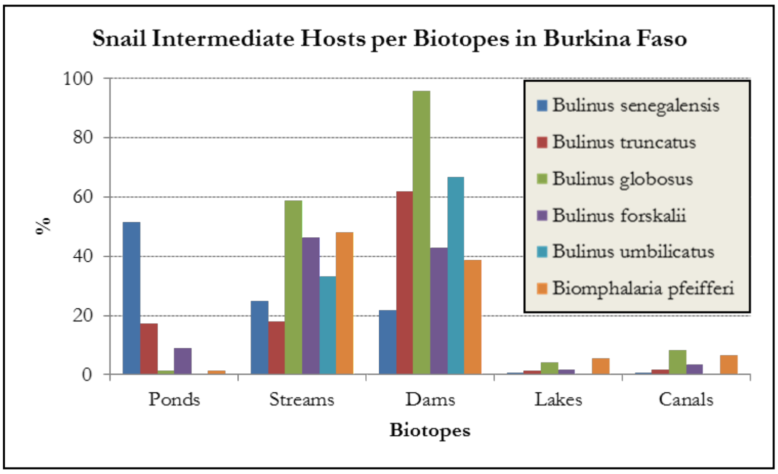


Figure 20: Pre-dominance of snail species per habitat in Burkina Faso (Poda, 1996; Poda et al., 2004)

- Overlapping of snail intermediate host biotopes distribution and schistosomiasis prevalence spatial pattern in Burkina Faso

In the sahelian area *S. haematobium* is hyper-endemic and transmitted by *B. truncatus* and *B. senegalensis*. *B. pfeifferi* is totally absent in this bio-climatic area (Poda, 1996; Poda et al., 2004). *S. mansoni* reported cases were found among migrants from the south-sudanian area. The prevalence patern remains the same in the sub-sahelian area. However, *B. globosus* and *B. pfeifferi* could be found in permanents dams. The north-sudanian area is colonized by all snail intermediate hosts, but *S. mansoni* prevalence rate was found not significant (Poda, 1996). In the south-sudanian area *B. pfeifferi* pre-dominates *Bulinus sp.*: 30% vs. 24.2% of prospected sites. In some studied sties, *S. mansoni* prevalence rate was nearly equal to that of *S. haematobium*, mostly due to *B. globosus* and *B. truncatus*. The sub-sudanian area was endemic mostly to *B. pfeifferi*, *B. globosus* and *B. truncatus*. The prevalence rate of *S. mansoni* overtook that of *S. haematobium* in some surveyed sites (Poda, 1996). Therefore, and as Figure 21 displays, prevalence rate of *S. mansoni* increases southward while that of *S. heamatobium* decreases. Both *S. mansoni* and *S. haematobium* are transmitted in the Sourou Valley (Figure 21). Figure 20 and Figure 21 demonstrated that the territory of *S. heamatobium* cover the whole country. The corollary of the widespread of *S. heamatobium* is manifested on ground by the large dominance of urinary form of the disease according to hospital recorded cases (Figure 22). Figure 22 also shows that schistosomiasis cases in the last decade varied between 8472 (in 2011) and 16779 patients (in 2004).

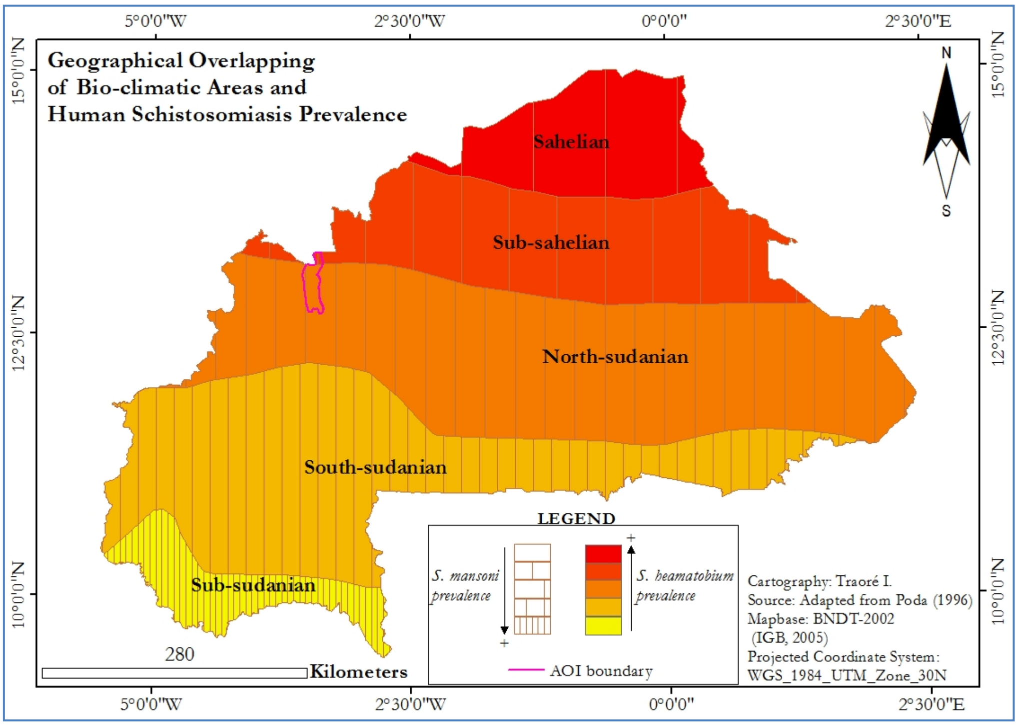


Figure 21: Influence of snail intermediate hosts ecology on schistosomiasis prevalence spatial distribution in Burkina Faso

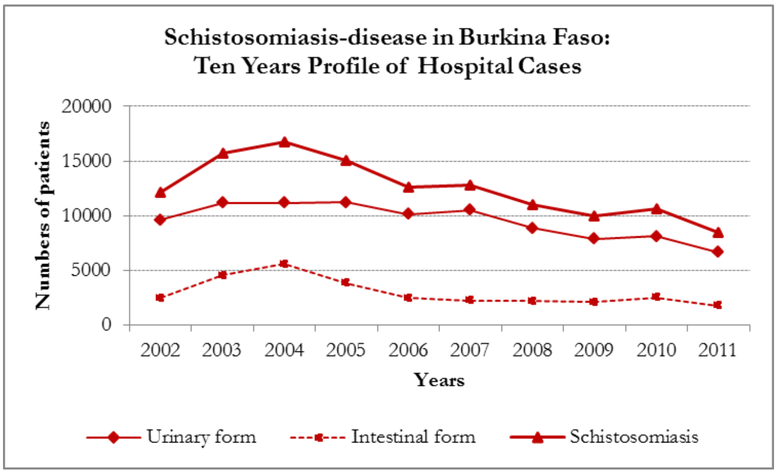


Figure 22: Ten years hospital schistosomiasis-disease cases for the whole country

2.3. Human data

2.3.1. Demographic structure

In Burkina Faso, the *Instittut National de la Statistic et de la Démographie* (INSD) distinguishes three age groups: children with less than 15 years old (0-14 years), adults in between 15 and 64 years old, and the elderly with at least 65 years old. Figure 23 shows the population pyramid based on results of the last general population census done in 2006 (Ouédraogo & Ripama, 2009). The pyramid relies on children who accounted for 46.6% of the total population, irrespective to the gender and the residential area. Adults and elderly represented 50.0 and 3.4%, respectively. However, average and median ages varied according to the gender and the residential area as indicated in Table 4 which shows lower values for rural area compared to the urban one. This later even overtook the national values. In 2006, there were 93.4 men for 100 women, that is to say 51.7% of females.

The large basis of the pyramid characterizes higher fecundity and birth rate while the tapered summit indicates higher and mortality. However, many efforts continue to be done to roll down crude rates of birth and mortality which resulted in the increase of the life expectancy (Baya et al., 2009; Dakuyo et al., 2009) (Figure 24). The average population growth rate is about 3.1%. The population went from 5.64 to 14.02 million inhabitants from 1975 to 2006, respectively (Figure 25). This means an increase of 8.38 million of persons in 31 years. Projected increase for 2011, 2016 and 2036 were 0.69, 7.47 and 21.49 million inhabitants, respectively. Proportions of urban populations are growing 6.43% vs. 22.70% in 1975 vs. 2006, respectively.

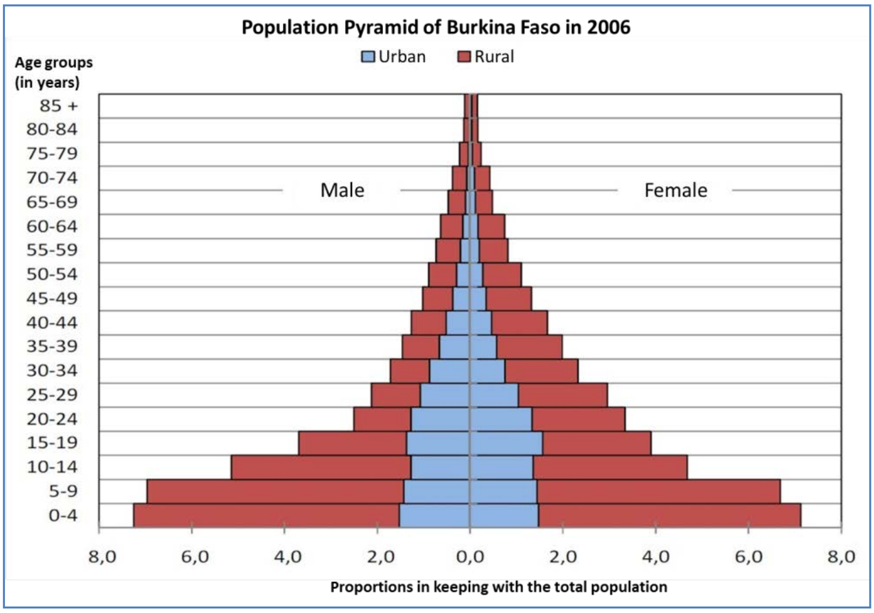


Figure 23: Pyramid per five-year age group according to the residential area (Source: Ouédraogo & Ripama, 2009)

Table 4: Gender and Residential area Age indicators (Ouédraogo & Ripama, 2009

Average and Median Ages per Residential Area in Burkina Faso in 2006									
	Urban area			Rural area			Country		
Indicator	*Male*	*Female*	*Total*	*Male*	*Female*	*Total*	*Male*	*Female*	*Total*
Average age	23.1	23.0	23.1	20.6	22.3	21.5	21.2	22.5	21.8
Median age	18.4	18.4	18.7	12.9	16.0	14.3	14.4	16.7	15.5

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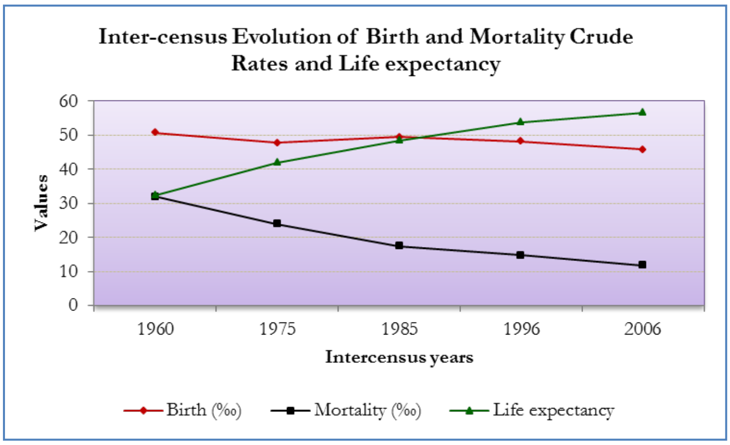


Figure 24: Birth, Mortality and Life expectancy in Burkina Faso (Baya et al., 2009; Dakuyo et al., 2009)

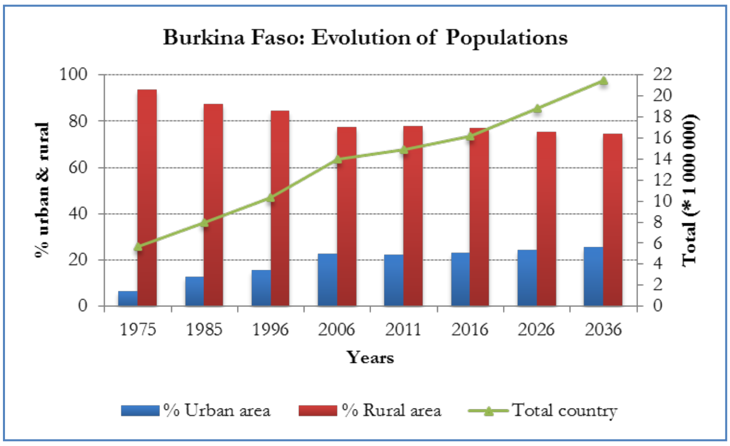


Figure 25: Evolution of the population per residential area (INSD, 2009; our projections)

- Unequal spatial distribution of population

Figure 26a shows the unequal spatial distribution of inter-census population sizes per region. In 2006, only 38.46% of regions (Cascades, Centre-Sud, Plateau Central, Sahel and Sud-Ouest) observed less than one million inhabitants. Figure 26 also shows that before 2006 the region of the Boucle du Mouhoun presented the highest population size and the Centre coming at the third place. However, the order has changed from 2006 with the region of the Centre occupying the first place and the Boucle du Mouhoun the third one. This situation could be attributed to the "*opération bayiri*" a massive comeback of national repatriated from

Côte d´Ivoire between 2002 and 2004 due to the socio-political crisis in this neighbouring country.

Dividing the population size of regions by the total population of the country and multiplied by 100, Figure 26b shows that only 30.77% of regions (Cascades, Centre, Est and Hauts-Bassins) observed clearly an increasing inter-census trend. Next, Figure 27 shows the distribution of population sizes and densities distribution per province and region in 2011 based on natural breaks (Jenks). Then, provinces were categorized into five classes according to their population size. From the smaller to the bigger number of inhabitants proportions of provinces by class were 24.44, 35.56, 26.67, 11.11 and 2.22%, respectively (Figure 27a).

In terms of population density, regions were categorized into classes with 30.77%, 61.54% and 7.69 of regions from low to high density, respectively (Figure 27). At the provincial level, five classes were categorized with 22.22, 35.56, 15.56, 24.44 and 2.22% of provinces from smaller to bigger values, respectively (Figure 27). The Sourou Valley fell into the second density class: 34-55 inhabitants/km^2.

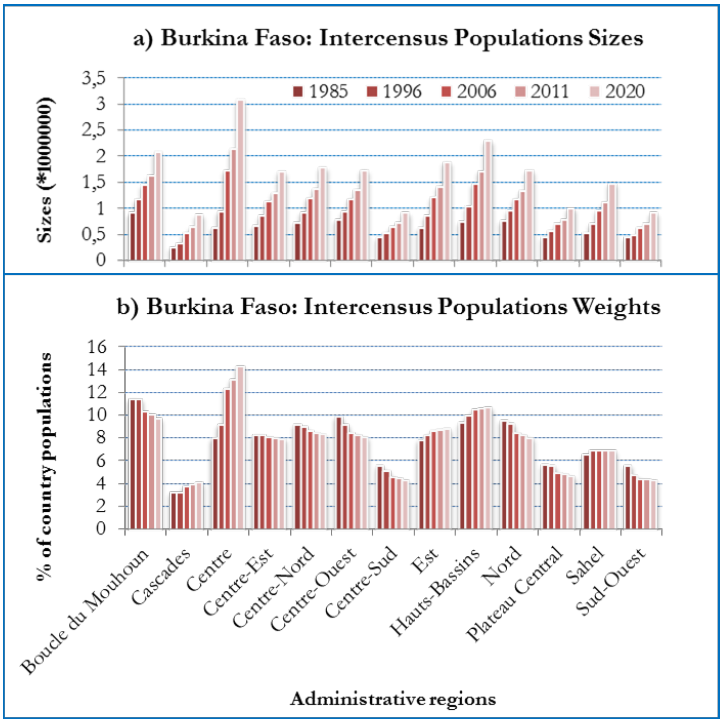


Figure 26: Inter-census populations per administrative region

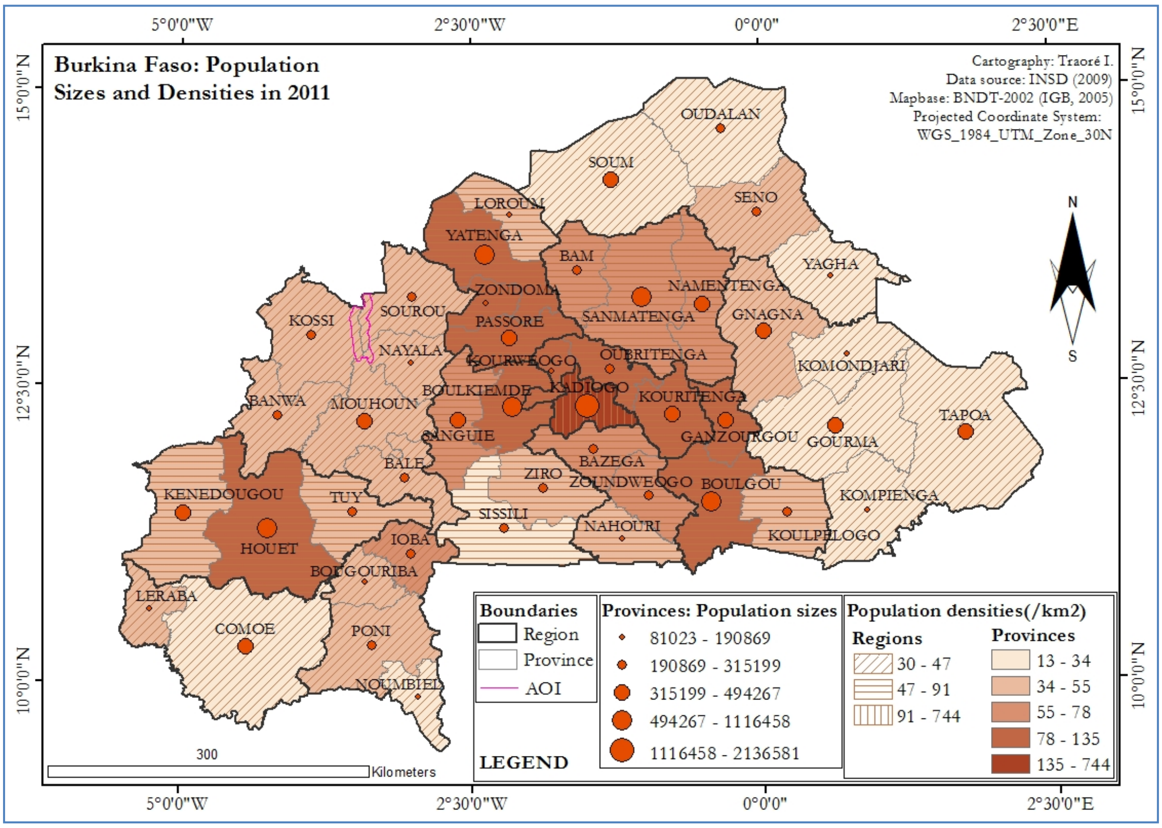


Figure 27: Spatial distribution of population sizes and densities per region and province in 2011

2.3.1.1. Economic characteristics of Burkina Faso

- Main occupational sectors and input in the country gross domestic production (GDP)

In Burkina Faso, the bulk of 84% of the active population is occupied in the primary sector (Figure 28a). This sector includes agriculture, cattle breeding and fishing (Compaoré et al., 2009). This means that the economy of the country relies on the primary sector, mainly. Paradoxically, it weighs only about 30% in the country GDP (Béré, 2011) (Figure 28b). These reasons explain the status of lower income country attributed to Burkina Faso with about US Dollar 666.8 GDP/inhabitant. Statistics on poverty showed higher values of indices for rural area than urban according to Table 5.

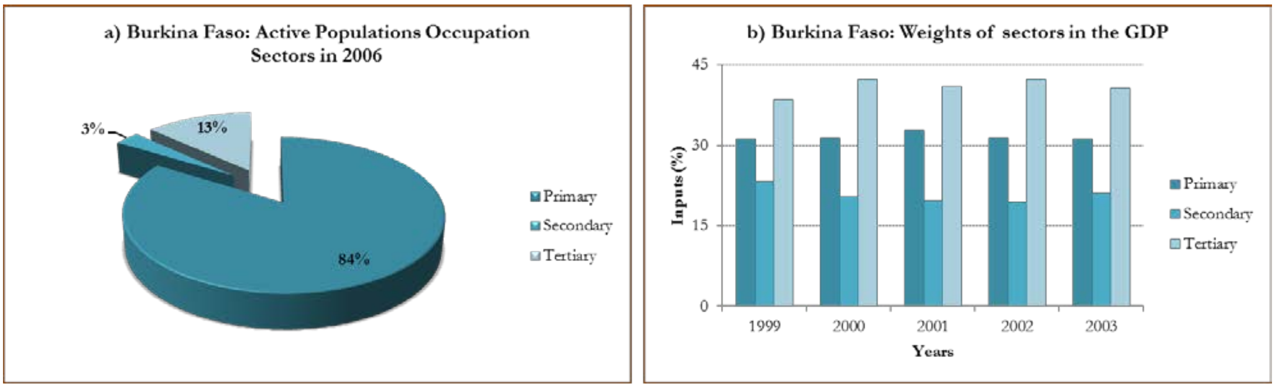


Figure 28: a) Main occupational sectors (Compaoré et al., 2009); b) Inputs of sectors in the GDP (Béré, 2011)

Table 5: Indices of poverty by residential area in 2003 in Burkina Faso (Source: Béré, 2011)

Indicators of poverty in 2003 in Burkina Faso				
Indices	**Measures**	**Urban**	**Rural**	**Country**
P0	Incidence	0.199	0.523	0.464
P1	Deepth	0.055	0.179	0.156
P2	Severity	0.055	0.082	0.071

- Main primary sector productions in the country

- Agriculture

Fourteen agricultural seasons data (1995/96 to 2008/09) show the pre-dominance of sorghum and millet crops both in terms of cultivated areas (Figure 29a) and quantities of production (Figure 29b). Maize competes with cotton while, rice (paddy) shows a timid evolution. Compared to areas, speed of curves representing production shows a marked uneven pattern. This means that cultivated areas could not always determine the yield of the speculation. Climatic parameters are among determinants factors. With more than 30% of the country total production, region of Hauts-Bassins came first in with respect to cotton, maize and rice (Figure 30a, b and c). Producing more than 15% of millet and sorghum, the region of the Boucle du Mouhoun was the first ranked (Figure 30e and f). In terms of garden crops, Figure 31a and Figure 31b show that onion bulbs, cabbage and tomatoes represented the main speculations.

- Fishing

Yields of fishing vary between 8000 and 10000 tonnes (Figure 32a) and the majority of 42.82% is provided by the Mouhoun fisheries (Figure 32b). The potential of fishing is estimated to 13000 tonnes/year for an average productivity of 65 kg/ha/year. The potential of fishing is composed by more than 100 species, 24 families and 59 genuses (MAHRH, 2007).

- Cattle breeding

The livestock is dominated by poultries, caprines, bovines and ovines (Figure 33a). Except for pigs, donkeys and poultries for which the region of the Centre-Ouest came first, the region of Sahel pre-dominated other regions in terms of livestock potential (Figure 33b).

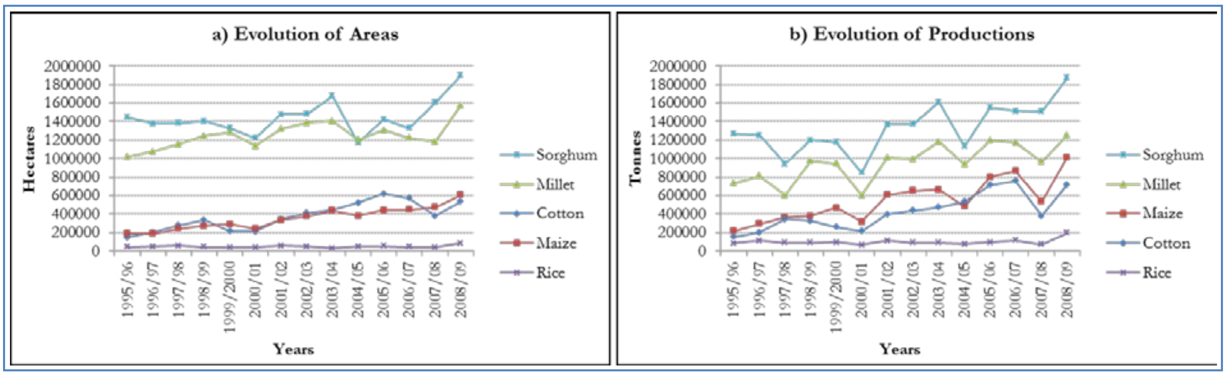


Figure 29: Seasonal variations of cultivated areas and yields per speculation (Source: http://www.insd.bf/fr/)

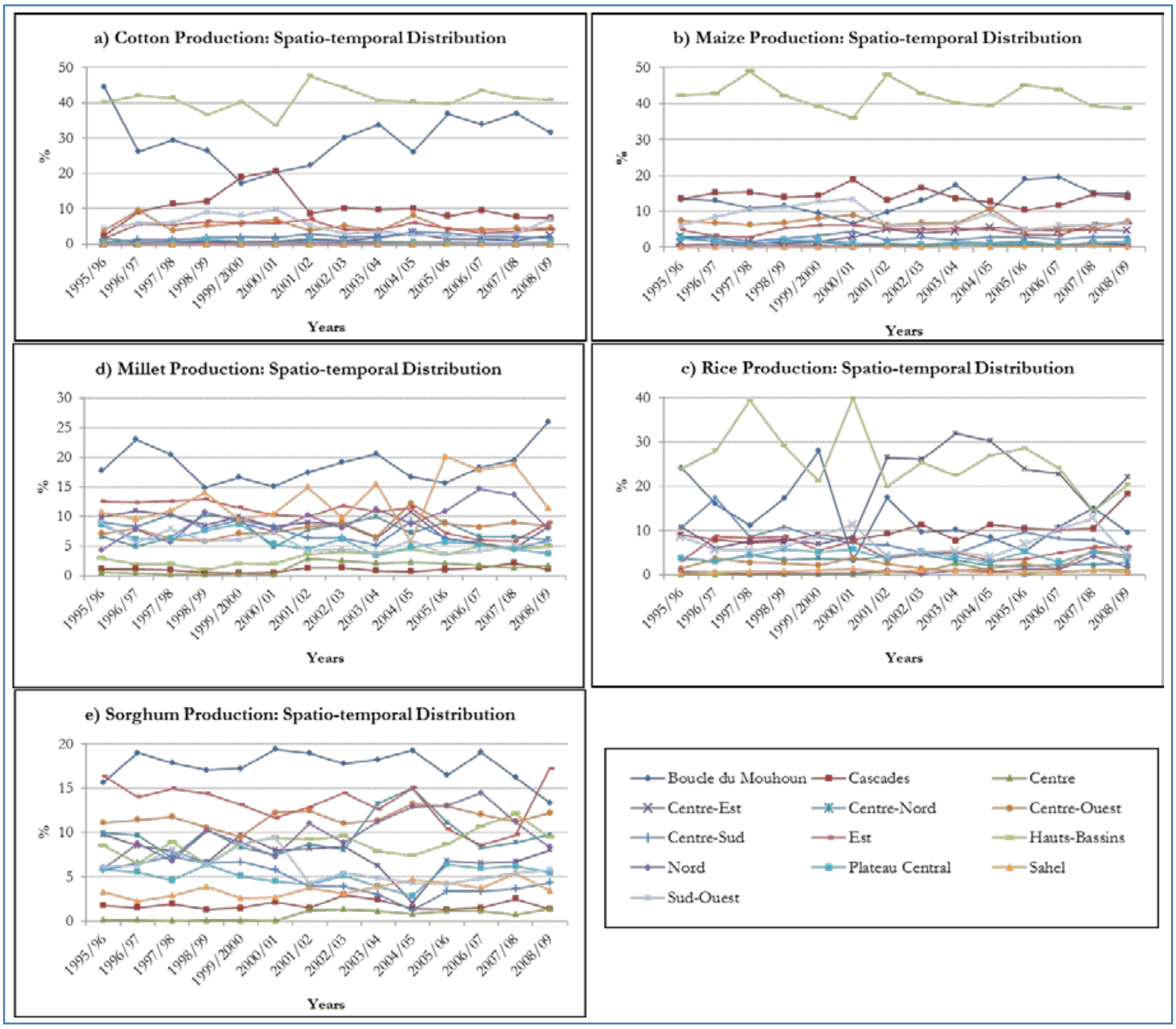


Figure 30: Spatio-temporal of Regions weights by speculation

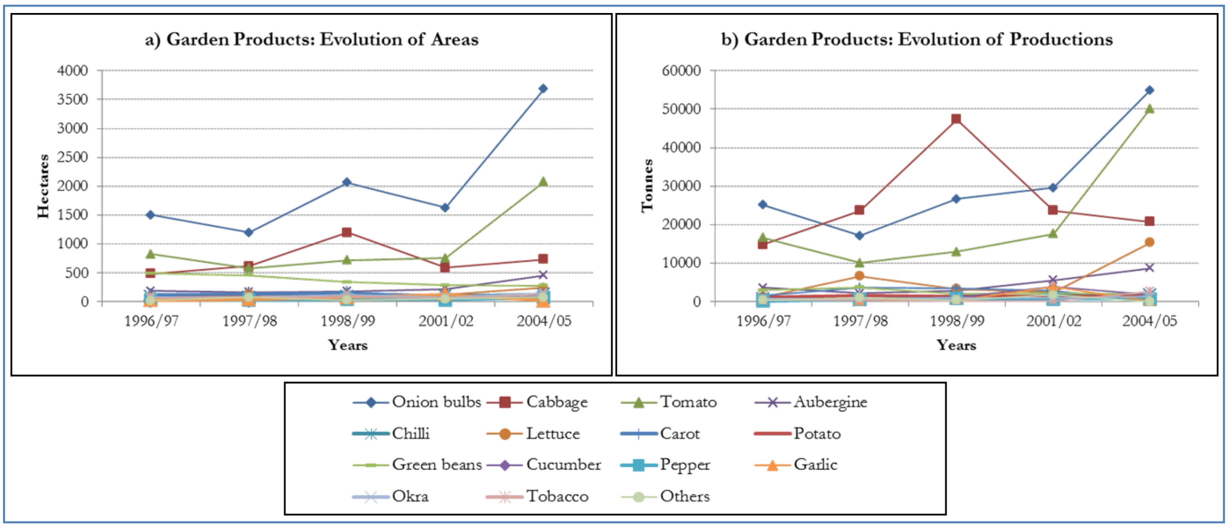


Figure 31: Seasonal variations of garden crops develpped areas and productions

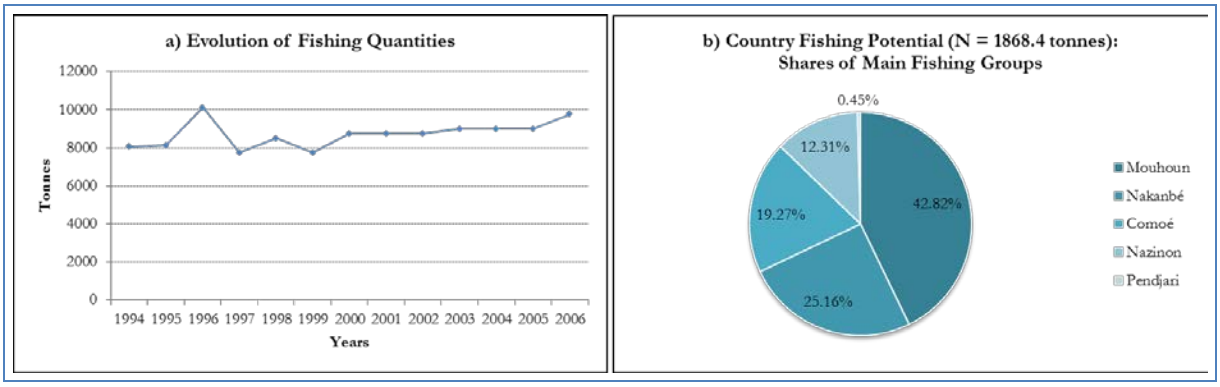


Figure 32: a) Evolution of fishing; b) Potential of fishing by fisherie (Source: MAHRH, 2007)

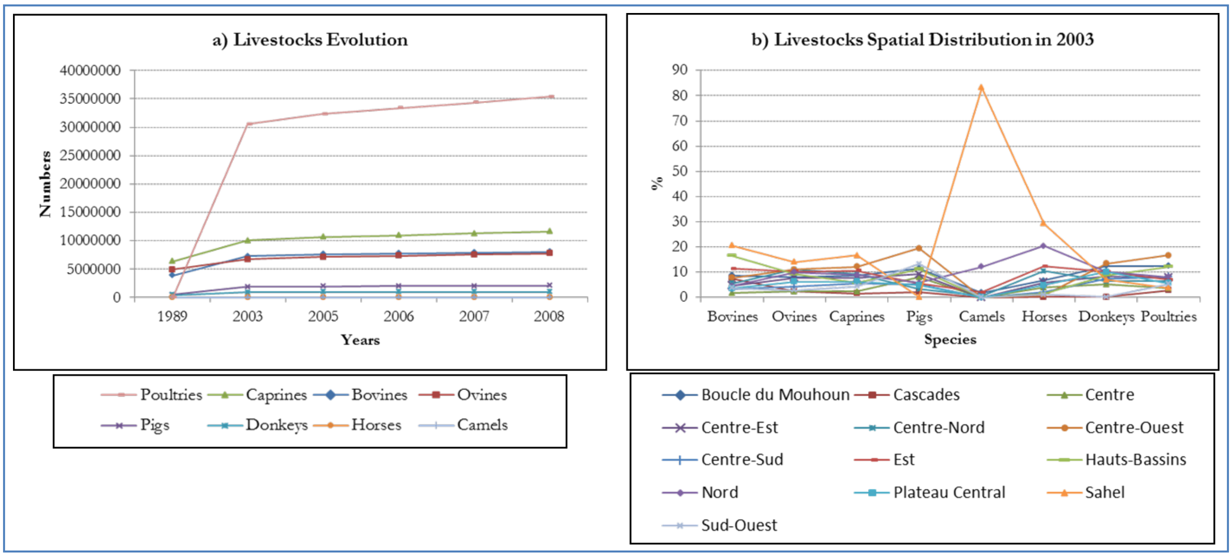


Figure 33: Livestocks: a) Temporal evolution; b) Spatial ditribtion by region in 2003

2.3.1.2. *Access to basic infrastructures*

- Access to healthcare services

In the literature, the definition of access remains subject of no consensus, since researchers – with different specialities – measure movements toward or away from a particular level of access to healthcare (Duncan & Clark, 1983). In fact, it is quite difficult to enumerate exhaustively all variables that determine the access to healthcare, since the access occurs as the inter-action of many factors related to three fundamental elements: the structure of the health system, the behaviour of the health professionals, and characteristics of the population seeking care. These three elements are in turn influenced in varying degrees by other factors at the macro-social level which are related to the politic of the government, macroeconomic policies and health policies (Puentes-Markides, 1992). However, all technical definitions of access to health, whatever the scientific domain of the study, can be linked to one or more of the five specific areas of the access dimension suggested by Penchansky & Thomas (1981) and Thomas & Penchansky, (1984) as follow: availability, accessibility, affordability, commodity and acceptability. The availability and accessibility remain dimensions which obviously interest the geographer in term of spatial analysis (Cadot & Harang, 2006). The availability represents the relationship of the volume and type of existing services (and resources) to the clients´ volume and types of need (Penchansky & Thomas, 1981; Thomas & Penchansky, 1984). The accessibility refers to the relationship between the location of supply and the location of clients, including transportation resources and travel time, distance and cost (Penchansky & Thomas, 1981; Thomas & Penchansky, 1984).

- Health care infrastructures

Figure 34a shows the qualitative and quantitative improvement of public health care provision in time on a period of 30 years (1982-2011). Face to an evenly growing population health care infrastructures increased timidly. The number of *Centre Hospitalier Uuniversitaire/National* (CHU/N), the highest ranked health center, went from three in 2001 to four in 2011. The second important health center is the *Centre Hospitalier Régional* (CHR) whose number evolved rapidly up to nine in 1987 and remained unchanged till 2011 (Figure 34a). The *Hôpital de District* (HD) comes at the third level. Data on HD were available from 1994. The infrastructure which varied unevenly, input/output, was the *Centre Medical* (CM) as its curve shows. This means that the status of CM is matter of big instability. Compared to others, only the curve representing the *Centre de Santé et de Promotion Sociale* (CSPS) adapts its speed to the population growth. The number of CSPS, the most peripheral health center, went from 218 to 1443, i.e., an increase with a magnitude of 6.6 (Figure 34a).

Figure 34b shows the qualitative and quantitative improvement of public health care provision in space for 2011. It shows clearly that the spatial inequity is influenced by the administrative function of the geographic entity. Ratios CSPS/villages, and CM/departments observed less than half an infrastructure per administrative geographic entity: 0.18 and 0.10, respectively. Conversely, ratios HD/provinces and CHR/regions showed more than half an infrastructure per geographic entity: 0.98 and 0.69, respectively. The most central healthcare facility is represented by the CHU/N with three located in Ouagadougou (political capital), and one in Bobo-Dioulasso (economic capital).

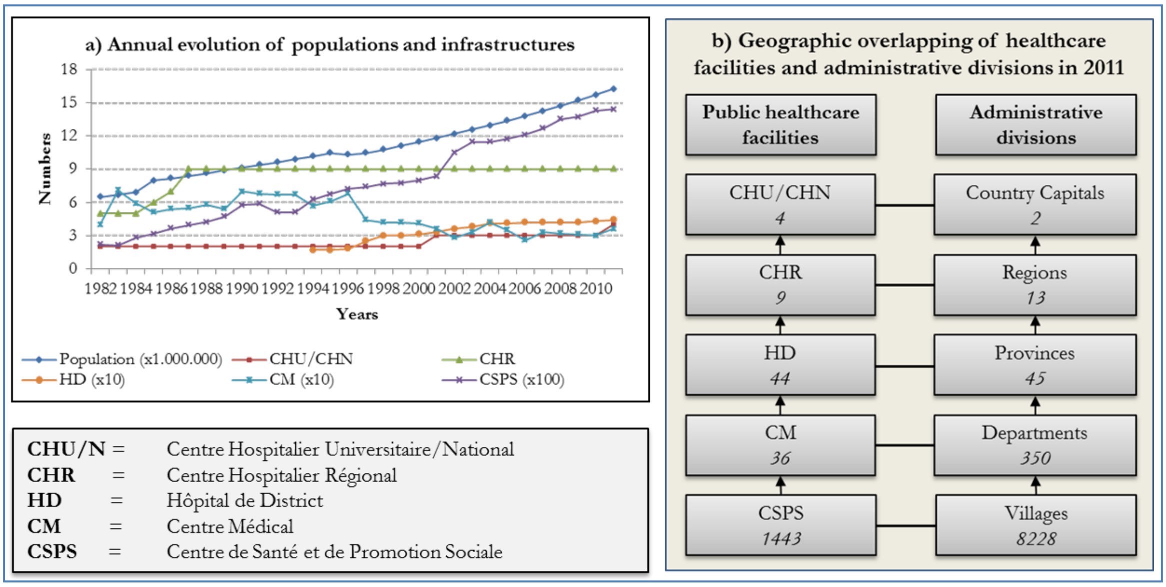


Figure 34: Health care infrastructures

a) Plot of numbers of population and public health care infrastructure types (Source: DGISS, 02/2011);

b) Influnce of the administrative function on the quality of health care infrastructures (Source: DGISS, 05/2012)

- Health care professional

Figure 35a shows that the number of inhabitants per physician was above 20,000 in 2011; that is to say 20 times higher than that recommended by the WHO. In the qualification of nurses, ratios were of 5056 and 5697 inhabitants per *Infirmier Diplômé d'Etat* (I.D.E) and *Infirmier Breveté* (I.B). In the category of *Agent Itinérent de Santé* (A.I.S) the ratio was of 7730. No data were available for the year 2005. Figure 35b shows the unequal distribution of these four categories of health care professionals per structures in 2011. Nearly half of physicians (47%) was concentrated in CHR and CHU/N. The sanitary district (DS) represented 33%. The rest (20%) of physicians was appointed in health regional directories (DRS) and other structures related to the Ministry of Health such as research centers. Conversely, 99, 85 and 76% of A.I.S, I.B and I.D.E, respectively, were concentrated in the DS.

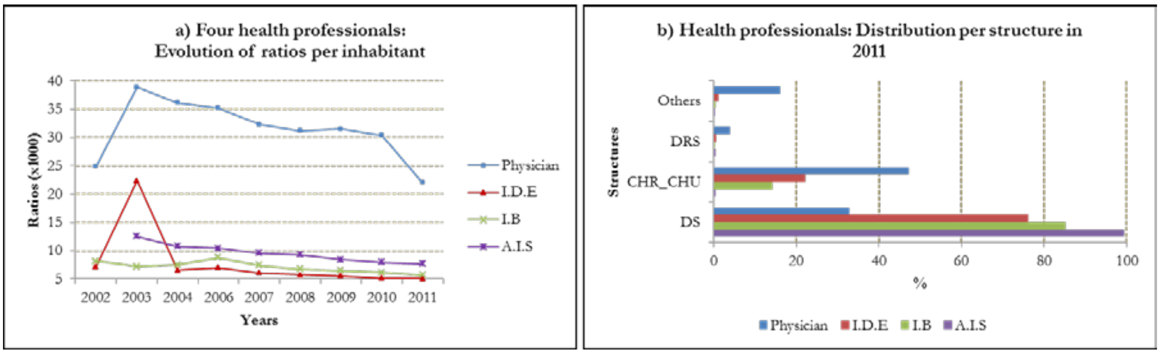


Figure 35: Public health care personal: a) Evolution of ratios per inhabitant (Sources: DGISS, 02/2011; 2012, 05/2011); b) Concentration of public health care professional according the structure (Source: DGISS, 2012).

- Health care system of reference

Figure 36 shows the pyramidal function of the three levels of the system of reference which follows a dependence and complementarity reasoning from the DS (bottom), via the CHR (medium) to the CHU/N (top). Primary healthcare are delivered at the DS level and represents the most decentralized functioning unit of the health system with a total number of 70 in 2011. This means that 37% of SD did not have any HD. The DS includes two steps in the reference system. The CSPS* (CM+CSPS) representing the basic structure (step_1) of the care provision. Patients are referred from these peripheral facilities to the HD (step_2). In 2011, the ratio CSPS*/HD was 33.61. Next, each DS must send patients to their respective CHR of reference. At their turn, CHR refers to CHU/N (Figure 36).

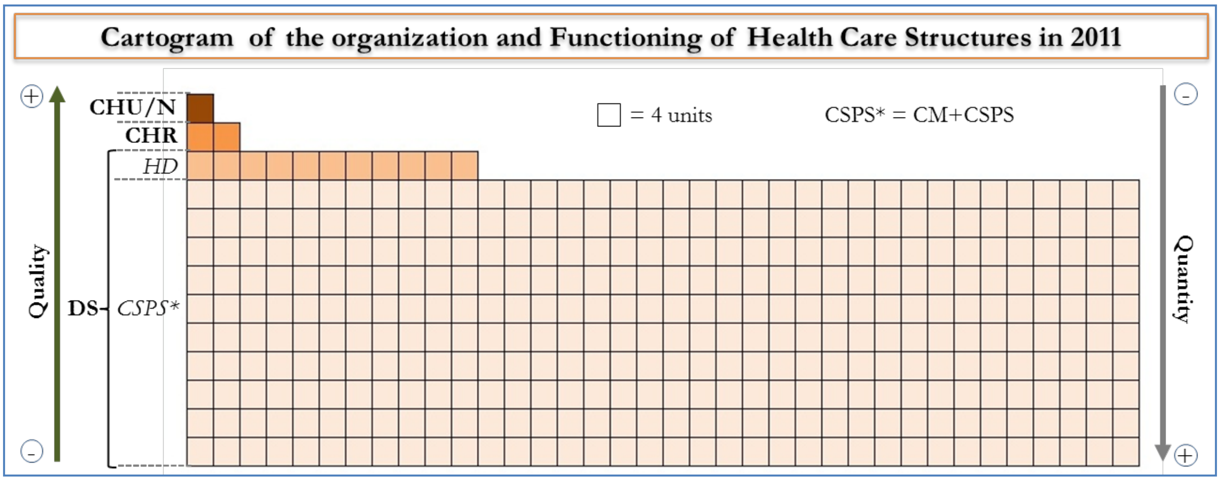


Figure 36: Pyramid of the system of reference in Burkina Faso

- Accessibility in time and space

Figure 37a shows a decreasing trend of distances to the CSPS of reference. This distance is called the theoretical effective average radius (TEAR). If the input of CSPS is maintained, the TEAR will go down in the range of 3 km and 4 km in 2012 and 2031 compared to 2011. Figure 37b shows that 85% of regions had the majority of their populations located less than

5 km from their CSPS of reference in 2011. Only Sahel and Est regions had the majority of their populations located at least 10 km. Then, Figure 38 compared the regional TEAR to the district one.

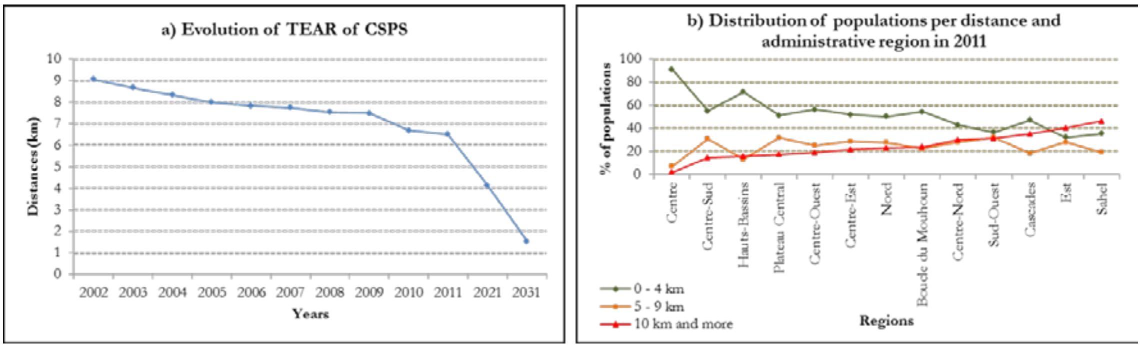
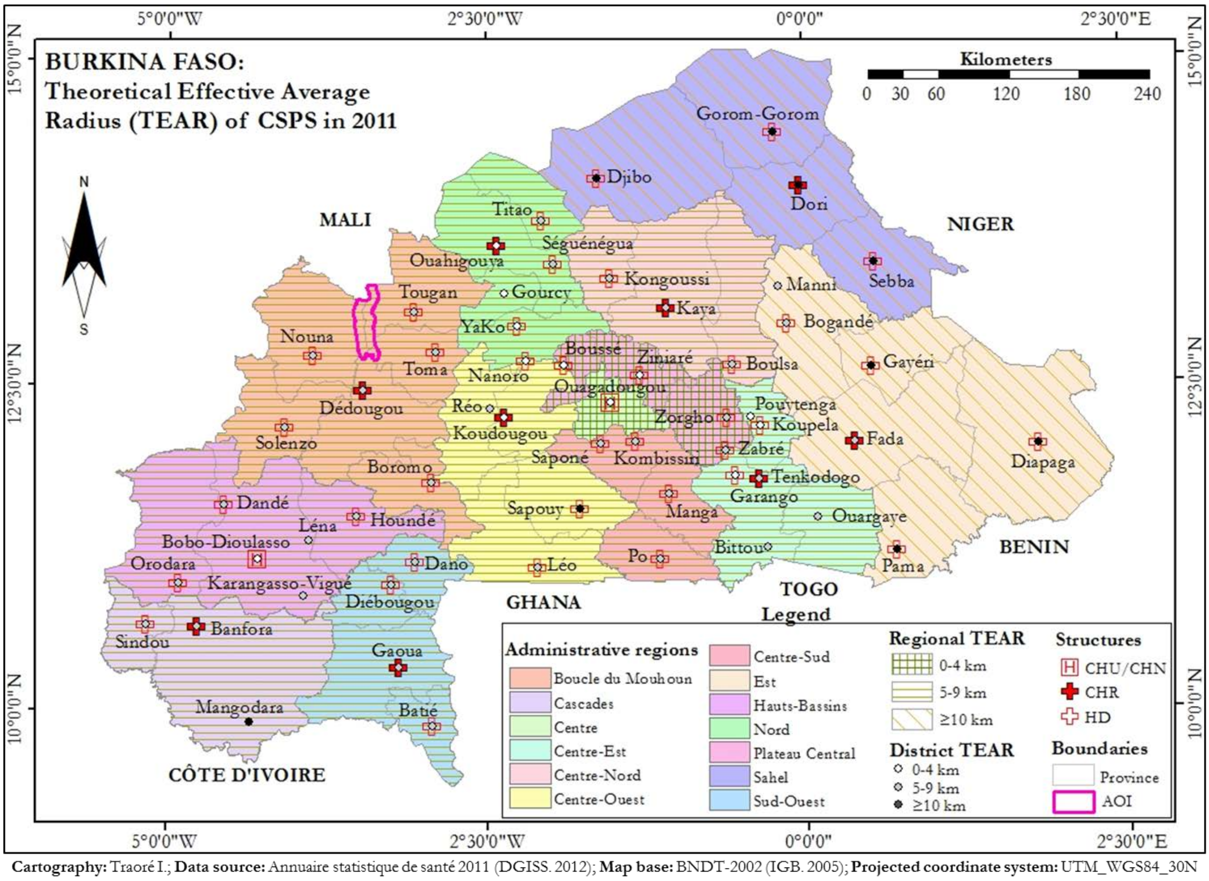


Figure 37: Accessibility to CSPSs: a) Temporal evolution (Sources: DGISS, 2012, 2011, 2010, 2009; DEP, 2008, 2007, 2006, 2005, 2004, 2002; our projections); b) Proportions of populations by region in 2011 (Source: DGISS, 2012)



Cartography: Traoré I.; **Data source:** Annuaire statistique de santé 2011 (DGISS. 2012); **Map base:** BNDT-2002 (IGB. 2005); **Projected coordinate system:** UTM_WGS84_30N

Figure 38: Accessibility to CSPSs in 2011 (Source: DGISS, 5/2012)

- Access to and utilization of health care services

Figure 39a shows that healthcare centers were visited at 70% for urinary schistosomiasis and 30% for the intestinal form in the last decade (2002-2011). Figure 39b shows that more than 50% of schistosomiasis patients was adults (≥ 15 years old). Children patients (<15 years old) observed a decreasing trend while adults showed an increasing trend. It also demonstrates that adult males represented between 40 and 50% of schistosomiasis patients, followed by children between 5 and 14 years old with 20 to 30% disease cases. Adult females and under five children recorded the lowest proportions of seeking care in case of schistosomiasis.

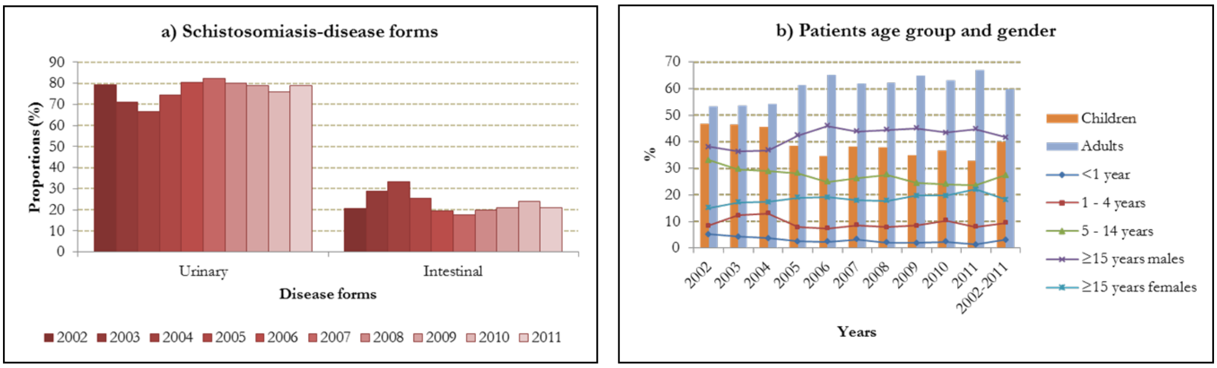


Figure 39: Hospital schistosomiasis: a) Diagnosed forms; b) Patients characteristics (Sources: DGISS, 2012, 2011, 2010, 2009; PED, 2008, 2007, 2006, 2005, 2004, 2002)

- Access to water and sanitation

Fully aware of the importance of water and sanitation as main determinants of health status and in accordance with the *Stratégie de Croissance Accélérée et de Développement Durable* (SCADD) and MDG, Burkina Faso has adopted in December 2006 a national program for water supply and sanitation to the horizon 2015 (PN-AEPA-2015). The global objective of the PN-AEPA-2015 is to improve the life quality of the population by ensuring equitable and adequate access to clean water and sanitation by 2015 within a framework of sustainable and equilibrated management of the water resource. The specific objective is to reduce of 50% by 2015 the proportion of persons having no adequate access to clean water and sanitation in 2005, according to standards, criteria an indicator in force in the country. Therefore, Burkina Faso was considered to be a country where there is a sector policy agreed and published (WHO, 2012b).

- Access to hydraulic works

Four years before the timeline of the PN-AEPA, Figure 40 takes stock of progress done. At the start-up of the program 38.46% of region had an access rate less than 50%. In 2011, two out of the five regions reached the rate of 50%. Therefore, the objective of 50% was reached in 76.92% of regions in 2011. However, at the provincial level data in Figure 41 show that in 2011 26.67% of provinces observed less than 50% as rate of access to clean water. The highest ranked access rate (≥ 75%) concerned 11.11% of provinces. Figure 41 also indicates that our AOI straddles the first two clean water access classes.

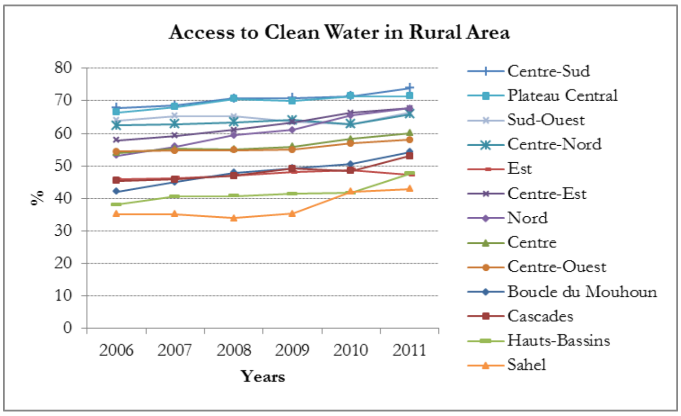


Figure 40: Spatio-temporal access to water by region in Burkina Faso (Source: ONEA, 2012)

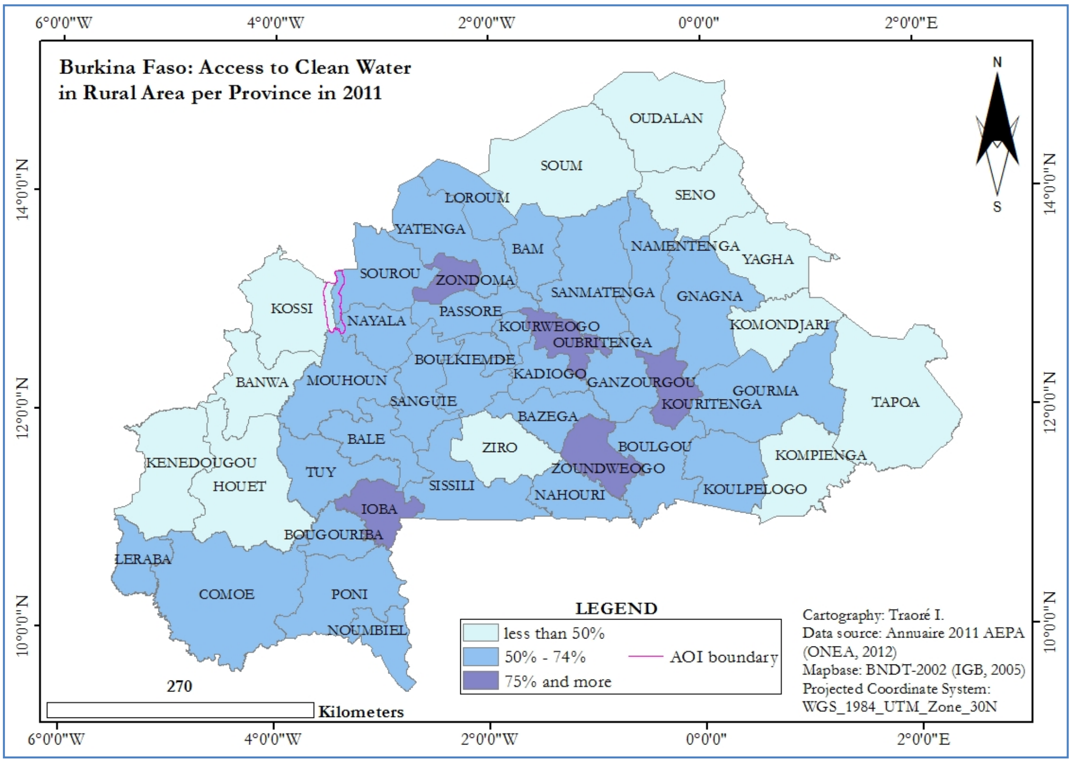


Figure 41: Spatial distribution of rates of access to water by province in 2011 (Source: ONEA, 2012)

- Access to familial sanitation

Compared to access to clean water, the access to familial sanitation showed an alarming picture as depicted in Figure 42. In terms of excreta disposal behavior a national scale survey conducted in 2010 showed that more than 60% of household was defecating in the open air at the country level and more than 75% in rural area (Figure 42a). At the provincial level, rates were divided into three classes using the natural breaks (Jenks) in ArcGIS. Therefore, Figure 43 shows that 82.22% of provinces had less than 1.1% as rate of access to familial sanitation. The Sourou Valley fell into this class.

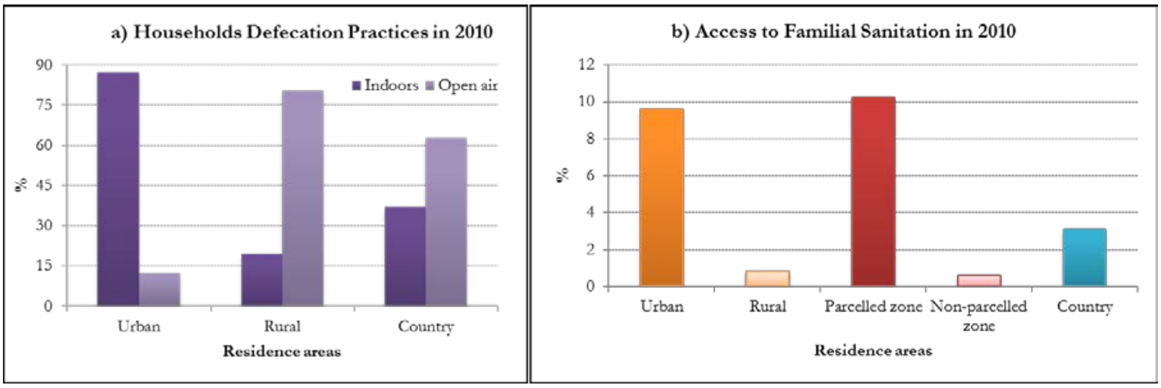


Figure 42: a) Households excreta disposal behavior; b) Access to familial sanitation (Source: DGAEUE, 2011)

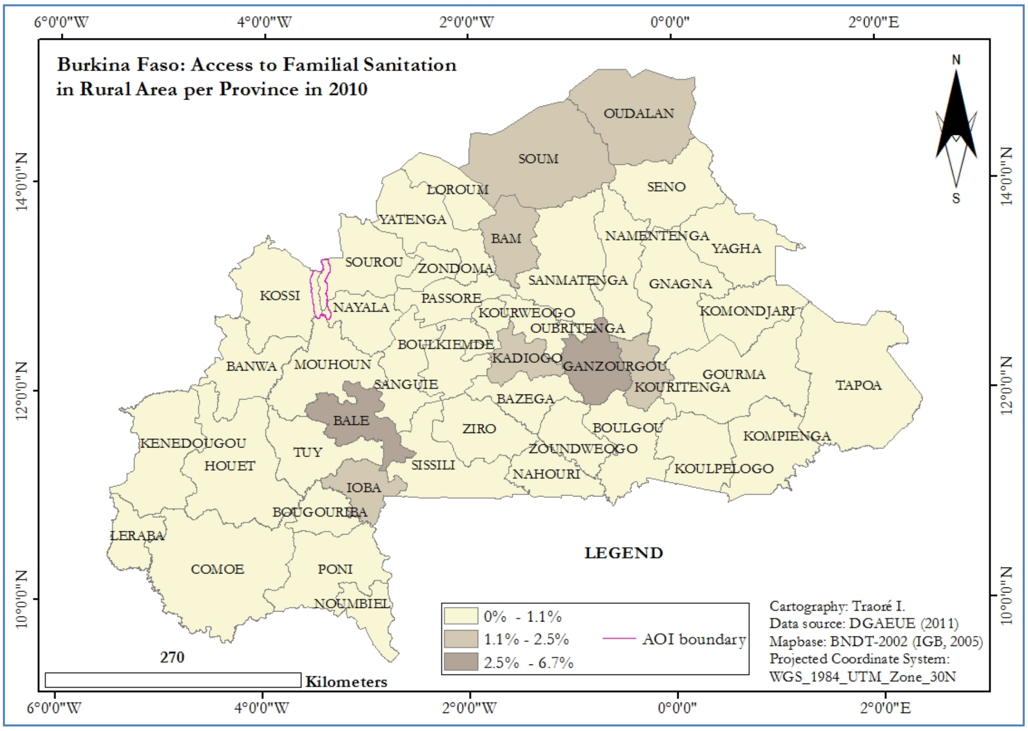


Figure 43: Spatial distribution of access to familial sanitation by province

- Access to education

- Pre-dominance of the illiteracy population in the country

Figure 44 shows that more than 70% of the population of Burkina Faso never attended a school. More than 80% of the illiteracy populations is concentrated in rural area. Figure 44 also allows to see a decreasing trend with increase of the educational level. For most of people, the primary education remains the highest level they have reached.

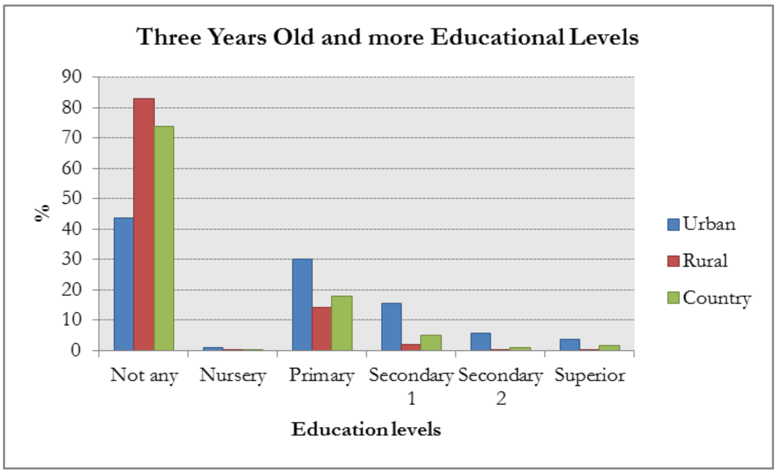


Figure 44: Burkina Faso Populations educational status in 2006 (Source: Kobiané & Bouma, 2009)

- Unequal distribution of the education crude rate

Figure 45a shows that till the school year 2002/2003 the primary education crude rate was below 50% and has evolved rapidly to reach 60% for 2005/2006 and more than 70% for 2007/2008. Similarly, the secondary* (including the superior) education crude rate is progressing. Concerning primary education, Figure 45b shows that public schools overtake private ones and that most of infrastructures were located in rural area. The distribution of primary education crude rates according to the gender shows 81.1% for boys vs. 78.1% for girls at the country level for the school year 2011/2012. However, as indicated in Figure 46, 17.77% of provinces showed higher rates for girls than did boys. Figure 47 shows that primary education crude rates are unequally distributed through the country. We categorized provinces into five classes based on natural breaks (Jenks) in ArcGIS. Then, from the lower to the higher crude rates classes were found 15.56, 17.78, 22.22, 28.29 and 15.56% of provinces. Our study area straddles the second, the fourth and the fifth classes (Figure 47).

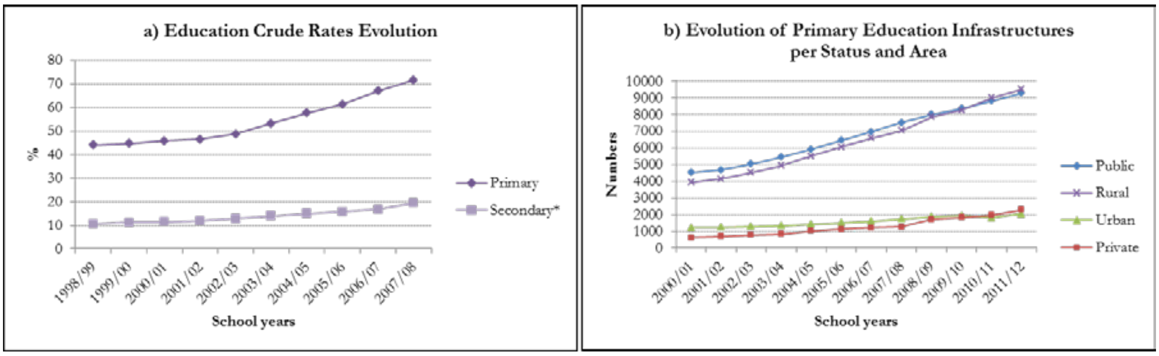


Figure 45: Burkina Faso: a) Primary and secondary education crude rates evolution (Sources: DEP/MENA, 2012; DEP/MESSRS, 2010); b) Primary education infrastructures improvement (Source: DEP/MENA, 2012)

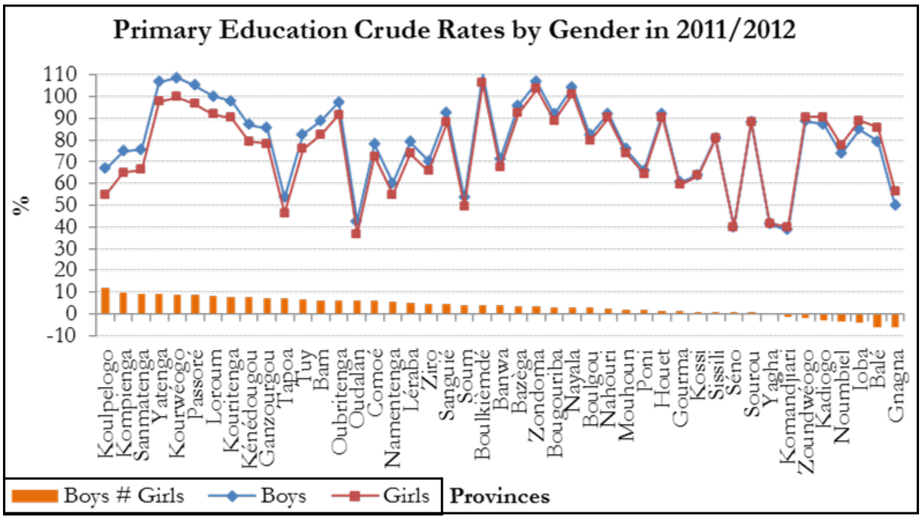


Figure 46: Primary education crude rates by gender

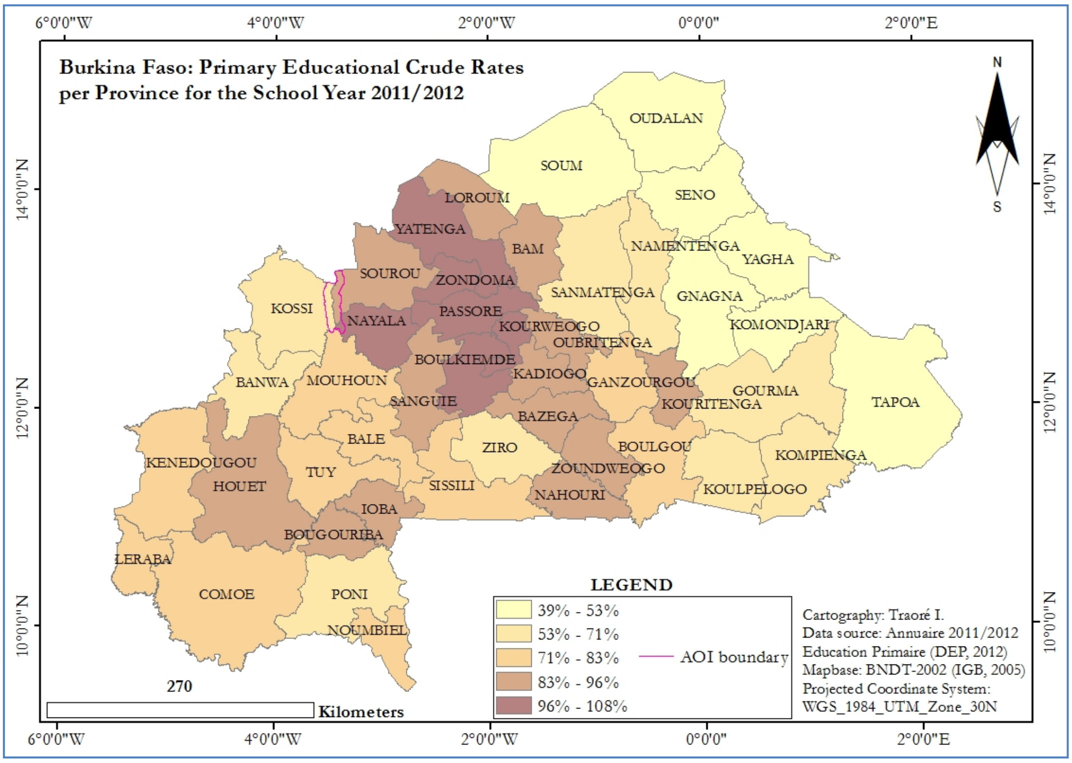


Figure 47: Spatial distribution of Primary education crude rates by province (DEP/MENA, 2012)

2.4. Schistosomiasis risk factors proper to the Sourou Valley

2.4.1. Hydro-agricultural modification

2.4.1.1. Background: The Office du Niger (ON)

The Office du Niger was created in January 1932 in Mali to supply France with cotton that was to progressively bring about its independent from the product of the American and English (Kohler, 1974; Marchal, 1974; Marchal, 1986; Morabito, 1977; Amselle et *al.*, 1985). The secondary objective was growing of rice parallel to the cotton for two reasons. The rice product was to serve supplies to the coastal colonies specialized in exportation to France, e.g. groundnut in Senegal, rubber and banana in Guinea, coffee and cacao in Côte d'Ivoire. "Make rice for Senegal and Côte d'Ivoire, it is to make groundnut and coffee for France." On the other hand, the production of rice should allowed to be supplied if needed in Mali and neighbouring regions in order to avoid food shortages or famines (Marchal, 1974; Morabito, 1977; Amselle et *al.*, 1985). For putting in farming, the program was foreseeing the settlement of 300000 farmers. Burkina Faso served as reservoir of labor in this project (Kohler, 1974; Marchal, 1974; Marchal, 1986; Morabito, 1977; Amselle et *al.*, 1985). Later on, the colonial administration decided to reproduce something similar to ON in Burkina Faso and particularly in the Sourou Valley (Figure 48). From 1952 experts of diverse domains were sent in the area for preliminary planning studies which contributed in the creation of a trial station in 1956 in Di (Marchal, 1986). Unfortunately this ambitious project was abandoned with the advent of freedoms in 1960. At the same time, the new independent government of Mali claimed the departure of the French from the ON which was malianized. This socialist option of the independent new State was deemed as insupportable by foreign farmers resettled in ON. Then, about 2000 farmers leaved ON and cameback in Burkina between 1963 and 1964 (Marchal, 1974; Morabito, 1977; Amselle et *al.*, 1985). The comeback of these people newly aroused hopes to see the realization of the "Sourou Valley project". In 1965, the government with aid of the national Red Cross had launched a campaign in favor of its nationals repatriated from the ON (Marchal, 1976).

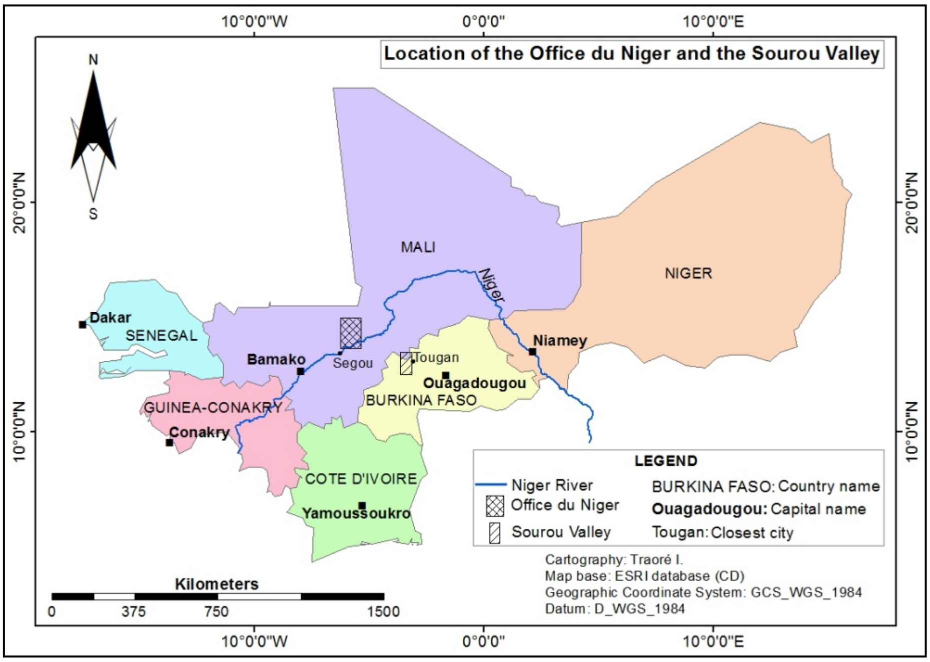


Figure 48: Geographic location of the Office du Niger compared to the Sourou Valley

2.4.1.2. Hydrological modification: The Mouhoun-Sourou complex

The Sourou River is a tributary of the Mouhoun River. It is considered as a mysterious river because it changes its flow direction according to seasons. Towards the end of the raining season, when the Mouhoun River is in spate, its overflow is poured in the Sourou River which flows in the South-north direction. Conversely during the low flow occurring in the dry warm season, the Sourou River change its flow direction North-south to give back water to the Mouhoun River. This particular hydrologic system could be used for hydro-agriculture purposes. In this logic, two major hydrologic modifications took place at the confluence of the Mouhoun and the Sourou Rivers. The complex Mouhoun-Sourou is a set of works composed by lifting sewage and a man-made canal both implemented at the confluence of the two rivers in order to control water for the benefit of irrigation activities in the Sourou Valley.

- The four sewages of Leri

About 10 years after the resettlement of farmers in Guièdougou and the starting of modern irrigation in the Sourou Valley, the river could not supply the quantity of water needed for the dry season. The first idea was to implement lift sewages on the Sourou River at the confluence with the Mouhoun River in 1976-77 (Figure 49a). It aimed to control the North-south flow of the Sourou River during the dry season so that the Sourou reservoir could maintain enough water for irrigation activities. Sewages are opened during the South-north flow of the Sourou River and are closed when the flood reach its maximum level. Therefore, during the low flow, the Sourou River could not give back the water like it should in the natural condition. Unfortunately, simulation of water management demonstrated that in the case of drought, the Sourou reservoir could not withstand the important evapotranspiration. Six years later on a revolutionary idea was implemented.

- The canal of the Revolution

In May-August 1984 a canal of 700m length, 35m wide and 9.50m deep (Bethmont et al., 2003) was dug to connect the Mouhoun River directly with the Sourou River (Figure 49b). It consisted in standing the way to the natural flow of the Mouhoun by an earthen dam (2a in Figure 49b). Therefore; the entire water of the Mouhoun flows directly into the Sourou River via the canal (2b in Figure 49b). The dead arm of the Mouhoun indicates clearly that the Mouhoun River is from 1984 merged to the Sourou River. Since then, the Mouhoun and the Sourou form a complex. The lifting sewages (1 in Figure 49) are used to control the North-south flow of the Sourou River. As a consequence, the Sourou River became as permanent as the Mouhoun River and could therefore store enough water for irrigation development in the Sourou Valley. Another direct impact of the hydrological modification is shown in Figure 50 and concerns Toma-Île village which became an island.

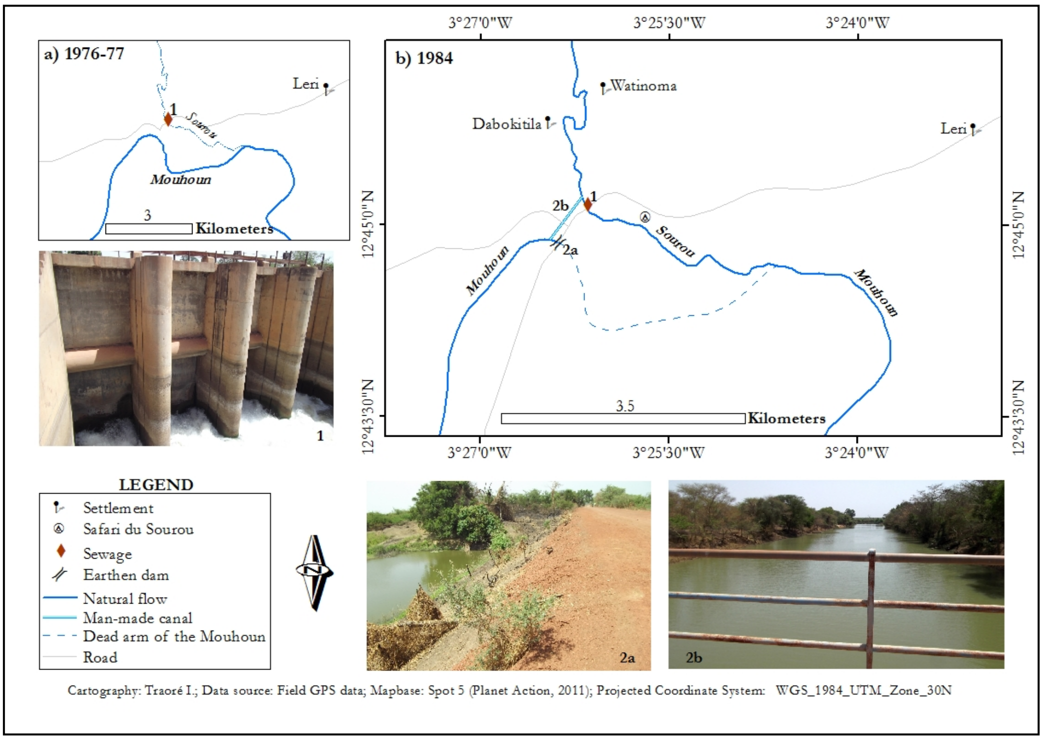


Figure 49: Hydrological modification at the confluance of the Mouhoun-Sourou

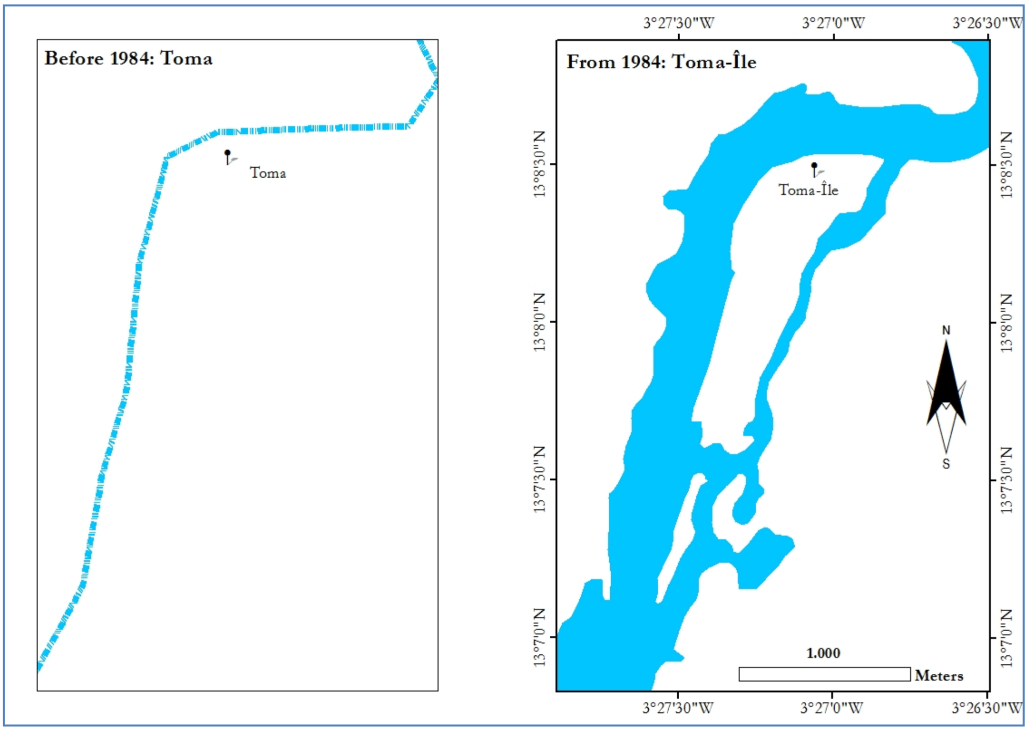


Figure 50: Direct impact of hydrological modification on Toma-Île village

2.4.1.3. Environmental modification: Irrigation developement projects

The hydrological modification allowed the development of series of irrigation projects in the Sourou Valley. In May 2011, there were 3818 hectares of lands developed for modern irrigation purposes (Table 6). About 27% of parcels were concerned with paddy production. Only 13% of cooperatives were specialized (100%) in rice against 47% in poly-culture (mainly garden crops and maize and 0% of rice). A total number of 3008 stakeholders was made a census for 14 co-operatives. Only 0.75% of stakeholders represented female and concerned only three co-operatives. Globally, there was more than one hectare per farmer.

Figure 51 shows the spatial distribution of developed perimeters. Only 5% of developed perimeters was found on the western bank in Kossi province, precisely in Sono department. The rest of 95% of modern irrigation fields were located on the eastern bank in Sourou province. Developed areas spread on three departments: Di, Lanfièra and Kassoum with 57%, 33% and 5% of irrigated parcels, respectively. Figure 51 also indicates a new development project in process at the North of Di. It was launched in December 2011 as one component of the agricultural development project of the Millennium Challenge Corporation (MCC) seeking to expand the productive use of land by increasing the area under irrigation in the Sourou Valley via the cleaning and conditioning of 2037 ha of land for irrigation.

In the Sourou Valley, the irrigation system is mainly based on the gravity-fed irrigation using hierarchized canals. The pressure-fed system was experimented in 1982 and was abandoned because of technical problems (Figure 51).

The creation of the *Autorité de Mise en Valeur de la Vallée du Sourou* (AMVS), Created in June 1986, the AMVS has as missions (GIRE, 2001): 1°) to research, to mobilize, to put in place and to manage findings, 2°) to study, to control, to develop and put in value lands, 3°) to do the research-development and the promotion of actions of protection of the environment, to manage hydraulic infrastructures and collect water taxes, 4°) To make farmers more responsible.

Table 6: Series of irrigation development projects (Source: AMVS, mai 2011)

Management Co-operatives		Developed fields details				Co-operators			Area/ Farmer (ha)
No.	***Name***	***Year***	***Area (ha)***	***% of Rice***	***% of Polycultures***	***Total***	***% of Male***	***% of Female***	
1	Badenya	1993	200	0.00	100	165	100	0.00	1.21
2	CAD	1996	475	57.89	42.11	405	100	0.00	1.17
3	CANI	1992	500	70.00	30.00	367	100	0.00	1.36
4	CAPIN	1987	50	100	0.00	63	100	0.00	0.79
5	CAPSO	1987	70	60.00	40.00	57	100	0.00	1.23
6	CIOEPA/C	1999	203	0.00	100	13	100	0.00	15.62
7	COPROMAG	1966/1982/1987-88	300	0.00	100	495	100	0.00	0.61
8	CRTO	1999	70	100	0.00	116	100	0.00	0.60
9	Fasokadi	1999	134	62.69	37.31	259	99.23	0.77	0.52
10	Heressira	1987	70	0.00	100	184	96.20	3.80	0.38
11	Sababougnouma	1999	206	31.55	68.45	455	97.14	2.86	0.45
12	SOCADI	1977/1980	420	0.00	100	125	100	0.00	3.36
13	SOCAMAD	1990	610	16.39	83.61	204	100	0.00	2.99
14	SOGCAM	1990	300	0.00	100	100	100	0.00	3.00
15	SONO	1999	210	0.00	100	ND	ND	ND	ND
Total	**15**	**-**	**3818**	**27.13**	**72.87**	**3008**	**99.25**	**0.75**	**1.27**

CAD	Coopérative Agricole de Débé
CANI	Coopérative Agricole de Niassan
CAPIN	Coopérative Agricole Pilote de Niassan
CAPSO	Coopérative Agropastorale de Sorokadi
CIOEPA/C	Comité d´Irrigants des Opérateurs Economiques Producteurs Agricoles du secteur C, Gouran
COPROMAG	Coopérative des Producteurs des Produits Maraîchers de Guiėdougou
CRTO	Coopérative Rizicole de Toma
SOCADI	Société Coopérative Agricole de Di
SOCAMAD	Société Coopérative Agricole et Maraîchére de Débé
SOGCAM	Société Coopérative Agricole et Maraîchére de Guiėdougou

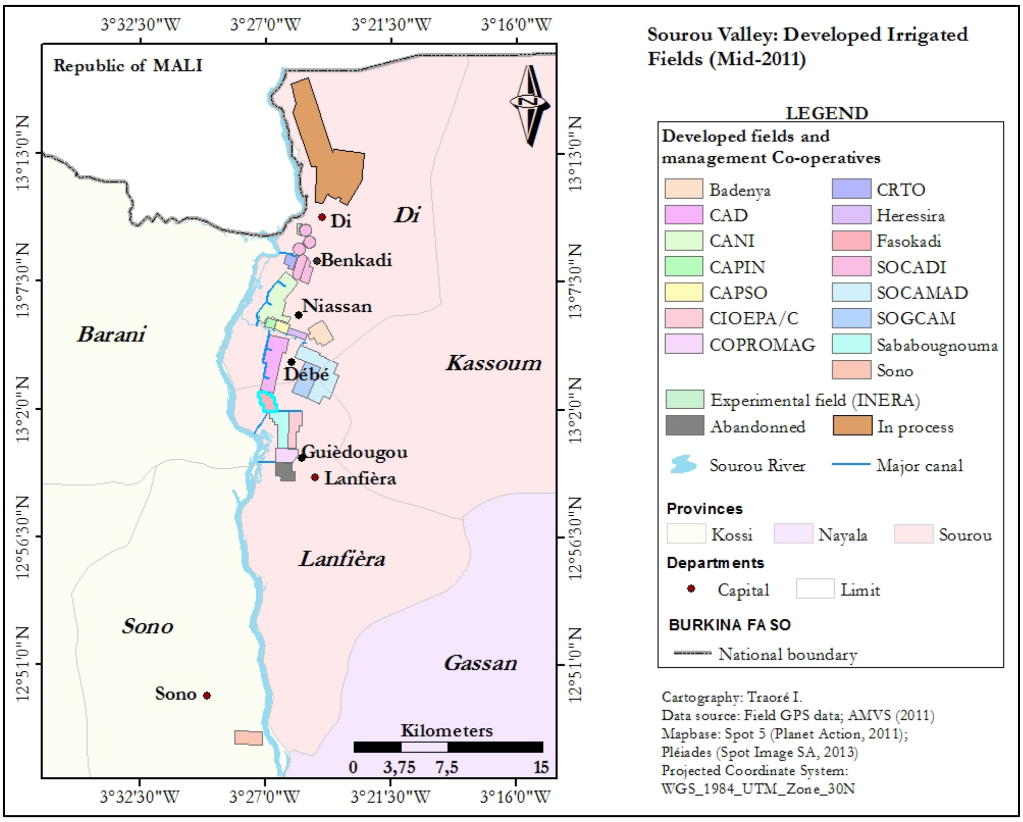


Figure 51: Environmental modification

2.4.2. Population migration through irrigation development projects

In 1966, the first modern irrigation field of 144 ha was developed in the Sourou Valley sponsored by the Aid and Cooperation Fund (ACF). Based on this new perimeter, the operation termed "of hundred families" was launched by the government with the help of the national Red Cross to resettle mainly the people repatriated from the ON in Mali. (Marchal, 1976; Interview with Zougouri Issa, the father funder of Guièdougou). Farmers recruited came from Sourou and Yatenga provinces in majority, and from Kossi, Mouhoun and Sanguié provinces in minority. Seventeen years later, in 1983, another 144 ha of lands was developed in Guièdougou (Figure 51). This allowed the resettlement of news farmers recruited in Mouhoun, Sourou and Yatenga provinces. 19 years later, in 1985 farmers recruited in Sourou, Passoré and Yatenga provinces have been resettled in Benkadi (Figure 51). Two years later, in 1987, farmers from Sourou and Nayala provinces joined Benkadi and formed the quarter Sababougnouma. With the development of 140 ha in 1987, 80 families coming from six provinces, Kossi, Mouhoun, Passoré, Sanguié, Sourou and Yatenga were resettled in Niassan (Figure 51). Six years later, in 1993, 460 families recruited throughout the whole country were resettled in Niassan. This migration with a national scope was made possible with the development of 500 ha (Cissé, 2000). In 1990 following the development of 460 ha next to Débé, the village served to resettle a total of 325 families from 13 provinces: Bam, Bazèga, Boulgou, Boulkièmdé, Kossi, Kouritenga, Mouhoun, Passoré, Sanguié, Sanmatenga, Soum, Sourou and Yatenga (Cissé, 2000). Seven years later, in 1997, with the development of 475 ha, new farmers from Passoré and Sourou provinces were resettled in Débé (Interview with Zaré Djibilirou, politico-administrative representative of Débé).

2.4.3. Impact of hydroagricultural modification and population migration on the epidemiology of schistosomiasis in the Sourou Valley

The Sourou Valley is a natural wetland and home to series of hydroargricultural modification associated with massive population migration. Until 1987, the Sourou Valley was endemic only to S. haematobium (Doumenge et al., 1987). According to Poda et al (2001) the direct connection of the Mouhoun River to the Sourou resulted in the colonization of the study area by *B. pfeifferi*, the snail intermediate host of *S. mansoni*. The upstream of the Mouhoun is located in the region of Bobo-Dioulasso which is endemic to *B. pfeifferi*. The first cases of *S. mansoni* were observed in 1999 in the Sourou Valley among migrants in villages located along the irrigation zone where prevalence rates increased from 8 to 69% (Dianou et al., 2003; Poda et al, 2004). This means that before the hydrologic modification the intestinal schistosomiasis was absent in the Sourou Valley. It also means that migrant farmers have introduced *S. mansoni* into the Sourou Valley. Nowadays, the study area is endemic both to *S. mansoni* and *S. haematobium*. Numerious works (Poda, 1996; Clements et al., 2008; Clements et al., 2009) point to the Sourou Valley as the highest schistosomiasis prevalence setting in Burkina Faso (Figure 52).

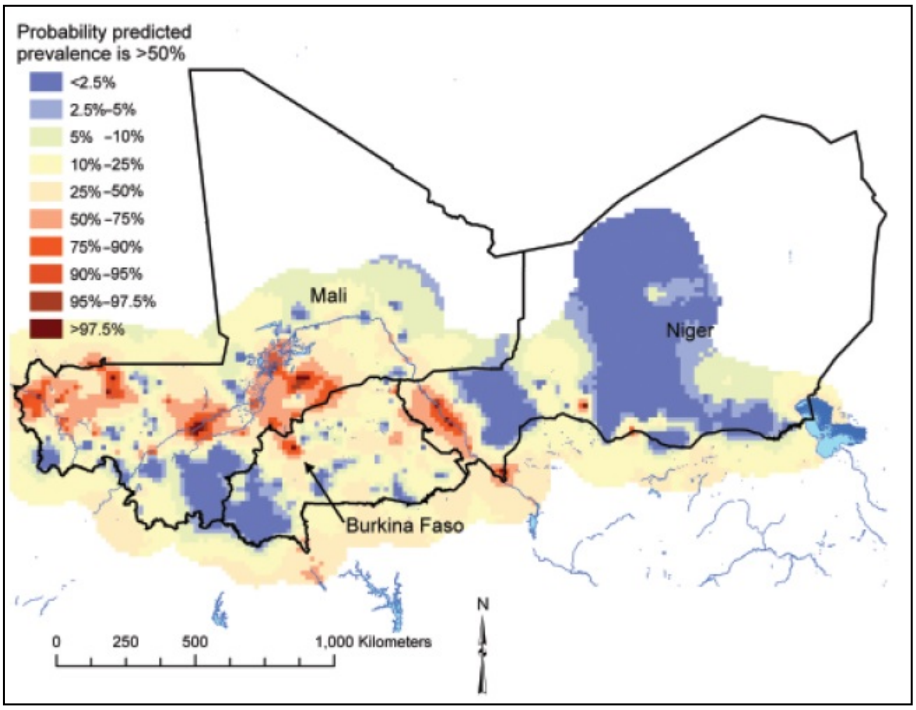


Figure 52: Probability of schistosomiasis in Burkina Faso, Mali and Niger (Clements et al., 2008, p. 1631)

Chapter 3. Methodology

3.1. Study concept

3.1.1. Eco-geographic perspective

In geography of health the eco-geographic concept (also called human ecology) aims to identify the natural and social geographic elements that determine the existence and distribution of the given disease (Figure 53), was introduced in 1950s by May, particularly when viewing tropical diseases (Pyle, 1976; Meade, 1977). Human ecology studies the relations between human and the natural environment, two things irremediably linked, pointing to the problem of schistosomiasis transmission by assessing and analysing the risk and the process within a spatial and temporal frame (Spate, 1960; Pyle, 1976; Good, 1977; Haggett, 1968; Lewis & Mayer, 1988; Salem, 1995; Gatrell, 2002; Grisorio et al., 2005). The eco-geographic concept relies on two phylosophies: naturalistic and humanistic (Gatrell, 2002). For naturalists schistosomiasis explanation rooted in the natural world while for naturalists the disease circumstances rooted in the social world.

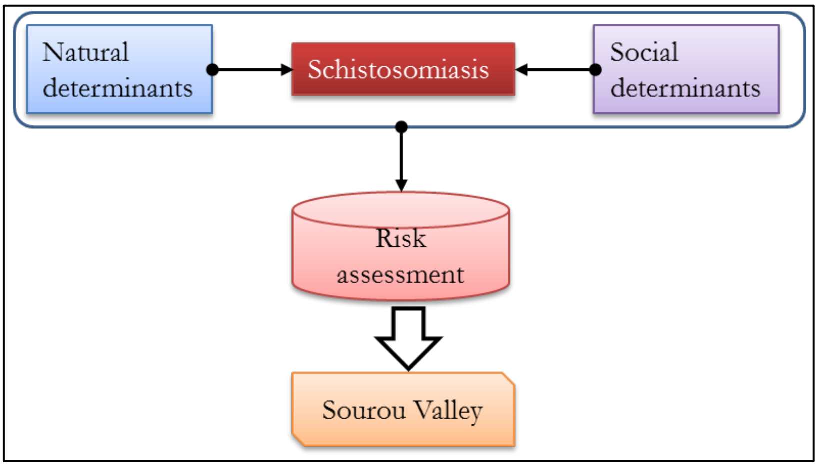


Figure 53: Eco:-geographic perspective

3.1.2. Area of interest (AOI) in the Sourou Valley

We defined an AOI within the Sourou Valley on which data collection was focused (Figure 54). On the one hand, aiming to include the totality of modern irrigation fields developed till mid-2011; a buffer of 7 km from the Sourou River allowed to fulfil this condition. On the other hand, aiming to include the total length of the Sourou River (in its Burkina Faso side); the AOI was limited at the North by the country boundary and at the South by the Mouhoun River. Then, our AOI covered 885.94 km^2 (about 0.32% of the country area). The vertical axis measured about 65 km. All settlements with the AOI were surved thus the sample size of 37 settlements.

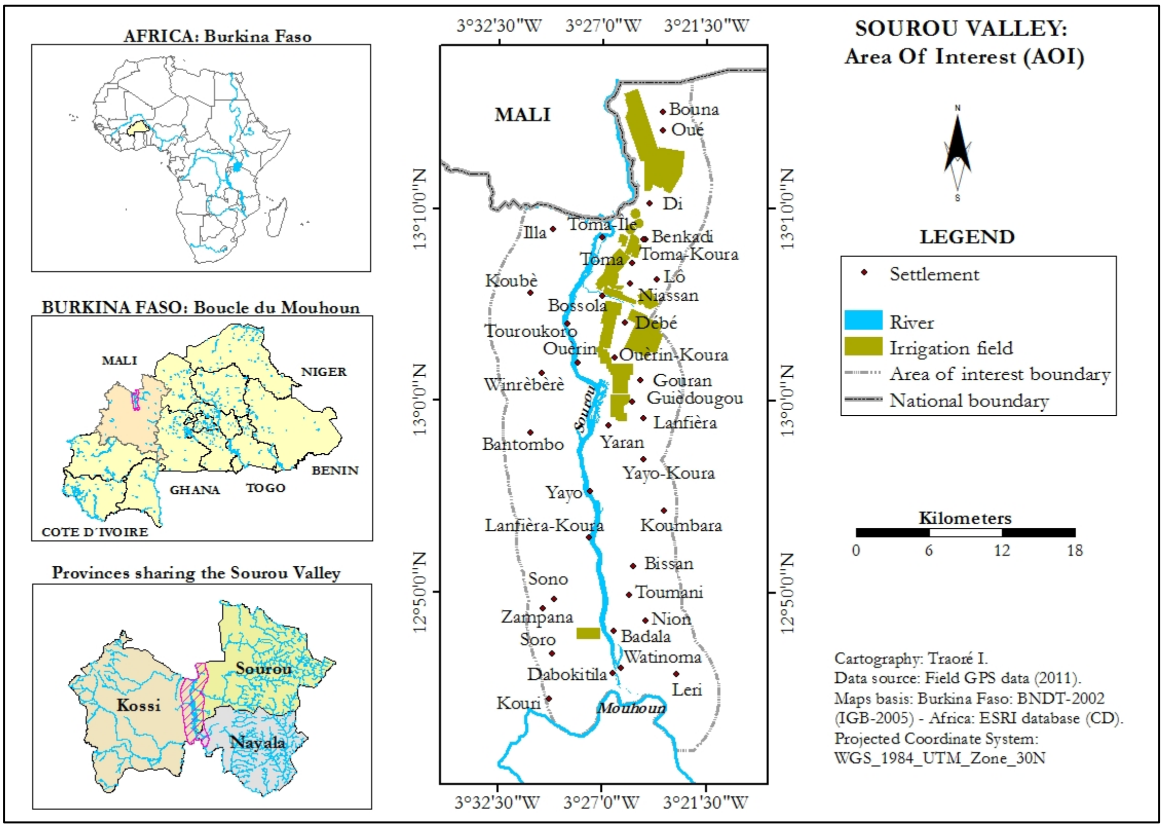


Figure 54: Our area of interest in the Sourou Valley

3.2. Data collection

3.2.1. A holistic approach

The eco-geographic approach used in this work required us to dispose of a multitude of layers of information. Data gathering following the holistic perspective included climatic, environmental and human data (Figure 55). In this thesis, physical data were collected to assess the heterogeneity and patterns of the vulnerability in time and space. Climatic variables were used to measure the risk in time (when?) while environmental layers were used to measure the risk in places (where?). Human data such as population sizes and movements as well as access to infrastructures were collected to serve pointing out risk in person (who?, how? and why?). To these three factors were addressed the question: Who does what, where, how and why of it?

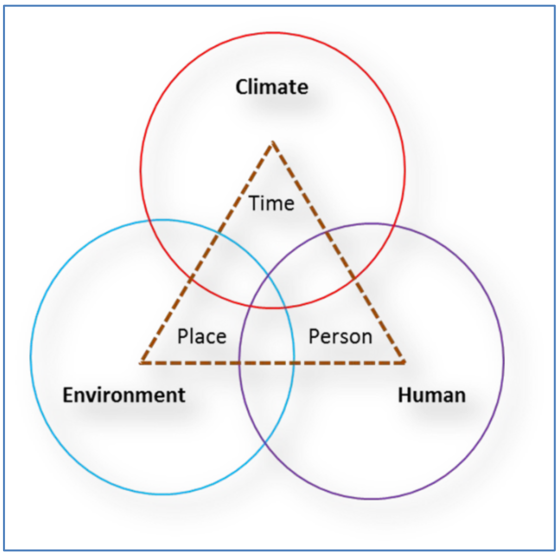


Figure 55: Holistic approach in data collection

3.2.2. Human data

To measure human determinants of schistosomiasis transmission, six variables were gathered from two parameters using three methods of collection as summarized in Figure 56. At the settlement level, we focused on residential units (compounds and populations) and associated infrastructures. Data about population movements were also collected at the settlement level. The circulation referred to population movements occurring at the micro scale, within-settlement or in the nearest neighboring. Movements at the meso level to important central places were termed mobility. Migration; herein immigration, concerned movements at the macro level, involving changes in residential location (Haggett, 1968; Daniel & Hopkinson, 1989; Maede, 1997).

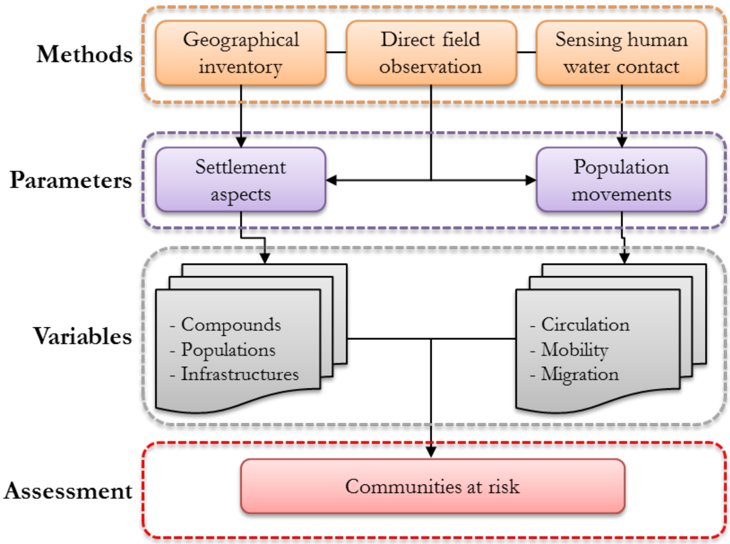


Figure 56: Flowchart of human data gathering

3.2.2.1. Geographic inventory

- Global Positioning System (GPS)

The GPS is currently the only fully functional Global Navigation Satellite System (GNSS). Twenty-four GPS satellites currently orbit Earth and transmit signals to GPS receivers, which determine the location, direction, and speed of the receiver. Since the first experimental satellite was launched in 1978, GPS has become an essential instrument for navigation, and an important tool for land surveying and cartography (Maddison & Mhurchu, 2009). GPS also provides a precise time reference, which is used in many applications including scientific study of earthquakes and synchronization of telecommunications networks. GPS was originally developed by the United States (U.S.) Department of Defense. Because of its military application, the U.S. Department of Defense applied selective error, a deliberate error embedded in the system designed to reduce the risk of hostile forces using the highly precise systems. The position of a GPS receiver is calculated by measuring the distance between itself and three or more GPS satellites satellites. Each satellite is equipped with an atomic clock. When first powered on, GPS devices undergo an initialization period, during which they acquire signals from the satellites, and synchronize the GPS clock with the satellite's atomic clock. GPS devices constantly receive and analyze radio signals from the satellites, calculating precise distance (range) to each satellite being tracked. GPS devices use trilateration, a mathematical technique, to determine user position, speed, and elevation.

- Geo-referencing

Geo-referencing is an extremely important step for building human geo-database. It was done using global positioning system (GPS) devices (Garmin GPSMAP 60CSx, USA) (Figure 57). This easy to wear handhold apparatus, 213g, with a horizontal precision of 3-5 m (GPSMAP 60CSx owner's Manual, 2007), performs well in the geographical inventory of rural settlements. These direct measurements of geographic co-ordinates (latitude and longitude) involved a team of five members: four fieldworkers and one supervisor n°1 in Figure 57. Co-ordinates were saved in GPS and manually reported on field forms designed in an easy to fill row - column table and coded per settlement. Team members were connected through cell phones. However, field problems were addressed by going to the field in the event where the supervisor could not proffer solutions to reported problems by simple phone call. Before fieldworkers move to next settlements, the supervisor collects correctly filled forms, downloads GPS data using a laptop on which MapSource software (Garmin Ltd, version 6.11.6) was installed. MapSource is a useful computer based tool for trip and waypoint management. This complete inventory lasted exactly one month: March 2011.

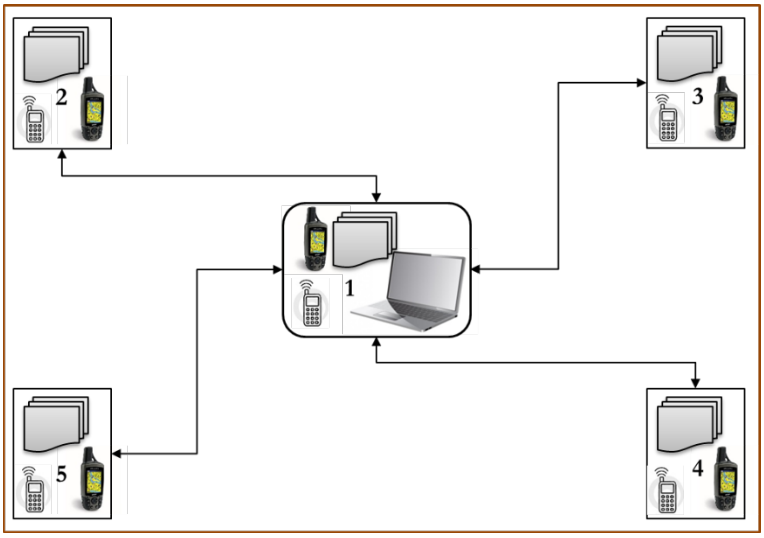


Figure 57: Geographic inventory practical organization

- At the compounds level

The compound (yellow dots in Figure 58) constituted the smallest geographic entity in the present study. A compound is defined as a residential unit formed by one or several buildings fenced or not, inhabiting one or several households (INSD, 2009c). Fieldworkers were assigned the task of gathering data at the compound level using the door-to-door technique. On the ground, fieldworkers were helped by the local community in identifying compounds.

Figure 58: Compounds

Within each compound, the head, or his representative, was subjected to an interview.

- Population size: the number of persons (all gender and age confounded) living in the compound at the date census.
- Private infrastructures: The availability, presence/absence, of sanitation (familial latrine), water connection (tap-water) and transportation means at the time of the survey were recorded.

  Additionally, 359 heads of compounds among those found with familial latrines were further interviewed randomly to understand determinants of the demand for latrines in rural area.

  Similarly, 375 heads of compounds among those found without any latrine were interviewed to gather reasons of the non-demand for latrines.
- Members' circulation and mobility: Three water contact activities were targeted to assess compound members' circulation: water lily (*Nymphea lotus*) bulbs gathering in ponds, traditional fishing in ponds and modern irrigation agriculture. The involvement or non-participation was reported separately for each targeted activity. Depending on the remoteness of activities from the residential units, the mobility was defined.

  Additionally, 274 heads of compounds were further interviewed about reasons for members' participation (54.38%) and non-participation (45.62%) in traditional fishing. Out of 227 compounds, proportions were 48.90% and 51.10% for water lily bulbs gathering, respectively, for participation and non-participation groups.

  Next, compounds involved in these two activities were deeply investigated for estimating related incomes, age and gender involvement status, and seasonal frequencies. Regarding modern irrigation, we had to access to CANI co-operative operating account (anonymous) for the year 2010 (wet and dry season) which concerned only paddy production. This database was used to compute individual incomes from rice irrigation as well as the seasonal fluctuations in irrigation activitiesand number of rice farmers.
- Compound immigrant status: The geographic origin of the head of compound was researched. When the status was different from first occupant status, we further investigate highlighting the link with irrigation projects.

- At the settlement level

The complete inventory concerned community-based collective or public infrastructures within each settlement.

- Hydraulic works: All types: traditional or modern, all natures: water fountain, hand pump, wells; all states: functional or out of condition; all access modalities: free or charged were recorded.

  Additionally, lengths of ropes used to draw water were measured for all wells.
- Health care facilities: An inventory of modern health care centers (CSPS), places where a traditional or alternative medicine is delivered against schistosomiasis and private drugstores were made. Additionally, drugstores of CSPS called COGES and private ones were further investigated for checking the availability of praziquantel.
- Education infrastructures: Both primary and secondary schools were geo-referenced. The number of classrooms, the size of each room, the geographic origin of each school attendant as well as individual age and gender were gathered through a school-based questionnaire survey which is largely discussed in the epidemiologic section.
- Administrative services: Central local administrative services, such as rural town hall and prefecture buildings and other governmental agricultural services (AMVS and INERA) were geographically recorded
- Trades and ludic infrastructures: Positions of local markets were measured. Additionally, dealers of street medicines (modern but prohibited) were met and interviewed in local market places to better understand their mobility, i.e. settlements and local markets frequented by them

3.2.2.2. Sensing human water contact movements

We tried to characterize population circulation (respectively mobility) taking place in water bodies so that each circulation depending on the nature of the activity could be distinguished through its particular ground signature. For this, GPS device were tied to individuals in order to record characteristic data (Figure 59). A Super Trackstick (Telespial Systems Inc.) was newly acquired for the implementation of this water activities sensing. Unfortunately, after one week of use the system was out of function. However, using Garmin GPSMAP 60CSx, we were able to complete the task between May and June 2012.

Figure 59: Child bearing a GPS whiles swimming

Details on the altitude of the activity occurrence place, the track length, the water contact duration and speed of movement in the water body coupled with the geo-visualization of the sensed track were essential for characterizing the activities particular ground signatures (Figure 60). From these sensed GPS data, we could better understand the spatial scope of local population circulation and mobility, identify the variety of places where exposures occur and the exact time and duration the water contact has taken. Heights of individuals were measured as well as the water body vegetation coverage.

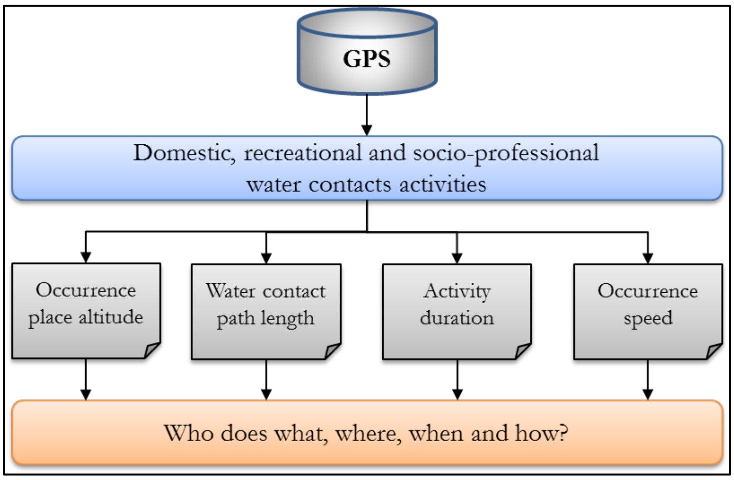


Figure 60: Flowchart of data derived from GPS for geo-visualizing human water contact activities

3.2.2.3. Direct field observations

- Assessing women and children vulnerabilities in Toma-Île

The first direct ground observation was done in Toma-Île, a village totally surrounded by water through the year with a marked total absence of clean water equipment (Figure 61). The recording of the daily occurrence of domestic and recreational activities aimed, on the one hand, to measure the vulnerability of women according to individual characteristics and, on the other hand, to measure the vulnerability of children due to the variability and rising of air temperatures.

The study schedule, data collection method and the two fieldworkers were introduced to the community through an informative meeting held in December 2010. The community in general and women in particular were made aware of the study by the delegated administrative representative. After agreement with the administrative representative and his assistants as well as representative of women, a monthly contract was drafted straightaway with two rowboat-drivers. It was agreed that the first driver should transport fieldworkers early in the morning before 6 a.m. (6H) to Toma-Île, and the second will bring them back in the afternoon, after 18 p.m. (18H). Three reasons were in favour for the selection of Toma-Île: first, its island environment; its closeness to Di and Niassan, where fieldworkers were dwelling and third, fieldworkers and the community were all familiar to one another.

- Observation periods

Two opposite sites, North and South, were selected and watched by two fieldworkers. Daily observations occurred from 6H to 18H (12 hours/day). Seasonal watching covered two different periods. The first period (dry cool) commenced from 3rd January to 2nd February 2011 (31 days) and the second period (dry warm) started from 3rd April to 3rd May 2011 (31 days). Therefore, the direct activities observation in Toma-Île lasted a total of 62 days.

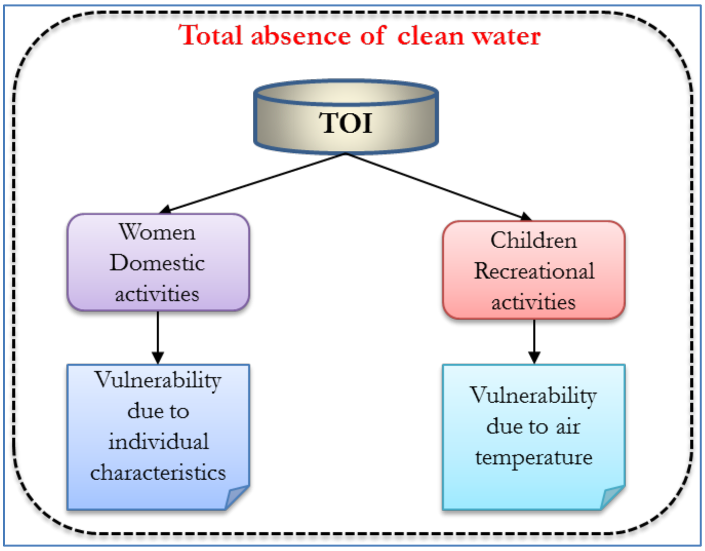


Figure 61: Flowchart of assessing women and children vulnerabilities

- Domestic water contact recording

Each field observer had to follow up the daily water contact pattern of 20 women, i.e.40 women for the two investigators. Women were enrolled in the study randomly, from the first seen at the observed sites to the 20th. Each of the 40 women was individually followed up. Individual characteristics such as the age, the mother status (breast-feeding, pregnant), the marital status (with or without co-wives) and the number of children under five years were recorded. Daily forms were prepared the day before, by filling in the women identification information (mostly names and surnames) as well as the date and name of the fieldworker. Next, forms were divided into four clusters of five followed up women so that individual forms could be easily found. Daily forms were designed in row-column table. The number of filled lines indicates the number of time a woman was seen in contact with the river. Columns contain variables associated to each single observed activity: entry and exit time (hour, minutes), nature of the activity leading to water contact. All mobility information, beyond the frontier of Toma-Île, was detailed by giving reasons for such movements.

Characteristics of women followed up and frequencies of domestic activities in the river within the same community were overlapped to point out gender group difference or similarity in vulnerability through domestic tasks in a context of a total absence of alternative water source.

- Recreational water contact recording

Fieldworkers were also asked to account and report the number of children undertaking recreational swimming activities. Children were not individually followed up. Only the hourly water contact frequencies at the observed sites were recorded in the day. Additionally, during the second period of observation, children exiting the river were interviewed to determine whether they have urinated while swimming. Daily volume of recreational recording, seasonal change in behaviour, particular peaks of swimming in the day were overlapped to point out the role of rising air temperature in children vulnerability to schistosomiasis. Temperature coupled with freshwater availability of such recreational swimming help to assess children spatial vulnerability due to climate variability in our AOI.

- Assessing the influence of hydraulic works on the utilization of freshwater

The second direct field observation was implemented in four villages with a more or less good access to clean water equipment (Table 7). The purpose was to assess and understand the influence of hydraulic works supply on the reduction of the utilization of freshwater bodies (Figure 62). Compared to the first observation done in Toma-Île, this second direct field observation of communities water source selection behaviour was very short in duration and lasted only three days: 24th to 26th April 2011. Data on the preference of the water source were gathered from nine water drawing sites and distributed as indicated in

Table 7. However, there was no change in the length of daily observation: 6H to 18H. Similarly, observation forms were designed in row-column table. Water drawers were not identified and therefore were not individually followed up. The number of filled lines indicates the number of times a water drawer of a team of drawers arrived to the observed site. In case of a team, numbers were reported by gender. Therefore, the number of lines does not necessarily imply the number of drawers. Numbers of containers were also counted per type. Time of arrival to and departure from the observed site and the transportation means used to carry water containers were reported. Drawers were further interviewed for reasons of the selection of the particular drawing site, domains for which water will be used, the geographic origin of drawers (name of quarter) (Figure 63a).

Further, additional data were collected through focus-groups with women in Guièdougou, Gouran, Niassan and Bantombo (Figure 63b). To show the influence of climate on water demand, we used data from the *Office National de l´Eau et de l´Assainissement* (ONEA) spanning the period of four years (2007 – 2010), which represents a water fountain located in the first district of Nouna (urban commune).

The selection and preference of water drawing sites, reasons and domains of utilization, availability of transportation means , and hydraulic works access modalities are essential for understanding why communities still have contact with freshwater. They have a more or less good access to clean water equipment, though. Monthly water consumptions plot with climatic data help to highlight a marked change in seasonal water source selection in rural areas.

Table 7: Details on the observed water drawing sites

Settlement (Code)	Quarter	Water drawing site observed	Type of water drawing site
Débé (DEB)	-	DEB1	Irrigation canal
	-	DEB2	Irrigation canal
Di (DII)	-	DII1	Sourou River
	Mandou	DII2	Water fountain
Guièdougou (GDG)	-	GDG1	Irrigation canal
	Dougoutiguikin	GDG2	Modern well
	Yinyinkin	GDG3	Hand pump
	Ouahigouyakin	GDG4	Water fountain
Niassan (NSN)	-	NSN1	Irrigation canal

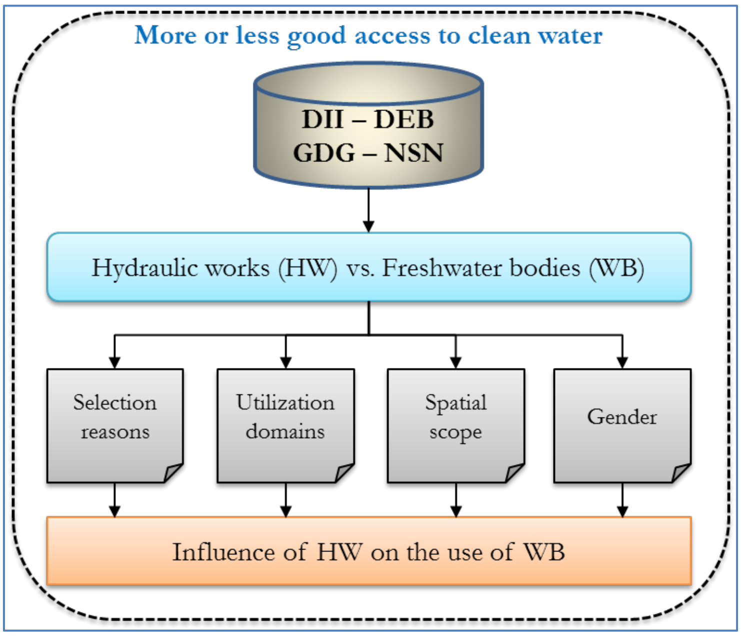


Figure 62: Flowchart of the assessment of water source selection behavior

Figure 63: a) Fieldworker observing and interviewing water drawers in Guièdougou; b) Focus group with a women organization in Niassan

3.2.2.4. Epidemiologic data gathering

Medical-based urinary and intestinal schistosomiasis disease data were gathered from modern health care center (CSPS) through a retrospective survey while self-reported visual symptomatic urinary schistosomiasis illness data were collected both at the compound and school levels through sectional studies (Figure 64).

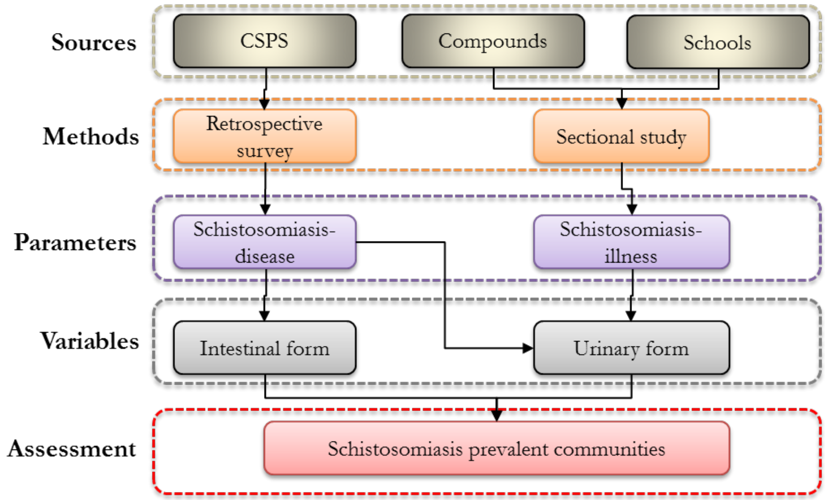


Figure 64: Flowchart of epidemiologic data gathering

- Retrospective survey of schistosomiasis-disease cases

Our AOI straddles nine CSPS belonging to three sanitary districts, Nouna (2 CSPS), Toma (1 CSPS) and Tougan (6 CSPS) in the sanitary region of the Boucle du Mouhoun. First of all, monthly disease cases, n = 210, were obtained from the *Centre d'Information Sanitaire et de Surveillance Epidémiologique* (CISSE) of respective sanitary district. The archive search was done directly at the CSPS level and included mainly the spatial reference (name of the geographic origin) and occupational status of the patient in the consultation registers. These details were not available from the CISSE database. The monthly list served to select registers of months of concern to limit the number of registers to be searched. According to the system of reporting epidemiologic data from the CSPS to the CISSE, the month ends each 24^{th}. Consequently, as the case might be, registers of months before or after the indicated one were needed to find certain cases. Therefore, the archive search also included the recording of the exact date of consultation together with the age and gender of the patient. This operation allowed us to find out 68% of cases listed by CISSE. It pointed out archiving problems at CSPS level, because all consultation registers were not found. The idea to firstly request for the monthly list was to gain time and save energy. The limitation of the time series of this retrospective survey to five years (2006 to 2010) followed the same idea. These medical base data served to measure the utilisation of CSPS in case of schistosomiasis in our AOI.

- Sectional study at the compound level

The complete geographical inventory of compounds was coupled with a sectional study. Then, within each compound the head was asked about the presence/absence of members suffering from urinary schistosomiasis illness on the date of the survey. The special word in local language, *gnèguèni-ouilé* meaning red urine, was employed.

Additionally, 169 heads of compounds among those having reported presence of symptomatic illness were further interviewed about seeking care. Age and gender of symptomatic subjects were also reported.

- Individual perception of schistosomiasis

A total of 205 individuals were interviewed through our AOI to measure their knowledge about forms of schistosomiasis, awareness of where to get the treatment, and the shame status attributed to the symptoms. Those who reported having experienced the illness were further interviewed about the type of medicine they have used. Individual characteristics such as the age, gender, educational status were reported as well.

- Repeated sectional study at primary schools level

We owe to Lengeler et al. (1991a,b) who were the first to work out an inexpensive and simple tool "a school based questionnaire" used for detecting urinary schistosomiasis prevalence. Since our first purpose was not the control of schistosomiasis, we could adapt the school-based questionnaire method in a repeated sectional study (Traoré et al., 2012). Except Leri School, all 22 primary schools within the AOI were surveyed. Enough questionnaires and 89 posters were designed, printed and distributed per classroom and per school at the beginning of April 2011. The questionnaire was designed in simple table and printed on white paper (A4 format). Teachers had to fill lines by writing down names of children, one line per child. Additional individual data were indicated by column headers: sex, age, village of origin, quarter in the village and self-report status. Poster (Figure 65) was artistically drawn on white paper (A3 format) and designed in three main parts:

- At the top: a school building with a teacher and late comer pupils running means that they are the targeted persons (Figure 65);

- At the middle: a pop-up that depicts the transmission route and shows school children (boys and girls) playing in a contaminated surface water, their often daily recreational activities after school (Figure 65);

- At the bottom: the hematuria symptom is displayed, two pupils (a boy and a girl), urinating with blood in their urines, and thinking about their activities after class. This also shows that both sexes can contract the disease (Figure 65).

Figure 65: Poster accompaining the school based questionnaire

Teachers (n = 89) administrated the questionnaire by interviewing children directly on their current urinary schistosomiasis status based on a daily recall-period in eight different days.

Day "0": the first time to present the poster to pupils. The teacher presented the poster (Figure 65) pedagogically from top to bottom as follows: "That is our school (1), and those of you who like playing or swimming in freshwater (2), run a risk of getting infected by a disease which manifests by abnormal red urine sometimes accompanied by pain when urinating (3)". The hematuria symptom on the poster was made clear using the local word. After having explained the content of the poster, the teacher asked children if they have noticed such manifestations when urinating yesterday or today. Answers were then written down individually using the following codes:

0 = did not report any symptom; 1 = have reported blood passing in urine only; 2 = have reported only pain when urinating; 3 = have reported blood passing in urine and pain when urinating.

At the end of this session, i.e. Day "0", the teacher kindly asked children to observe their urine and pay more attention to the symptoms displayed on the posters. At interval of every two days between sessions and for the next seven sessions, the children were only asked whether or not they have noticed changes in their disease status the day of the interrogation or the day before.

All questionnaires, correctly filled, were gathered at the end of April 2011but the posters were given as present to all children in the classrooms; particularly those suffering from urinary schistosomiasis. Teachers were asked to hang up the poster on the classroom walls, so that it could each day remind the children of the danger.

All three secondary schools located within our AOI were also surveyed. Here, a short questionnaire was prepared occupying one-third of an A4 paper, printed and administered to pupils. These questionnaires were anonymous and were filled in about 40 min to one hour and returned. Questions to be answered were the same as those addressed to primary schools.

- Sectional parasitological survey in primary schools

Randomly, 124/847 subjects (~15%) were selected, with 60 having reported symptoms and 64 having not. Children urine samples were taken from five primary schools for parasitological examinations (Figure 66). The schools were all located on the western bank of the river: Bantombo (N=20), Koubè (N=13), Kouri (N=12), Illa (N=54) and Sono (N=25). Due to partial non-availability of lab technicians and their involvement in other routine studies and works, accessibility to the villages, remoteness from the laboratory (minimum distance = 50 km, maximum = 70 km), bad state of rural paths, urine sample collection was extended to four consecutive days (May 16^{th} -19^{th} 2011). This way, samples could be collected and analyzed within the same day. The first two days were dedicated to Koubè and Illa, the third day for Kouri and Sono and the fourth day for Bantombo. The field team included two lab technicians, one geographer and a driver. However, the team was supported on the field by teachers to facilitate data collection. Before collecting urine samples, pupils were asked to do some physical activities to increase the chance of dropping eggs into their urine. Each child was given a wide-mouthed polythene bottle and asked to urinate into it. After urine collection, an individual code was written on the bottle. All urine samples were collected between 10-14 a.m., and kept at 4° C using cooler and ice-boxes (Figure 66). The urine samples were then brought to the laboratory located in Nouna health district hospital using a car (4x4). In the laboratory, urine samples were centrifuged to check for *S. haematobium* eggs microscopically (Figure 66). Children whose urine contained one or more eggs were defined as infected; if no eggs were seen, children were defined as uninfected.

Figure 66: Sectional parasitological survey in primary schools

3.2.3. Physical data gathering

3.2.3.1. Environmental data gathering

The environmental vulnerability was assessed based on three main variables derived from high spatial resolution satellite imageries using two technics as indicated in Figure 67. All satellite images were archived ones and sponsored by Planet Action, an Astrium GEO initiative focused on climate change, and Spot Image S.A. trading under the business name Astrium GEO-Information Services both located at rue des satellites, Toulouse, France (Table 8). Figure 68 shows the collation of satellite images together with the acquisition dates and plotted on the study area.

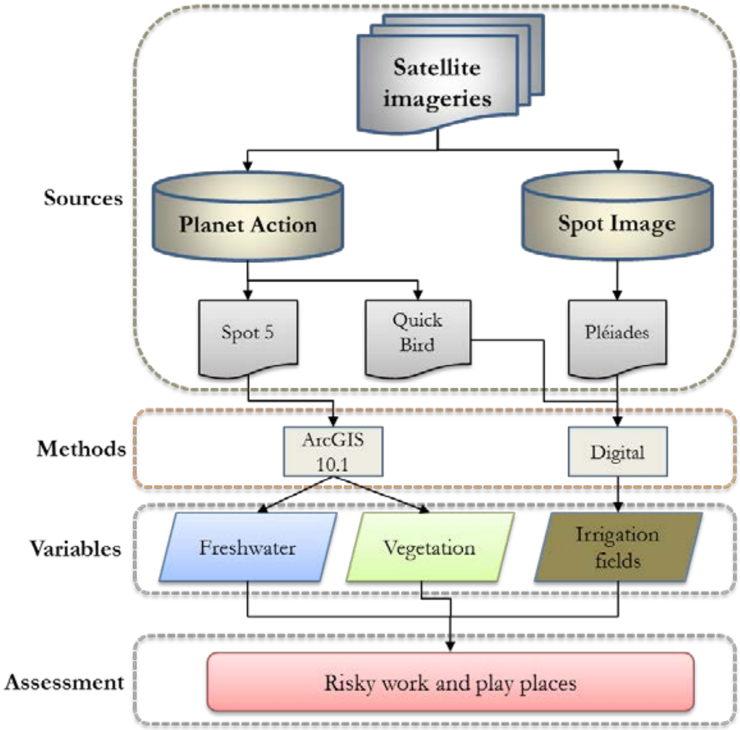


Figure 67: Flowchart of envrionmental layers derived from satellite imageries

Table 8: Deatails on Satellite imageries

Type of image	Acquisition date	Number of spectral bands	Spatial Resolution (MS)	Number of scenes	Granted by (delivery date)	Coverage of the study area
Spot 5 (HRG1)	24/09/2007	04	10m	02	Planet Action (10/12/2010)	97.12%
QuickBird	27/10/2009 09/11/2009 20/01/2010 02/02/2010	04	2.4m	04	Planet Action (22/02/2012)	56.87%
Spot 5 (HRG2)	24/04/2012	04	10m	01	Planet Action (26/04/2012)	81.04%
Pléiades (PHR 1A)	29/01/2013	04	2.8m	01	Spot Image (15/02/2013)	23.22%

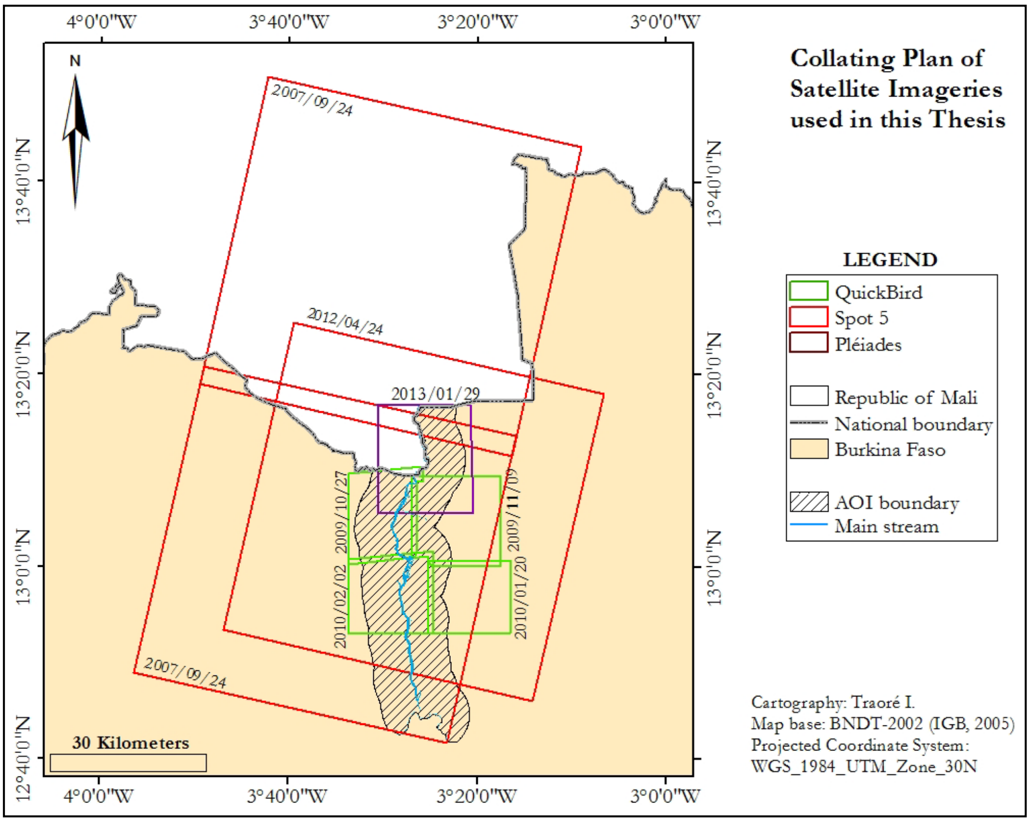


Figure 68: Collating plan of satellite images used in this thesis

- Remote sensing of water body, vegetation, bare soils and intermittent flood areas

Only Spot 5 (24/07/2007) (the end of the raining season) was covered at more than 97% of study area. Therefore, the remotely sensing of freshwater and vegetation, bare soils and intermittent flood layers was focused on this multispectral image with a spatial resolution of 10m (Figure 69). There were no substantial changes in the AOI environment between September 2007 and mid-2011. Therefore, the situation by the end of 2007 could well explain that of mid-2011.

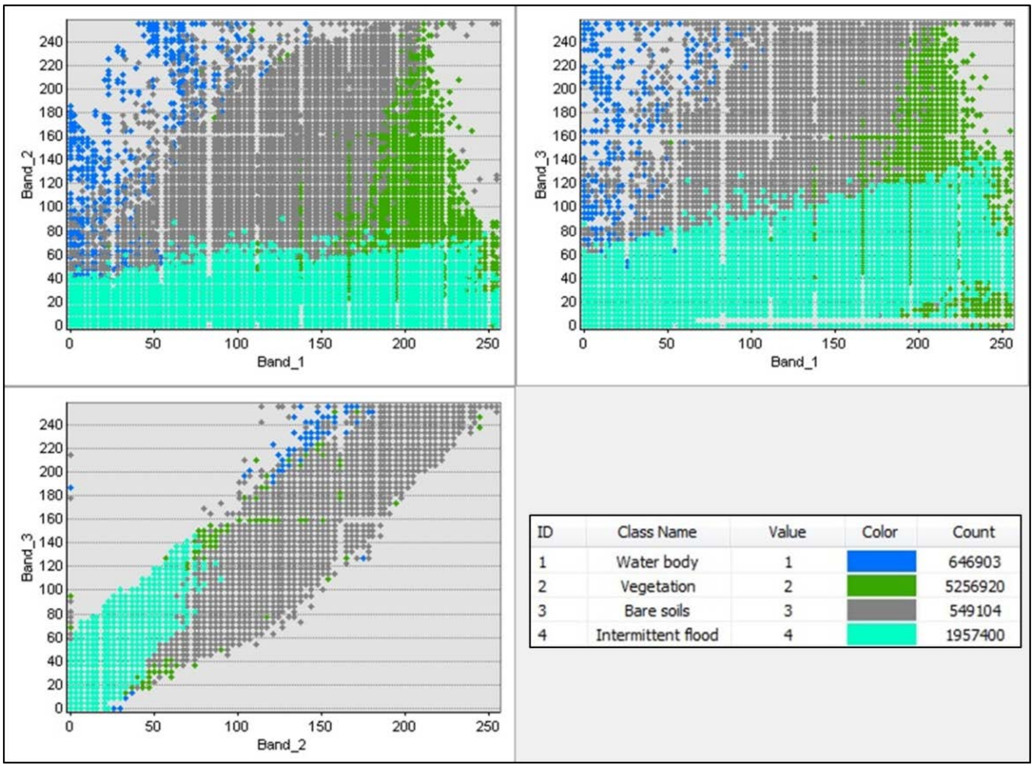


Figure 69: Scatter plot of pixel values for water body, vegetation, bare soils and intermittent flood

- Classification of water bodies into three different layers

For freshydraulic worksater, Type 1 was supervised by the Sourou River and considered as permanent freshwater. Type 2 was centered on ponds in which traditional fishing and water lily bulbs gathering usually take place and were defined as semi-permanent water bodies. Type 3 concerned episodic water bodies (Figure 70). Spot 5 on 2012/04/24 (one month before the onset of the raining season) was used to map in detail semi-permanent ponds, because in this period of the year they are well individualized. It was also used to better classify and distinguish the three freshwaterlayers.

- Classification of the vegetation into four different layers

Concerning vegetation, Type 1 focused on woodlands (mostly used as collective open air defecation sites); Type 2 focused on savanna with gallery forest; Type 3 represented shrublands savanna; Type 4 designated grasslands savanna (Figure 71).

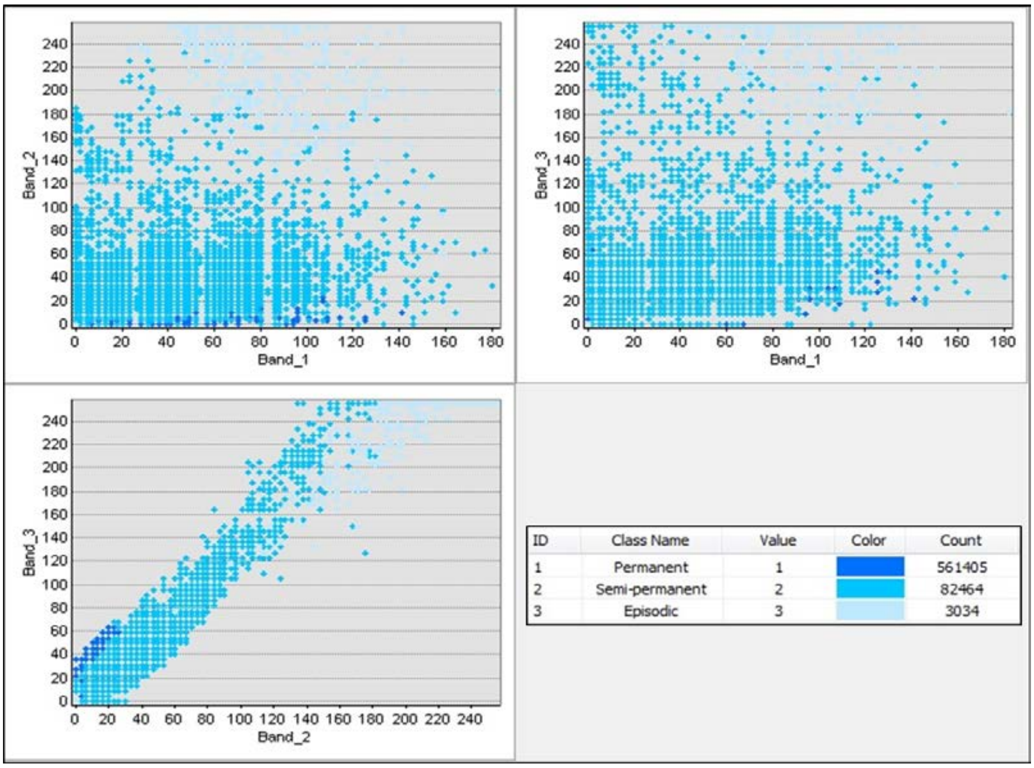


Figure 70: Scatter plot of pixel values for permanent, semi-permanent and episodic water bodies

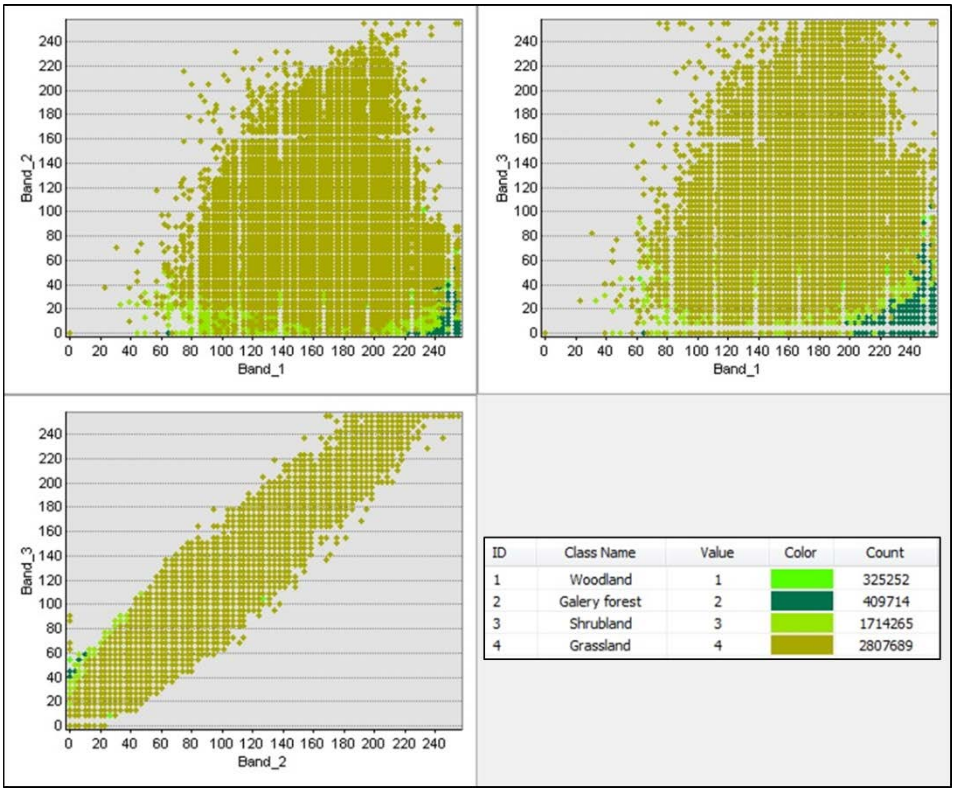


Figure 71: Scatter plot of pixel values for woodland, gallery forest, shrubland and grassland

- Irrigation fields digitizing

Multispectral QuickBird images, with a spatial resolution of 2.4m, served to map in detail irrigation fields by distinguishing rice parcels from other irrigated crops. It appeared quiet impossible to detect, remotely rice parcels from others. First of all, we prepared fine scale images of irrigated perimeters so that major, primary and even secondary irrigation canals could be identified. Next, these higher resolution images were printed out and brought on the ground. Based on these images and with help of agricultural managers at AMVS, parcels of land irrigated for rice production were distinguished from poly-culture (garden crops mainly) parcels with respect to the dry season of the year 2011. Finally, irrigation parcels were digitized using ArcGIS. The Spot 5 of May 2012 was used here to map traditional irrigation fields. This type of irrigation field appears in the AOI environment only during the dry season. Pléiades image of January 2013 with a spatial resolution of 2.8m served to digitlize irrigation perimeters in process in the Sourou Valley launched by the Millennium Challenge Corporation (MCC) in December 2011 in Di. One year after the launch, the Pléiades image allowed us to see the level of progress done.

3.2.3.2. Climatic data

Climatic data used in this thesis were gathered from archives of the Di-Sourou (agro-climatic) weather station (Figure 72). Variables are observed and measured using analogic instruments (Figure 73). On the date of the request (mid-2011), data were available on a 31-year period from 1980 to 2010. Daily recorded data were saved at Di-Sourou on designed forms as decadal per month and year because the station is a manual weather station. Therefore, these climatic variables gathering for us included making hard copies of archive documents and hard copies digitalization using Access 2003 database.

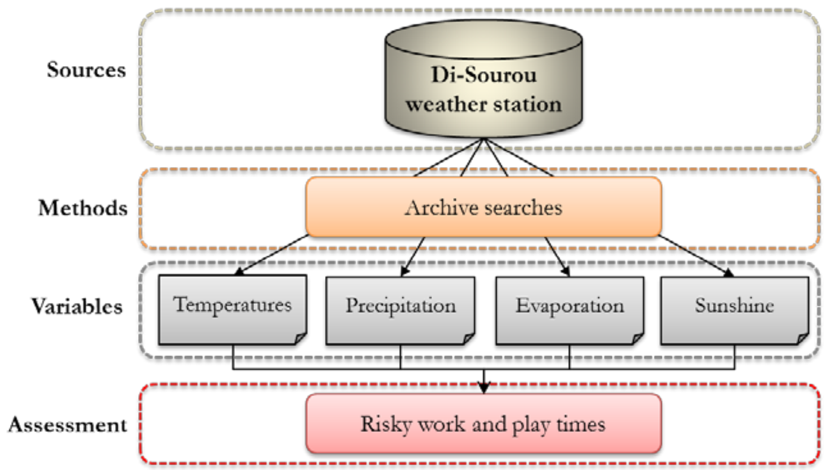


Figure 72: Flowchart of climatic variables gathered from Di-Sourou weather station

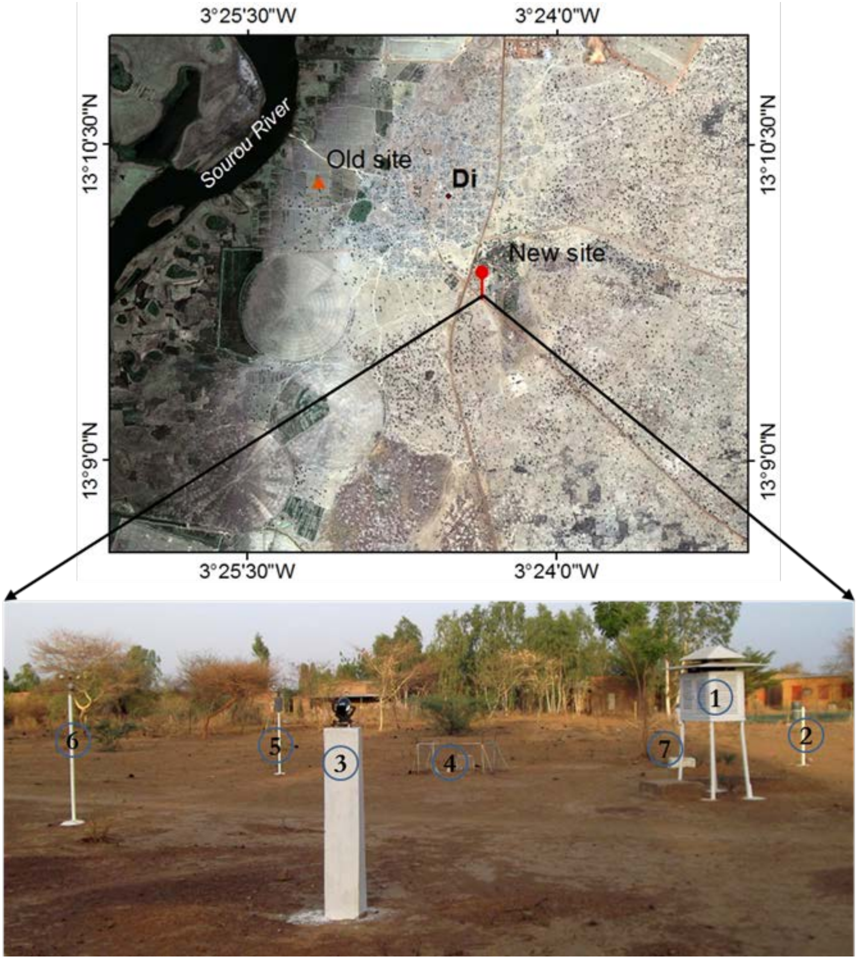


Figure 73: Di-Sourou weather station

- Air temperatures

Observed three times daily (7 a.m., 12 and 5 p.m), air temperatures were measured in degrees Celsius (°C) under shelter ((1) in Figure 73) at two meters above the ground using alcohol and mercury thermometer for minima and maxima, respectively. Therefore, lowest daily minima were always recorded at 7 a.m., because nights are colder in such tropical areas while, highest daily maxima were recorded at 5 p.m., because the heat reaches its maximum at about 14 p.m. That is why indexes of reading were reset in the afternoon (5 p.m.) for the alcohol thermometer and in the morning (7 a.m.) for the mercury one.

- Rainfall

Rainfall amounts are measured using a metallic bucket rain gauge ((2) in Figure 73) which contains a graduated plastic cylinder. The capacity of the cylinder is 8 mm while the bucket can contain more than 500 mm. This design allows the bucket to catch the rainwater overflowing the graduated inner cylinder. In this case, the height of the water in the cylinder was measured first and poured, and the excess overflow in the bucket was carefully poured into the graduated cylinder and measured to give the total rainfall.

- Physical evaporation

At its former location, about 400 m next to the Sourou River, the observation site was fenced. Displaced on 23rd November 2007 to avoid series of floods, about 1700 m (121° south-east ward) from the former position, the new site was not enclosed, as Figure 73 shows. As a consequence, the evaporimeter bac "A" could not be set because of animals. However, evaporation data continue to be recorded using the Piche evaporimeter included in the shelter box ((1) in Figure 73). The Piche evaporimeter is a type of atometer used to measure the rate of evaporation from a wet disc of absorbent paper. It is used mainly in hot, dry climates where water loss through evaporation must be observed regularly. Since the results are dependent on wind speed past the disc, as well as the wet bulb saturation deficit, it is almost essential to expose the evaporimeter inside a meteorological screen. A glass tube graduated in steps of 0.1 ml will contain just over 30 ml of water. A metal clip holds the paper disk against the open end, while a ring at the closed end allows the tube to be hung vertically.

- Sunshine duration

The sunshine daily duration is measured using a sunshine recorder (Campbell-Stokes) ((3 in Figure 73). It consisted of a glass sphere (10 cm in diameter) originally designed and set into a wooden bowl by Campbell (1853) and refined in metal by Stokes (1879) The unit is designed to record the hours of bright sunshine which will burn a hole through the card. In the northern hemisphere, the winter card is used from October 15th to February 29th, the equinox card from March 1st to April 11th and September 3rd to October 14th and the summer card from April 12th to September 2nd. At the Di-Sourou cards were set every morning (7 a.m.), and removed in the afternoon (5 p.m.) to measure the length of the burnt side which determines the daily sunshine total duration (Figure 74).

Figure 74: Sunshine recorder card on 2011/04/26 used at Di-Sourou weather station

- Other observed variables at the Di-Sourou weather station

Temperatures at 10cm above ground, at the ground, 50cm and 1m under the ground ((4) in Figure 73); wind speed ((5) in Figure 73) and direction ((6) in Figure 73); Tipping bucket rain gauge recorder (out of condition) ((7) in Figure 73).

3.3. Ethical consideration of the study

- Local Ethics Committee approval

After having submitted the full proposal of the present study, we gained the approval of the local ethics committee of the Nouna Health Research Centre (CRSN)/Ministry of Health.

- Educational local authorities

After having addressed to them an official letter requesting the permission to involve the schools in the study, authorizations were obtained from the two provincial directorates of the primary education of Kossi and Sourou. Circulars were sent by the provincial directors to all district inspectors, town councils, school head teachers and presidents of the association of school children parents. The names of the investigated schools, the topic and objectives of the study, the references of the study principal investigator were clearly mentioned in the circulars. The school children were neither obligated to participate in the study nor give an answer if the teacher asks them. In particular, pupils were free to provide urine samples or not. Leri School was not investigated because we had no authorization from the provincial directorate of Nayala since we could not travel to Toma, capital province of Nayala.

- Health care authorities

The confidentiality of medical based data is rigorously observed in Burkina Faso. The access to non-published data, such as consultation registers, remains strictly under a legal authorization from the head of the sanitary district. Request letters were addressed to heads of sanitary district of Nouna and Tougan through our local institutional cover, the CRSN. The head of the sanitary district of Toma was contacted per phone via the kind help of his counterpart in Nouna. Then, heads of CISSE in respective district were informed about the feasibility of our request. In turn, CISSE contacted heads of CSPS.

3.4. Data processing

All the human and climatic data were manually collected used field forms. Data were entered using Microsoft Access database. In order to minimize entry mistakes, the data entry screen was similar to the data gathering forms. Each type of data was entered using a separated database.

3.5. Data Analysis

3.5.1. Global approach: Spatial and temporal analysis

Two types of analysis were done: spatial and temporal (Figure 75). To assess the spatial pattern of schistosomiasis risk in the study area we combined human and environmental data. To assess the temporal pattern of the disease risk we combined human and climatic data.

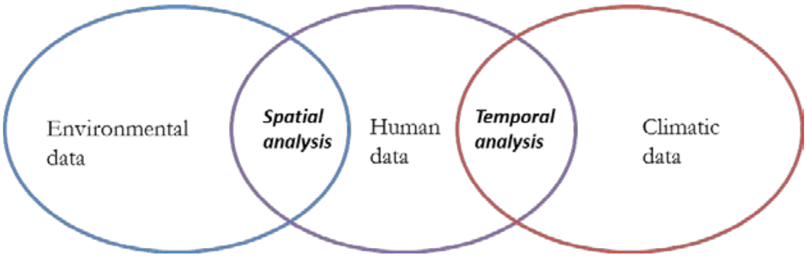


Figure 75: Ground collected data and type of analysis of schistosomiasis risk

3.5.2. Spatial analysis

Geography of health is defined by Picheral in “Dictionnaire raisonné de la santé” (2001) as: “spatial analysis of disparities of level of health of populations and the environmental factors (physical, biological, social, economic, and cultural) which contribute to explain these inequalities”. The concern is usually to detect areal pattern or to model the way in which disease incidence/prevalence varies spatially. The ultimate objective of schistosomiasis mapping is to understand the relation between the parasites communities including freshwater intermediate snails, their human definitive host, and the environment that inhibits or encourages their relationship. Then, elements of that system could be identified and interfering with them could allow to control and to limit, if not to eliminate, the transmission risk (Koch, 2005). Settlement provides a focus for interdisciplinary study. The economist, sociologist, epidemiologist and geographer are all able to examine a settlement from a clearly defined disciplinary base. Geography acts as an integrator, borrowing from the other disciplines but, at the same time, marking its own distinctive contribution, particularly with respect to spatial organization. Looking for patterning both within and among settlements provides some insight into how things are organized spatially (Haggett, 1960; Spate, 1960; Daniel & Hopkinson, 1989; Carter, 1990; Gatrell & Bailey, 1996; Gatrell et *al.,* 1996; Gatrell, 2002; Macintyre et al., 2002).

Two approaches were used in order to assess the spatial heterogeneity patter in terms of schistosomiasis risk Figure 76. The descriptive approach was employed for categorizing settlements with respect to their peculiar aspects. Based on the settlement aspect, we measured the inequal spatial distribution of schistosomiasis risk following a quantitative approach.

Figure 76: Descriptive and quantitative approaches for schistosomiasis spatial risk assessement

3.5.2.1. Settlements aspects

- Summary of settlements' categorization

The various local specific aspects of rural settlement which the geographer has to consider in order to assess their influence on health or health-related behaviours in particular population groups are summarized into Table 9 (Haggett, 1960; Pattison, 1964; Smith, 1965; Daniel & Hopkinson, 1989; Mayer, 1989; Carter, 1990; Meade, 1997; Gatrell, 2002; Macintyre et al., 2002). Modern researchers typically distinguish between "horizontal," health-related studies of factors that may generally promote health or retard disease, and "vertical," disease-specific programs independent of the rest of the health care systems (Unger et al., 1999; Koch, 2005). The word vertical does not refer neither to a vertical program nor to a vertical structure, but rather, to an intellectual exercise through which one deals with a health problem viewed in isolation. Similarly, a horizontal approach would be a perspective whose starting point would be constituted by health care services (Unger et al., 1999; Koch, 2005). The determination of the number of class per geographic parameter followed a horizontal reasoning. In fact and according to Berube (1988) in order to produce "useful" representations of the space inhabiting human-beings, geographers always have to explore places, name them, develop abstract models, propose metaphors, state theories and formalize concepts.

Table 9: Summary of geographic apsects and parameters for categorizing settlements

Geographic aspects (n = 7)	Geographical parameters (n = 16)	Number of Classes (n = 59)
Population typology	Population sizes	4
Residential units spatial distribution	Spatial organization patterns	3
	Geographic extension shapes	3
	Locational distance with respect to the main stream	4
Functions	Agricultural functions	3
	Administrative functions	3
Access to infrastructures	Hydraulic works availability	5
	Hydraulic works accessibility	4
	Familial latrines availability	5
	Accessibility to modern health care	3
	Access to education	3
Occupational activities	Modern and traditional activities	6
Schistosomiasis-illness prevalent settings	Schistosomiasis-illness prevalence rates	3
Environmental aspects	Freshwater bodies potential	3
	Vegetation cover potential	4
	Modern irrigation field potential	3

- Population typologies

According to a March 2011 field census, the total number of populations (TNP) at the settlement level varied between 40 and 8282 inhabitants. Using three different population's moments (m_1, m_2 and m_3) (King, 1969), settlements were divided into four classes: very large, large, small and very small (Figure 77). We used the arithmetic mean of populations of the 37 settlements $m_1 = 1393$ inhabitants to demarcate big settlements with TNP $\geq$ 1393. Next, $m_2 = 3902$ inhabitants, populations' moment of big settlements was used to demarcate very large settlements with TNP $\geq$ 3902. Similarly, $m_3 = 464$ inhabitants, the arithmetic mean of populations of small settlements, was used to demarcate very small settlements with TNP $<$ 464. Therefore, relationships between classes and between settlements within the same class were asymmetric and also transitive (King, 1969).

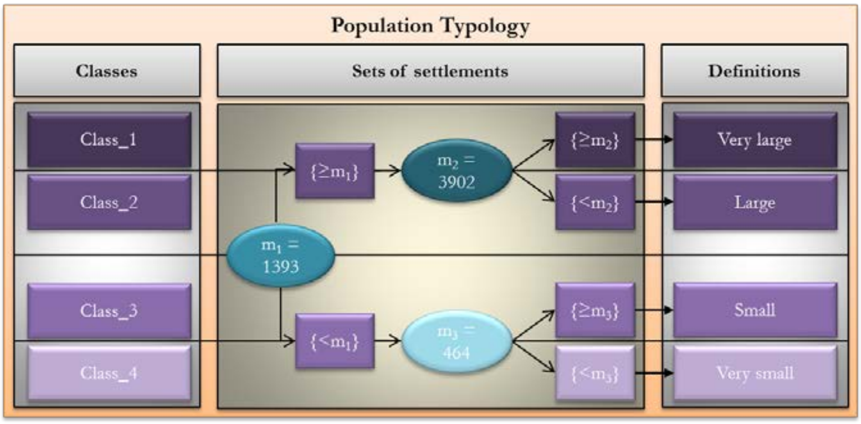


Figure 77: Categorizing settlements into four population classes

- Residential units' distribution

- Settlements spatial organization pattern

To analyze spatial organization patterns, we used the average nearest neighbor tool in ArcGIS (Levine, 2007; Scott & Janikas, 2010). The randomness of compounds' spatial arrangement in two-dimensional pattern was based on the assumption that the first nearest-neighbor distances in a random point patterns are normally distributed (Clark & Evans, 1954; King 1969; Campbell & Clarke, 1971). Assuming the n compounds in the settlement are distributed randomly in accordance with a Poisson probability function with density λ, and the distribution of distances between compounds and their first nearest neighbors is normal, then the expected value for these distances (EMD) will be: $EMD = \frac{1}{2\lambda^{1/2}}$ .This represents the average distance between neighbors in a hypothetical random distribution. The standard error of this mean distance is given as: $\delta_{EMD} = \frac{0.26136}{(n\lambda)^{1/2}}$. The statistic: $c = \frac{(OMD-EMD)}{\delta_{EMD}}$ where OMD is the observed mean nearest neighbor distance is distributed as a normal variate and is used in the test of the randomness. The nearest neighbor index is expressed as the ratio: $NNI = \frac{OMD}{EMD}$ and defined as the nearest neighbor measurement, provides an index of the departure from randomness (Clark & Evans, 1954; King 1969; Campbell & Clarke, 1971). Rather than NNI, settlements were categorized into three patterns using z-scores values as indicated in Figure 78. These values and patterns are automatically provided by running the average nearest neighbor tool in ArcGIS.

Spatial Organization Patterns

Classes	Sets of Settlements {z-scores}	Definitions
Pattern_1	{< -1.65}	Clustered
Pattern_2	{-1.65 – 1.65}	Random
Pattern_3	{> 1.65}	Dispersed

Figure 78: Categorizing settlements into three spatial organization patterns

In this thesis, we defined the nearest neighboring status between two compounds within a settlement based on the mean of nearest neighbor distances ($NNCD$), as follows:

$$NNCD = \frac{(OMD + EMD)}{2}$$

Therefore, two residential units within a settlement were defined as nearest neighbors only when the distance separating the two points is less or equal to $NNCD$. Similarly, we calculated the nearest neighbor settlement distance (NNSD) to define the nearest neighbor status between two settlements.

- Settlements geographic extension shapes

We combined the standard distance (SD) and the standard deviational ellipse (SDE) spatial statistics in ArcGIS (Levine, 2007; Scott & Janikas, 2010) to assess residential units' geographic extension shapes within settlements.

The SD was suggested by Bachi as a measure of the dispersion of a set of points, the expression for the distance between two points in Euclidian space (Bachi, 1963, cited, King 1969, pp. 92-93): $d_{ij} = \left[\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2\right]^{1/2}$. For a set of n points, n^2 of these distance can be computed, assuming the distance from each point to itself is included, and every distance d_{ij} is measured twice, once for the i and again for the point j. Bachi suggests "the mean quadratic distance," as a summary statistic for this set of n^2 distances defined as: $D = \left[\frac{\left(\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}^2\right)}{n^2}\right]^{1/2}$. By introducing the concept of the "mean center of the distribution" having the coordinates: $\bar{x} = \frac{\left(\sum_{i=1}^{n} x_i\right)}{n}$ and $\bar{y} = \frac{\left(\sum_{i=1}^{n} y_i\right)}{n}$ Bachi showed that $D = \left(\frac{2\sum_{i=1}^{n} d_{ic}^2}{n}\right)^{1/2}$. And; d_{ij}, the distance from point i to the mean center c, equals $[(x_i - \bar{x})^2 +$

$(y_i - \bar{y})^2]^{1/2}$. Finally, $d = \left[\frac{\sum_{i=1}^{n} d_{ic}^2}{n}\right]^{1/2}$ is defined as the SD. The value is a distance representing the dispersion of compounds around the center, so the compactness can be represented on a map by drawing a circle with the radius equal to the SD value.

The SDE summarizes the spatial characteristics of compounds: central tendency, dispersion, and directional trends. It is referred to as the SDE, since the method calculates the standard deviation of the x-coordinates and y-coordinates from the mean center to define the axes of the ellipse. According to Lefever (1926), the mean center of an area is found in the same manner as the arithmetic mean of a frequency distribution. Next, Seymour provides a computer algorithm for locating this mean center in a two-dimensional distribution pattern. "The bivariate mean of an arbitrary number of points is located by obtaining the arithmetic mean of the x-coordinates and the arithmetic mean of the y-coordinates of all the data points. The resulting means are the coordinates of the bivariate mean." (Seymour, 1965, cited King, 1969, 93-94). The corresponding formulae are: $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ and $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$. The SDE is given as:

$SDE_x = \left[\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}\right]^{1/2}$ and $SDE_y = \left[\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n}\right]^{1/2}$ where x_i and y_i are the coordinates for the compound i, $\{\bar{x}, \bar{y}\}$ represents the mean center of compounds within the settlement, and n is equal to the total number of units (Lefever, 1926; Furfey, 1927, Gong, 2002).

The SDE_x and SDE_y were provided by the SDE tool named XStdDist and YStdDist in ArcGIS. The rest of the spatial statistics were computed using a simple Microsoft Excel 2010 sheet. First of all, we calculated the mean distance, $\overline{SDE}_{x,y}$ of SDE_x and SDE_y, through the formula:

$$\overline{SDE}_{x,y} = \frac{(SDE_x + SDE_y)}{2}$$

Then, the gap distance G between d and $\overline{SDE}_{x,y}$ was computed using the expression:

$$G = d - \overline{SDE}_{x,y}$$

Next, we determined R_1, the ratio between d and $\overline{SDE}_{x,y}$, through the formula:

$$R_1 = \frac{d}{\overline{SDE}_{x,y}}$$

Ratios between SDE_x and SDE_y; and inversely between SDE_y and SDE_x were named R_2 and R'_2 and obtained with formulae:

$$R_2 = \frac{SDE_x}{SDE_y}$$

and

$$R'_2 = \frac{SDE_y}{SDE_x}$$

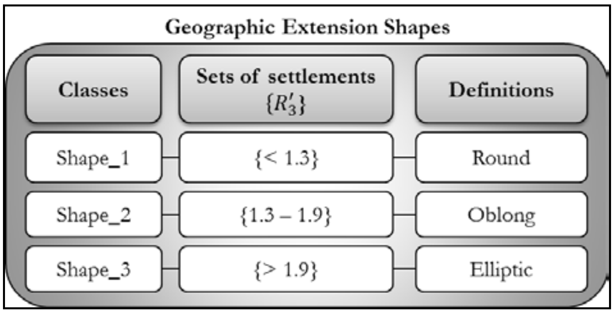
Similarly ratios between the lower values of SDE_x and SDE_y and the higher ones; and between the higher and the lower were named R_3 and R'_3 and calculated through the following formulae:

$$R_3 = \frac{Lower_{SDE_{x,y}}}{Higher_{SDE_{x,y}}}$$

and

$$R'_3 = \frac{Higher_{SDE_{x,y}}}{Lower_{SDE_{x,y}}}$$

Finally, only the ratio R'_3 provided comprehensive indices for categorizing settlements into three shapes or layouts as indicated in Figure 79. Settlements with a ratio below 1.3 were classified as having a round shape while a ratio above 1.9 indicated settlements with an elliptic shape.


Geographic Extension Shapes

Classes	Sets of settlements $\{R'_3\}$	Definitions
Shape_1	{< 1.3}	Round
Shape_2	{1.3 – 1.9}	Oblong
Shape_3	{> 1.9}	Elliptic

Figure 79: Categorizing settlements into three geographic extension shapes

- Settlements locational distance with respect to the main stream

First of all, seven buffer zones (1 km, each) were drawn from the main stream using ArcGIS 10.1. Next, based on an equal interval length (Figure 80), the seven ring buffers were merged to create four consecutive wave areas. Settlements were attributed the locational distance within which the majority of their compounds fell into. Therefore, the very close locational distance grouped settlements with the bulk of compounds located within 1 km to the main stream. The very distant locational distance represented settlements with majority of compounds laocted at least 6 km from the main stream.

Locational distances with respect to the main stream

Classes	Sets of Settlements {distances}	Definitions
Location_1	{0 – 1 km}	Very close
Location_2	{2 – 3 km}	Close
Location_3	{4 – 5 km}	Distant
Location_4	{6 – 7 km}	Very distant

Figure 80: Categorizing settlements into four locational distances with respect to the main stream

- Settlements functions

• Agricultural function

The way the site was created and colonized was used as criterion to categorized settlements into three agricultural functions as shown in Figure 81. The complete modern agricultural function was attributed to settlements that were created by new immigrant farners through modern irrigation projects in the Sourou valley. It means that they were absent on the Sourou valley map before the implementation of the irrigation projects. Next, ready existing settlements that served to resettle new farners were attributed to the mixed modern-traditional agricultural function. The third class represented traditional settlements which did not receive any input from immigrant farmers through ways of irrigation projects.

Agricultural Functions

Classes	Sets of Settlements {Criteria}	Definitions
Agricultural_1	{New sites + new input of farmers}	Complete modern
Agricultural_2	{Ancient sites + new input of farmers}	Semi-modern
Agricultural_3	{Ancient sites}	Traditional

Figure 81: Categorizing settlements into three agricultural functions

• Administrative function

Settlements were categorized into three administrative functions as indicated in Figure 82. The highest ranked function refers to the capital of rural commune which differs from the others by the presence of the town hall office. Administrative villages are autonomous geographic entities vis-à-vis others but remain under the responsibility of the capital of rural commune. All quarters found beyond the nearest neighbor settlement distance (2.63 km) from the centroid of their administrative villages were classified as hamlets of villages.

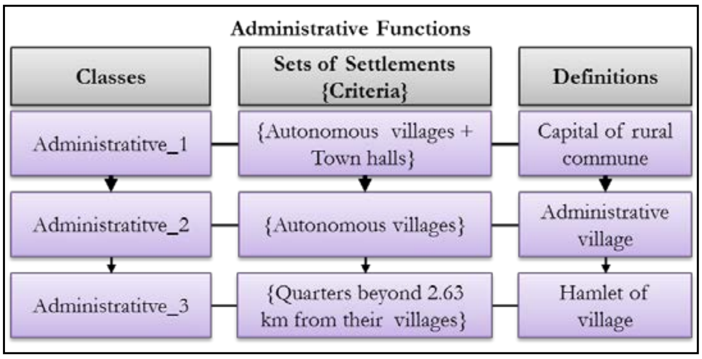


Figure 82: Categorizing settlements into three administrative functions

- Access to infrastructures

- Hydraulic works availability

First of all, we considered only hydraulic works found in condition at the date of inventory within settlements. Although the PN-AEPA-2015 does not classified traditional wells as clean water equipment, we took them into account because they represented 56% of works, not only, but also play an important role in limiting people exposure to contaminating surface water in terms of schistosomiasis transmission. Therefore, hydraulic works were categorized into two groups. In the first group we put only works recognized by the PN-AEPA-2015 while in the second we considered all works together confounded. Next, we took only community based hydraulic works for assessing their availability at the settlement level. For that private tapwater were removed as well as the corresponding populations. Then, for each group of works, we calculated the water demand index (WDI) which expresses the number of inhabitants per unit of hydraulic work and was obtained as follows:

$$WDI = \frac{Total\ population}{Number\ of\ works}$$

The categorization of settlements into the five hydraulic works availability levels (Figure 83) was based on the balanced normalized water demand index (BNWDI) which is the difference between the ratio of population and the number of hydraulic works in condition within the settlement:

$$BNWDI = \frac{Population\ size}{Recommended\ number\ of\ person} - Number\ of\ works$$

The ratio of population was obtained by dividing the total population size made a census within the settlement by the number of person recommended per unit of hydraulic work (PN-AEPA-2015). This ratio expresses the number of works in a normal availability condition within the settlement. In other words it is the normalized water demand index (NWDI). The BNWDI values are useful in pointing out the number of hydraulic works in excess (BNWDI<0) or the missing number of works (BNWDI>0) to be supplied in order to normalize the quantitative availability in settlements (Figure 83). The standard number of persons per work depends on the type: 300 persons per modern water point (hand pump or modern well) and 500 persons per water fountain (PN-AEPA-2015). Then, for each category of works and settlement, we did three simulations playing with the recommanded number of persons per work: 300 persons, 400 persons and 500 persons. 400 persons being the mean value of 300 and 500. That means that for each settlement, we had a total of six BNWDI, three for each category of works.

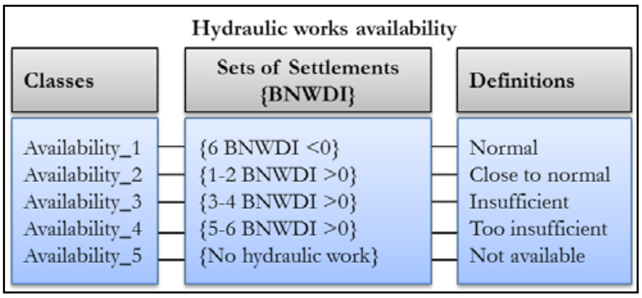


Figure 83: Categorizing settlements into five hydraulic works availability classes

The normal availability of hydraulic works grouped settlements which observed an excess of works for all six simulations (6 BNWDI<0). The too insufficient availability class indicated settlements with deficit in hydraulic works for five to six simulations (5-6 BNWDI>0). The not available class categorized settlements within which none hydraulic work was made an inventory.

- Hydraulic works accessibility

We used the compound as the referential spatial entity to assess the accessibility to hydraulic works in the study area. According to the PN-AEPA-2015, standards of distance to hydraulic works largely depend on the quality of the equipemnt: 1000m for a modern water point (hand pumps and modern wells), and 500m for a water fountain. Then, the determination of the five accessibility living conditions combined quality and quantity of the equipement and the travel distance.

First of all, compounds having private tapwater connexions were categorized as having a very good accessibility, because people do have no distance to travel. Next, we drawn buffers around water fountains (500 m) and modern water points (1000 m) in ArcGIS 10.1. Then, the intersection areas between 500m and 1000 m buffer zones were used to define the good accessibility class. The third class, defined as fairly-good accessibility, grouped compounds found within only 1000 m buffer area of a modern water point. The fourth class indicated compounds found beyond any recommended catchment area of hydraulic works recognized by the PN-AEPA-2015, but at least within 1000 m buffer area of a traditional well. The fifth and last class represented compounds found beyond 1000 m distance from any hydraulic works and therefore were classified as having no access to clean water.

Settlements were categorized according to the accessibility class the majority of their compounds fell into. Consequently, settlements were categorized into four accessibility levels. None of settlements had its majority of compounds into the very good class.

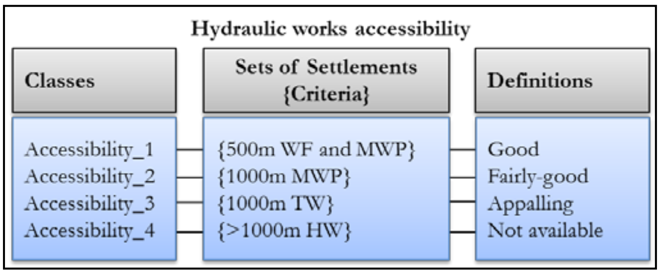


Figure 84: Categorizing settlements into four hydraulic works accessibility classes

- Accessibility to modern health care

The access to health is measured based on the theoretical effective average radius (TEAR):

$TEAR = \left(\frac{A}{\pi N}\right)^{1/2}$ where, A is the area and N represents the number of health care facilities within the given area. This value allows comparisons between different sanitary areas according to the type of infrastructure. However, within the same sanitary area, the accessibility is measured based on three buffer distances from the CSPS of reference: 0-4 km, 5-9 km and 10km and more. These buffer distances allow comparisons between settlements belonging to the same sanitary area.

We used in our case the distance to the closest CSPS to categorize settlements (Figure 85). There were a total of nine CSPS serving the study area. Three buffer zones were drawn from each CSPS in ArcGIS 10.1. Then, settlements were categorized according to the radius in which the majority of their compounds fell into. A good accessibility defined settlements with bulk of compounds located less than 5 km with respect to the closest CSPS while the appalling accessibility categorized settlements with majority of compounds located at least 10 km from a CSPS.

Accessibility to the closest CSPS

Classes	Sets of Settlements {Distances}	Definitions
Accessibility_1	{0 - 4 km}	Good
Accessibility_2	{5 – 9 km}	More or less good
Accessibility_3	{≥ 10 km}	Appalling

Figure 85: Categorizing settlements into three accessibility classes to the closest CSPS

- Access to education

Settlements were categorized into three classes based on the proportion of the population attending schools which was calculated as follows:

$$School\ attendance\ rate = \frac{Number\ of\ school\ attendants}{Total\ population} \times 100$$

Then, settlemenst which observed a rate of at least 5% of population enrolled in school attendance were categorized as having a high access to school (Figure 86). Settlements found without any school-goers for the school year 2010-2011 were classified as such.

Access to education

Classes	Sets of settlements {School attendants}	Definitions
Attendance_1	{≥ 5%}	High
Attendance_2	{< 5%}	Low
Attendance_3	{0%}	No pupils

Figure 86: Cetgorizing settlements into three schools attendance classes

- Availability of familial latrines

Settlements were divided into five classes according to the availability rate of familial latrines which were calculated as follows:

$$Familial\ latrine\ availability\ rate = \frac{Number\ of\ compounds\ with\ latrines}{Total\ number\ of\ compounds} \times 100$$

Then, settlements, with at least 75% of their compounds found with familial latrines, were categorized into the very good availabiliaty class (Figure 87). The no access to familial latrines classified settlements within which no single compound had a latrine on the date of the survey (March 2011).

Familial latrines availability

Classes	Sets of Settlements {Rates}	Definitions
Latrine_1	{≥ 75%}	Very good
Latrine_2	{< 75%}	Good
Latrine_3	{< 50%}	Fairly-good
Latrine_4	{< 25%}	Not good
Latrine_5	{0%}	No access

Figure 87: Categorizing settlements into five familial latrines availability classes

- Occupational activities

Three targeted activities were: modern irrigation (IRR), traditional fishing in ponds (TFP) and water lily bulbs gathering (WBG). A multiple response was allowed, therefore, compounds were distributed within settlements in a manner that a compound falls into one and only one combination of activities. Settlements were categorized into six classes based on combinations of activities the majority of compounds reported (Figure 88). In the case where combinations of activities showed equal proportions of compounds, we prioritized the most complex combination. Then, the first class categorized settlements with majority of their compounds having reported involving in all three targeted activities (IRR+TFP+WBG). Settlements within which the bulk of compounds did not mention their involvement in the three targeted activities formed the sixth class NTA meaning Non-Targeted Activities (Figure 88).

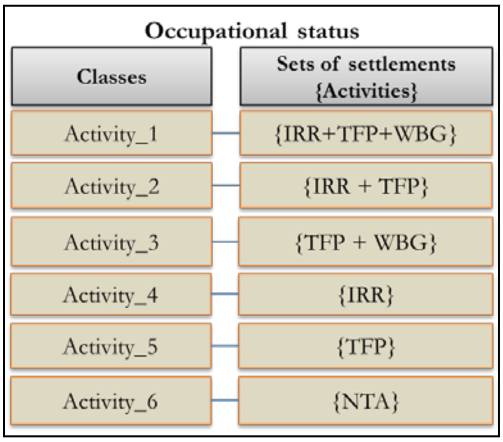


Figure 88: Categorizing settlements into six occupational activities classes

- Schistosomiasis-illness prevalent settings

Based on the work of Ansell et al. (1997), it was recommended that a prevalence of self-reported urinary schistosomiasis of 30% be used to define communities where the true prevalence is expected to be above 50% (Clements et *al.*, 2008). Adapting these endemic thresholds, settlements were categorized as into three prevalence classes using urinary schistosomiasis-illness status reported at the compounds level (Figure 89). The prevalence rate was calculated after Chitsulo et al. (1995) as follows:

$$Schistosomiasis\ prevalence\ rate = \frac{Number\ of\ compounds\ with\ illness}{Total\ number\ of\ compounds\ surveyed} \times 100$$

Then, settlements, within which less than 10% of compounds having reported a presence of symptomatic urinary schistosomiasis person within the compounds, were categorized as low schistosomiasis prevalent settings. While settlements where more than 30% of compounds reported the illness were classified as high urinary schistosomiasis prevalent settings (Figure 89).

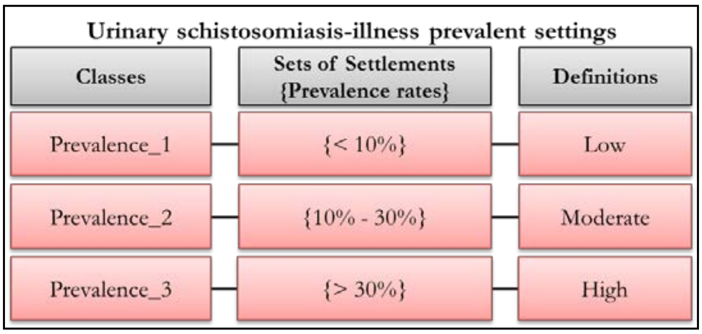


Figure 89: Categorizing settlements into three schistosomiasis-illness prevalent settings

- Settlements' envirionmental aspects

We used the set of 37 dots, each dot representing the mean center of compounds of the settlement, and ran the average nearest neighbor command in the analyzing patterns tool in ArcGIS (Levine, 2007; Scott & Janikas, 2010). Spatial statistics obtained were 2999.78 m (~3 km) for the observed mean distance, 2252.51 m (2.25 km) for the expected distance. Using these distances we calculated the nearest neighbor settlement distance between two settlements ($NNSD$):

$$NNSD = \frac{(3+2.25)}{2} = 2.63\ km.$$

This nearest neighbor distance (2.63km) was used as a radius to draw buffer areas from the centroid of the settlement. Then, the assessment of the potential of the environment data within the nearest neighboring of the settlement was done within this buffer area. But we had to solve overlap problems between nearest neighbor settlements. To solve the spatial overlapping problem, we used relative values so that we get 100% for each layer by summing up the 37 buffer areas. For that, we divided the area that covered a layer within a single buffer zone by the sum of areas that covered the layer within all 37 buffer areas and multiplied by 100 and the expression is:

$$Layer\ (\%)\ within\ a\ buffer = \frac{Area\ covered\ within\ a\ buffer\ zone}{Total\ area\ covered\ for\ all\ 37\ buffer\ zones} \times 100$$

- Freshwater bodies potential

The permanent water body layer was used as criterion for categorizing settlements into three groups (Figure 90). Settlements whose buffer zones contained more than 2% of the total area covered by the 37 buffer zones were defined as lakeside settings. Conversely, highland settings constituted settlements that nearest neighboring buffer area did not contain any permanent water body. The lowlands class represented settlements with buffer zones containing between 2 and 0.03% of the total area covered by permanent water bodies.

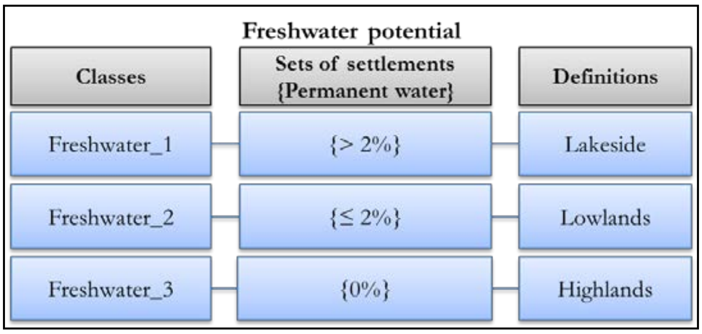


Figure 90: Categorizing settlements into three classes with resoect to freshwater

- Vegetation potential

Settlements were categorized into four classes based on the pre-dominant type of vegetation within their respective area as indicated in Figure 91. The dense vegetation cover grouped settlements whose nearest neighboring buffer zones contained more gallery forest compared to others vegetation types within the buffer area. The more or less dense vegetation cover represented settlements for which woodland dominated others types of vegetation. The degraded land cover constituted settlements whose nearest neighboring areas contained more grassland than others types of vegetation. The intermittent flood grouped settlements with a high potential of aquatic vegetation because of the flood.

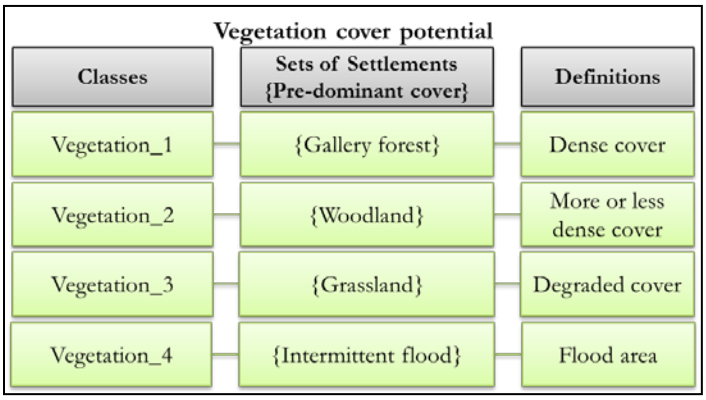


Figure 91: Categorizing settlements into four vegetation cover classes

- Modern irrigated fields potential

Settlements classification was based on the presence/absence of modern irrigation parcels within their nearest neighboring area. Then, settlements fell into three combinations as shown in Figure 92. Settlements were qualified as having a heterogenous environment when their nearest neighboring buffer zones contained both paddy and poly-culture parcels. The semi-natural environment constituted settlements whose nearest neighboring buffer areas contained only one type of parcel (paddy or poly-culture). The natural environment was attributed to settlements whose nearest neighboring did not contain any modern irrigation field.

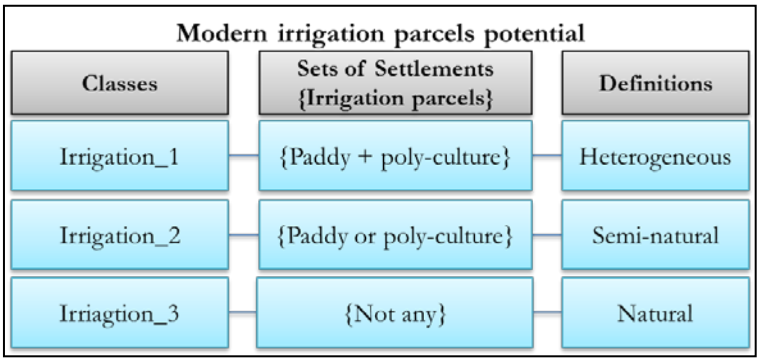


Figure 92: Categorizing settlements into three environmental modification classes

3.5.2.2. Spatial assessment of schistosomiasis susceptible risk

Schistosomiasis-susceptible area is a concrete concept and a major issue in geography of health of schistosomiasis transmission. Initiated in 80s by the Schistosomiasis Control Office of the Chinese Central Government, it is defined as areas where there are frequent human activities, severe cercaria contamination and more chance of infection (Hua, 1994, cited Zhao et *al.*, 2006, p. 45). So defined, the concept of schistosomiasis-susceptible area itself refers to a risky geographic space that presents high probability for people to contaminate their local environment and to become infested.

- Summary of therminologies used

Table 10 summarizes therminologies included in the spatial assessment of schistosomiasis risk. Three risk statuses are distinguished: human infestation, environmental contamination and schistosomiasis transmission. For each risk status, five risk levels are distinguished: high-high, high, medium, low and low-low. For the purposes of comparability, three statistic indicators were used for mapping schistosomiasis risk statuses: absolute scores, critical z-scores and standard residuals. These statistic indicators were obtained using three statistic methods: nominative, hot sopt and geographic weighted regression, respectively. Still for comparability purposes, we used four quantitative classification methods in ArcGIS 10.1: equal interval, quantile, natural breaks (Jenks) and geometrical interval for assessing the stability of the risk levels. For each risk level, we computed proportions of settlements, compounds and populations by dividing numbers of settlements, compounds and population into each risk level by 37, 4868 and 51540, respectively, and multiplied by 100.

Table 10: Summary of therminologies used for assessing the spatial risk of schistosomiasis

Risk statuses (n = 3)	Risk levels (n = 5)	Statistic Indicators (n = 3)	Statistic methods (n = 3)	Quantitative classification methods (n = 4)	Indicators of Magnitude (n = 2)
- Human infestation - Environmental contamination - Schistosomiasis transmission	- Hihg-high - High - Medium - Low - Low-low	- Absolute scores - Z-scores - Standard residuals	- Nominative - Hot spot - Geographic weighted regression	- Equal interval - Quantile - Natural breaks (Jenks) - Geometrical interval	- Urinary schistosomiasis-illness prevalence rate - Familial latrines availability rates

- Statistic indicators and methods

Absolute scores were calculated based on a nominative method while z-scores and standard residuals were derived from absolute scores based on the hot spot (Getis-Ord Gi*) and the geographic weighted regression methods in ArcGIS 10.1, respectively (Figure 93).

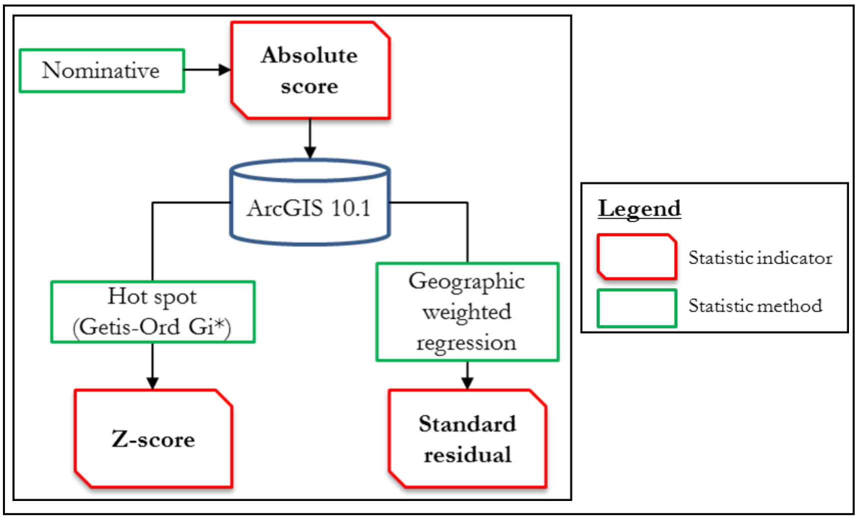


Figure 93: Statistic indicators and methods

- Nominative calculation of absolute scores based on indicators of magnitude

Since, settlements were categorized exhaustively into classes per geographic parameter; the nominative method included attributing scores to classes according to the magnitude of the problem. To do so we used two indicators of magnitude depending on the risk status.

On the one hand, urinary schistosomiasis-illness prevalence rates were used as indicator of magnitude to rank classes with respect to the human infestation risk status. The higher the prevalence rate the higher the absolute score attributed to the class. Therefore, the absolute score (AS) of the settlements with respect to human infestation (HI) was calaculated as the cumulative sum of score for each geographic parameter using the illness prevalence rate as indicator of magnitude:

$$AS_{HI} = \sum Absolute\ scores\ of\ all\ geographic\ parameters$$

On the other hand, familial latrines availability rates served as indicator of magnitude in ranking classes with respect to the environmental contamination risk status. The higher the latrine availability rate the lower the absolute score attributed to the class. Therefore, the absolute score (AS) of the settlement in terms of environmental contamnination (EC) was calaculated as the cumulative sum of score for each geographic parameter using the latrines availability rate as indicator of magnitude:

$$AS_{EC} = \sum Absolute\ scores\ of\ all\ geographic\ parameters$$

As schistosomiasis transmission forms a dynamic system, the determination of settlements' scores for schitosomiasis transmission (ST) risk status was calculated by multipling the score for human infestation by that of enviromental contamination:

$$AS_{ST} = AS_{HI} \times AS_{EC}$$

- Standard residuals derivation from absolute scores

We used the geographic weighted regression (GWR) which is a local form of linear regression employed to model spatially varying relationships (Brunsdon et al., 1999). GWR was based on two kernel types.

- The fixed kernel type: The spatial context (the Gaussian kernel) used to solve each local regression analysis is a fixed distance.
- The adaptive kernel type: The spatial context is a function of a specified number of neighbors: where settlements distribution is dense, the spatial context is smaller; where settlements distribution is sparse, the spatial context is larger.

Next, for each kernel type two bandwidth methods were employed.

- Akaike Information Criterion (AICc): The extent of the kernel is determined using AICc.
- Cross Validation (CV): The extent of the kernel is determined using CV.

AICc and CV were selected to allow the tool to find the optimal distance/neighbor parameter automatically in ArcGIS. GWR constructs these separate equations by incorporating the predicted and explanatory variables of features falling within the bandwidth of each target feature. Table 11 shows in our case independent and dependent variables.

Table 11: Explanatory and predicted variables used to compute standard residuals

Risk status	Explanatory variable	Predicted variable	Standard residuals
Human infestation	Urinary schistosomiasis-illness prevalence rate	Absolute score for human infestation	Standard residuals for human infestation
Environmental contamination	Familial latrine availability rate	Absolute score for environmental contamination	Standard residuals for environmental contamination
Schistosomiasis transmission	Urinary schistosomiasis-illness prevalence rate	Absolute score for human infestation	Standard residuals for schistosomiasis transmission (ST1)
	Familial latrine availability rate	Absolute score for environmental contamination	Standard residuals for schistosomiasis transmission (ST2)

GWR output provides automatically standard residuals together with other accompanying spatial statistics. Only standard residuals were used in understanding the spatial heterogeneity of schistosomiasis-susceptible communities.

- Z-scores derivation from absolute scores

This method was used to identify statistically significant hot spots and cold spots using the Getis-Ord Gi* statistic in ArcGIS. The spatial relationships among settlements were conceptualized according to two methods: the inverse distance and the fixed distance band methods.

- Fixed distance band (FDB): In fixed distance band, each settlement is analyzed within the context of neighboring settlements. Neighboring settlements inside the specified critical distance receive a weight of one and exert influence on computations for the target settlement. Neighboring settlements outside the critical distance receive a weight of zero and have no influence on a target settlement's computations.
- Inverse distance (ID): In inverse distance, nearby neighboring settlements have a larger influence on the computations for a target settlement than settlements that are far away.

Gi* z-scores are automatically provided by running the hot spot analyzing tool in ArcGIS 10.1 and were used to define community schistosomiasis-susceptible degrees.

- Quantitative classification methods

- Equal interval

This divides the range of attribute values into equal-sized sub-ranges. Specifying the number of intervals, ArcGIS 10.1 automatically determine the class breaks based on the value range. This method emphasizes the amount of an attribute value relative to other values.

- Quantile

It assigns the same number of data values to each class. There are no empty classes or classes with too few or too many values. In fact, features are grouped in equal numbers in each class using quantile classification. Similar features can be placed in adjacent classes, or features with widely different values can be put in the same class. Therefore, the resulting map can often be misleading. This distortion can be minimized by increasing the number of classes.

- Natural breaks (Jenks)

This classification is based on the Jenks' Natural Breaks algorithm. Class breaks are identified that best group similar values and that maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values.

- Geometrical interval

The algorithm creates geometric intervals by minimizing the sum of squares of the number of elements in each class. This ensures that each class range has approximately the same number of values with each class and that the change between intervals is fairly consistent. It is a compromise method between equal interval, Natural Breaks (Jenks), and quantile. It creates a balance between highlighting changes in the middle values and the extreme values, thereby producing a result that is visually appealing and cartographically comprehensive.

- Determination of risk levels

For each of the abovementioned model, communities were quantitatively categorized into five levels of susceptibility following the defense readiness condition (DEFCON), an alert posture used by the United States Armed Forces (Table 12). In fact, DEFCONs are a subsystem of a series of alert conditions prescribing five graduated levels of readiness (or states of alert) for the U.S. military, and increase in severity from DEFCON 5 (least severe) to DEFCON 1 (most severe) to match varying military situations. Colors representing levels are also adapted from the DEFCON system except L1 for which we replaced the white by the black to enhance the visibility.

Table 12: Read key of schistosomiasis-susceptible maps

Symbol	Level of risk	Meaning
● (blue)	L5	Low-low
● (green)	L4	Low
● (yellow)	L3	Medium
● (red)	L2	High
● (black)	L1	High-High

3.5.3. Temporal analysis

Three scales of time were included in the assessment of schistosomiasis-susceptible risk heterogeneity in time in the study area (Table 13). The first scale took into account the short term or the daily scale which the target to establish the daily influence of climatic variables on local populations' water contact behavior. The mean term or the monthly scale looked for the relationship between seasonal variability of climatic variables and local people vulnerability to schistosomiasis transmission. The long term or the yearly scale enabled the understanding of exposure patterns through the year.

Table 13: Scales of the temporal analysis

Scale	Unit	Influence measured
Day	Hour	Short term
Month	Day	Mean term
Year	Month	Long term

Chapter 4. Settlement Aspects in our Area of Interest (AOI)

This chapter deals with the various aspects of the rural settlement associated with schistosomiasis transmission. Particularly, this chapter is concerned with the categorization of AOI settlements into different classes according to the given geogen as descripted in chapter 3.

4.1. Population typology

Table 14 shows the result of settlements categorization into the four population sizes. There was a trongly correlation between the number of compounds within a settlement and its population size: r = 0.99; r^2 = 97% (p-value < 0.001). The mean number of inhabitants per compounds varied unevenly as well as the variance. While the higher the population size the lower the standard error (Table 14). Figure 94 shows that the majority (45.95%) of settlements fell into very small class. However, 42.17 and 41.62% of compounds and populations, respectively, were concentrated into very large population size class. Figure 86 shows the spatial distribution of settlements. Then, it appeared that that 100% of settlements classified as very large are located on the eastern bank of the Sourou River.

Table 14: Settlements' Population Typology a March 2011 census

Area of Interest: Population Typology (March 2011)						
Class	**Settlement**	**Population**	**Compound**	**Mean**	**Variance**	**Std. Error**
1. Very big	Guièdougou	8282	692	11.97	82.07	0.09
	Di	7981	730	10.93	68.79	0.09
	Niassan	5188	631	8.22	28.54	0.10
2. Big	Débé	3664	343	10.68	42.08	0.13
	Sono	3005	320	9.39	41.85	0.14
	Gouran	2929	253	11.58	106.74	0.15
	Oué	2462	226	10.89	56.68	0.16
	Yaran	2145	195	11.00	68.71	0.17
	Illa	1729	170	10.17	40.88	0.19
	Koumbara	1631	135	12.08	67.37	0.21
3. Small	Leri	1343	145	9.26	27.15	0.20
	Nion	1040	95	10.95	33.77	0.25
	Benkadi	1036	82	12.63	47.91	0.27
	Lanfièra	984	92	10.70	71.47	0.25
	Bouna	893	52	17.17	126.30	0.33
	Yayo	884	88	10.05	59.56	0.26
	Kouri	811	96	8.45	25.68	0.25
	Bissan	652	67	9.73	21.14	0.29
	Bantombo	579	57	10.16	24.39	0.32
	Ouèrin	555	52	10.67	44.22	0.33
4. Very small	Toma-Île	460	40	11.50	66.36	0.37
	Toumani	458	49	9.35	18.56	0.34
	Koubè	398	30	13.27	135.44	0.43
	Toma-Koura	357	23	15.52	79.08	0.48
	Touroukoro	352	27	13.04	86.34	0.45
	Soro	289	30	9.63	28.45	0.43
	Lô	224	30	7.47	31.09	0.43
	Toma	217	18	12.06	63.23	0.54
	Winrèbèrè	190	20	9.50	65.53	0.51
	Zampana	150	18	8.33	15.41	0.54
	Badala	138	9	15.33	154.75	0.72
	Ouèrin-Koura	125	10	12.50	68.50	0.69
	Watinoma	115	14	8.21	32.49	0.60
	Dabokitila	98	11	8.91	23.09	0.66
	Lanfièra-Koura	92	7	13.14	39.48	0.79
	Bossola	44	5	8.80	4.70	0.91
	Yayo-Koura	40	6	6.67	5.87	0.85
Total Area of Interest		**51540**	**4868**	**10.59**	**59.17**	**0.04**

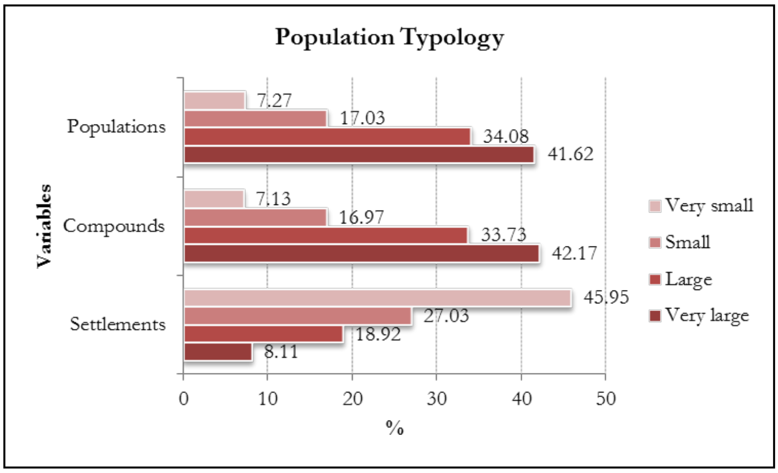


Figure 94: Proportions of settlements, compounds and populations per population typology

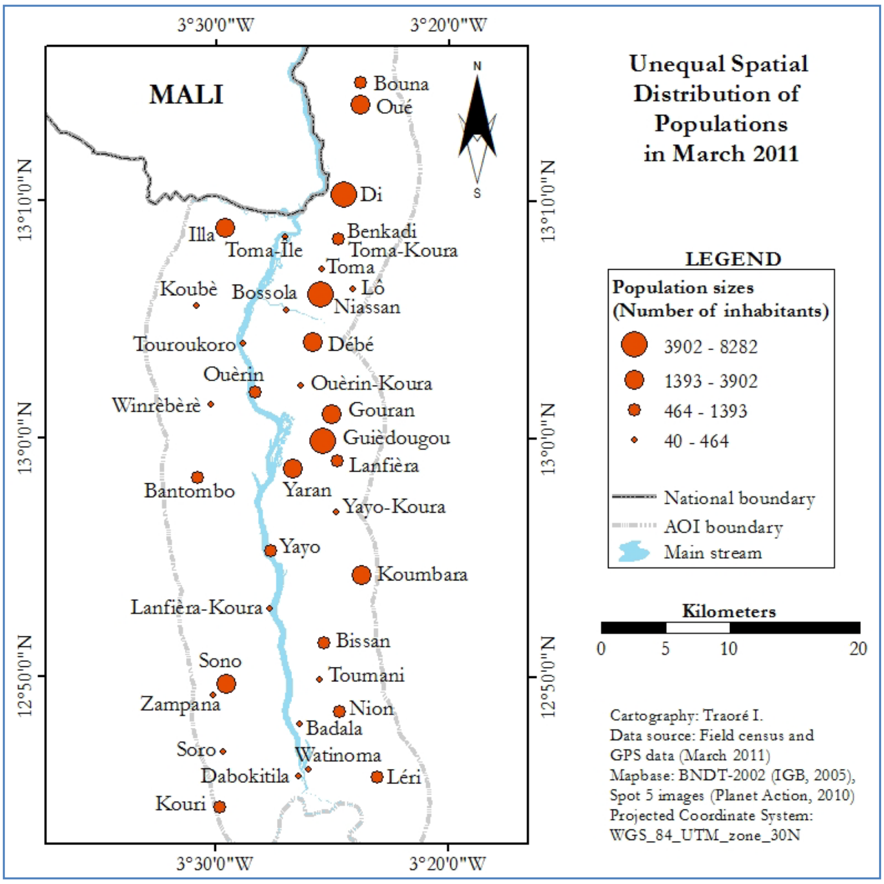


Figure 95: Spatial distribution of AOI settlements according the population size

4.2. Residential units spatial distribution

4.2.1. Residential units spatial organization patterns

Table 15 shows the output of settlements classification with respect to the spatial organization pattern. Values of the observed and the expected mean distances (OMD and EMD) showed no clear pattern of compounds arrangement within the settlement. Values of the nearest neighbor compounds distance (NNCD) were proper to each settlement and cannot be extrapolated to another, even within the same pattern. Values of the nearest neighbor index (NNI) increased from the clustered pattern (NNI< 1) to the dispersed pattern (NNI> 1). The perfect random pattern was observed only at Zampana (NNI= 1) (Figure 96). Values of z-score increased evenly from pure clustered to pure dispersed pattern. Results showed a likelihhod from 1 to 5% for clustered pattern and 1 to 10% for dispersed. The random pattern showed the biggest p-values. Summarizing Table 15, Figure 97 shows that the majority (37.84%) of settlements fell into the dispersed pattern while 75.55 and 75.44% of compounds and population were concentrated into the clustered pattern.

Table 15: Settlements' Spatial Organization Patterns

Compounds Spatial Organization Patterns within Settlements								
Class	**Settlement**	**OMD (m)**	**EMD (m)**	**NNSD (m)**	**NNI**	**z-score**	**p-value**	**Result**
	Niassan	25.72	43.05	34.39	0.60	-19.34	0.000	1%
	Di	28.19	38.29	33.24	0.74	-13.63	0.000	1%
	Débé	28.83	46.13	37.48	0.62	-13.30	0.000	1%
	Gouran	41.63	70.41	56.02	0.59	-12.44	0.000	1%
	Sono	30.49	44.08	37.28	0.69	-10.55	0.000	1%
	Guièdougou	29.71	37.04	33.38	0.80	-9.96	0.000	1%
1. Clustered	Toumani	41.48	103.36	72.42	0.40	-8.02	0.000	1%
	Koumbara	36.06	50.05	43.05	0.72	-6.21	0.000	1%
	Oué	36.88	45.14	41.01	0.82	-5.27	0.000	1%
	Benkadi	32.48	45.45	38.97	0.71	-4.94	0.000	1%
	Nion	53.77	66.90	60.33	0.80	-3.66	0.000	1%
	Lanfièra	36.53	42.60	39.57	0.86	-2.62	0.009	1%
	Lô	26.63	33.82	30.23	0.79	-2.23	0.026	5%
	Bouna	39.76	44.56	42.16	0.89	-1.48	0.138	-
	Soro	80.24	89.71	84.98	0.89	-1.11	0.269	-
	Ouèrin	11.29	12.19	11.74	0.93	-1.02	0.309	-
	Illa	36.94	38.40	37.67	0.96	-0.95	0.343	-
2. Random	Zampana	43.73	43.87	43.80	1.00	-0.03	0.980	-
	Bissan	43.69	43.47	43.58	1.01	0.08	0.937	-
	Leri	37.36	36.54	36.95	1.02	0.52	0.603	-
	Watinoma	60.34	56.24	58.29	1.07	0.52	0.602	-
	Lanfièra-Koura	31.03	25.75	28.39	1.20	1.04	0.300	-
	Koubè	47.23	42.34	44.79	1.12	1.21	0.226	-
	Toma-Koura	23.37	19.35	21.36	1.21	1.91	0.057	10%
	Bantombo	48.30	42.41	45.35	1.14	2.01	0.045	5%
	Kouri	33.72	29.85	31.79	1.13	2.44	0.015	5%
	Yayo-Koura	56.86	36.63	46.74	1.55	2.59	0.010	1%
	Yaran	24.95	22.67	23.81	1.10	2.69	0.007	1%
	Yayo	12.09	10.48	11.28	1.15	2.76	0.006	1%
	Dabokitila	36.57	25.45	31.01	1.44	2.77	0.006	1%
3. Dispersed	Toma	40.73	29.64	35.18	1.37	3.04	0.002	1%
	Badala	125.29	74.14	99.72	1.69	3.96	0.000	1%
	Ouèrin-Koura	66.67	39.81	53.24	1.67	4.08	0.000	1%
	Winrèbèrè	31.53	20.98	26.25	1.50	4.30	0.000	1%
	Toma-Île	11.64	8.20	9.92	1.42	5.07	0.000	1%
	Touroukoro	12.30	7.94	10.12	1.55	5.46	0.000	1%
	Bossola	27.75	6.91	17.33	4.01	12.89	0.000	1%

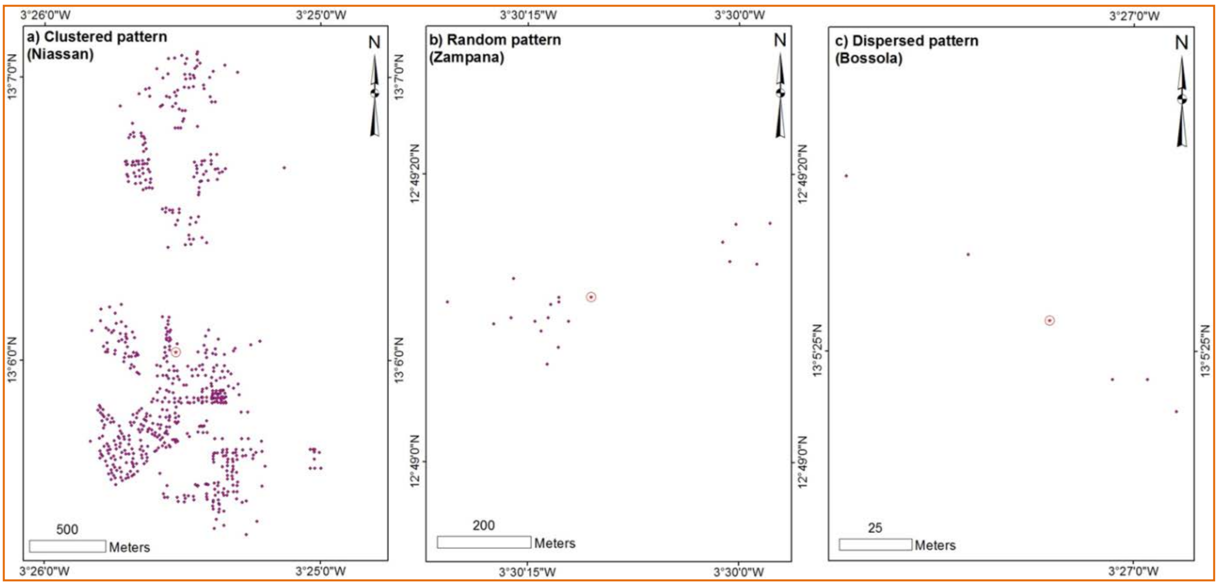


Figure 96: Illustration of spatial organization patterns

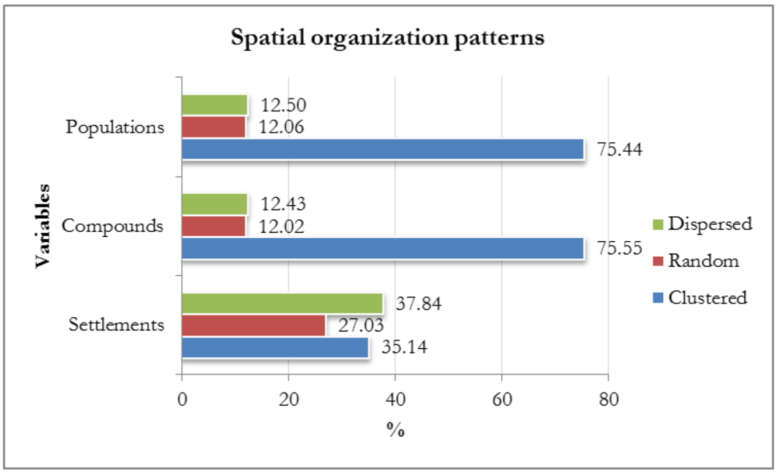


Figure 97: Proportions of settlements, compounds and populations per spatial organization pattern

The ratio, NNI, was used by Clark & Evans (1954) to distinguish between perfect uniform, random and complete aggregated patterns of distribution. However, in this present study only the critical z-score was used to provide demarcation thresholds.

4.2.2. Residential units' geographic extension shapes

Table 16 shows results of settlements categorization into three shapes. Figure 98 illustrates examples for each shape. Values of $\overline{SDE}_{x,y}$ did not say more that those of SDE_x and SDE_y. Values of G increased from round shape to elliptic one. In all cases G was found positive which means that $SD > \overline{SDE}_{x,y}$. Moreover, 80% of round shape settlements had $G < 1$ m while 81.25% of those with the oblong shape had $G < 10$ m; and 93.75% of the elliptic settlements had $G > 10$ m (Table 16). This implies that G is the starting point of the process of the demarcation between round, oblong and elliptic shapes. But, the disadvantage of G is that it does not provide any clear cut off criteria between round and oblong shapes. Table 16 shows that 100% of round shape settlements had R_1 = 1.0, meaning $SD \approx \overline{SDE}_{x,y}$ (Figure 98a). However, 94% of oblong shape settlements had also R_1 = 1.0 while, 100% of elliptic shape settlements had $R_1 \geq 1.1$. These ratios express the weakness of R_1 to demarcate round shape from oblong one. R_2 and R_2' , individually considered, did not help more than SD , $SDE_{x,y}$ and $\overline{SDE}_{x,y}$, as shown in Table 16. Results show that values from R_3' was better than those from R_3. This was also observed by comparing Leri to Sono, and Winrèbèrè to Toumani. In the first case both settlements had the same R_3, but Sono presented higher R_3'. This difference was confirmed using G. Similarly, values of Toumani minus those of Winrèbèrè were 0.0, 0.3 and 21.7 m, respectively. Figure 99 shows that the elliptic and oblong shapes accounted for 43.24% of settlemens, each. However, the majority of compounds and populations (50.74 and 51.29%, respectively) were concentrated into the oblong shape.

Table 16: Settlements' Geographic Extention Shapes

Compounds Geographic Extension Shapes within Settlements											
Class	Settlement	SD (m)	SDE_x (m)	SDE_y (m)	$\overline{SDE}_{x,y}$ (m)	G (m)	R_1	R_2	R'_2	R_3	R'_3
1. Round	Toma-Koura	79.56	74.02	84.74	79.38	0.18	1.00	0.87	1.14	0.87	1.14
	Illa	359.64	383.89	333.63	358.76	0.88	1.00	1.15	0.87	0.87	1.15
	Touroukoro	34.07	31.22	36.69	33.96	0.12	1.00	0.85	1.18	0.85	1.18
	Yayo	74.29	67.75	80.31	74.03	0.26	1.00	0.84	1.19	0.84	1.19
	Leri	321.32	352.56	286.70	319.63	1.69	1.01	1.23	0.81	0.81	1.23
2. Oblong	Sono	445.46	493.42	391.67	442.55	2.91	1.01	1.26	0.79	0.79	1.26
	Ouèrin-Koura	118.28	132.89	101.59	117.24	1.04	1.01	1.31	0.76	0.76	1.31
	Kouri	213.10	239.83	182.49	211.16	1.94	1.01	1.31	0.76	0.76	1.31
	Gouran	650.33	551.23	736.22	643.73	6.61	1.01	0.75	1.34	0.75	1.34
	Koumbara	298.52	341.93	247.62	294.78	3.75	1.01	1.38	0.72	0.72	1.38
	Nion	423.58	351.28	485.22	418.25	5.33	1.01	0.72	1.38	0.72	1.38
	Oué	439.25	362.22	504.66	433.44	5.81	1.01	0.72	1.39	0.72	1.39
	Débé	561.30	615.89	434.36	525.13	36.18	1.07	1.42	0.71	0.71	1.42
	Di	610.27	490.79	709.91	600.35	9.92	1.02	0.69	1.45	0.69	1.45
	Toma	116.64	93.79	135.69	114.74	1.90	1.02	0.69	1.45	0.69	1.45
	Toma-Île	41.45	48.74	32.58	40.66	0.79	1.02	1.50	0.67	0.67	1.50
	Bissan	285.20	216.23	340.46	278.35	6.86	1.02	0.64	1.57	0.64	1.57
	Soro	399.61	290.97	484.47	387.72	11.89	1.03	0.60	1.67	0.60	1.67
	Bantombo	222.59	161.61	270.14	215.88	6.72	1.03	0.60	1.67	0.60	1.67
	Koubè	166.08	118.51	202.76	160.64	5.45	1.03	0.58	1.71	0.58	1.71
	Winrèbèrè	88.92	58.94	111.08	85.01	3.91	1.05	0.53	1.88	0.53	1.88
3. Elliptic	Toumani	419.78	538.59	249.72	394.16	25.62	1.07	2.16	0.46	0.46	2.16
	Watinoma	157.88	91.86	203.51	147.69	10.20	1.07	0.45	2.22	0.45	2.22
	Lanfièra	258.89	334.38	149.13	241.76	17.14	1.07	2.24	0.45	0.45	2.24
	Bouna	268.05	152.10	347.23	249.67	18.39	1.07	0.44	2.28	0.44	2.28
	Yaran	258.20	336.31	142.20	239.26	18.95	1.08	2.37	0.42	0.42	2.37
	Guièdougou	609.41	328.28	796.87	562.58	46.83	1.08	0.41	2.43	0.41	2.43
	Ouèrin	78.67	40.16	103.75	71.96	6.72	1.09	0.39	2.58	0.39	2.58
	Niassan	886.73	1185.47	408.94	797.21	89.53	1.11	2.90	0.34	0.34	2.90
	Dabokitila	102.43	137.59	45.32	91.46	10.98	1.12	3.04	0.33	0.33	3.04
	Benkadi	343.15	134.04	466.41	300.23	42.93	1.14	0.29	3.48	0.29	3.48
	Yayo-Koura	145.38	50.27	199.36	124.82	20.57	1.16	0.25	3.97	0.25	3.97
	Zampana	226.52	69.41	312.74	191.08	35.45	1.19	0.22	4.51	0.22	4.51
	Lô	247.53	342.18	73.88	208.03	39.50	1.19	4.63	0.22	0.22	4.63
	Lanfièra-Koura	110.88	29.23	154.07	91.65	19.23	1.21	0.19	5.27	0.19	5.27
	Badala	462.94	651.02	69.27	360.15	102.80	1.29	9.40	0.11	0.11	9.40
	Bossola	53.01	74.89	3.39	39.14	13.87	1.35	22.09	0.05	0.05	22.09

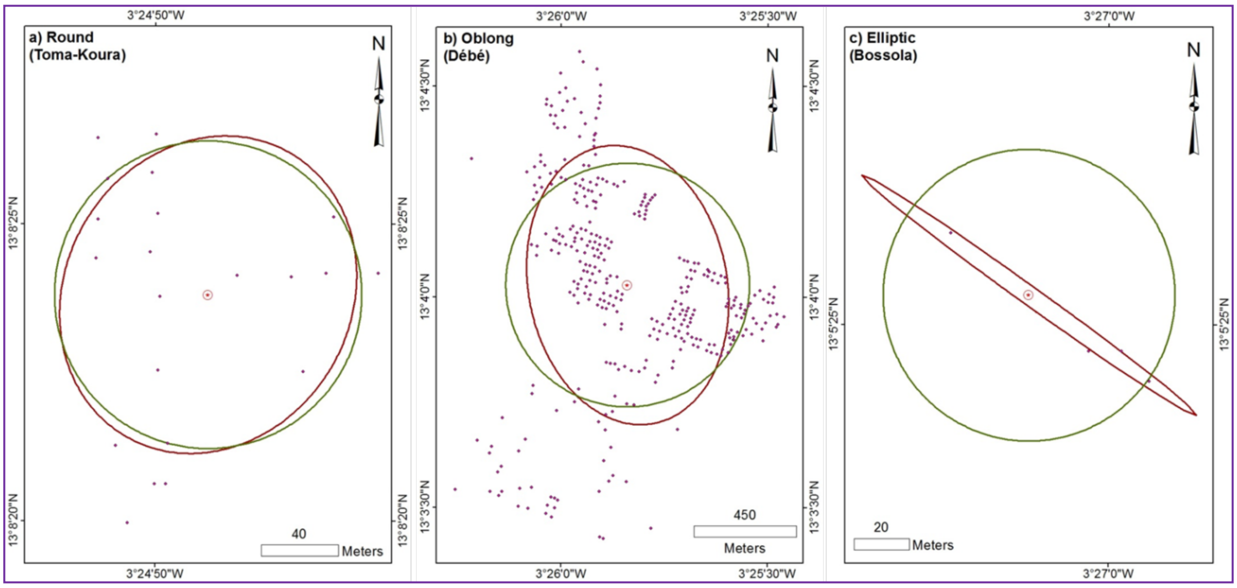


Figure 98: Illustratzion of geographic extension shapes

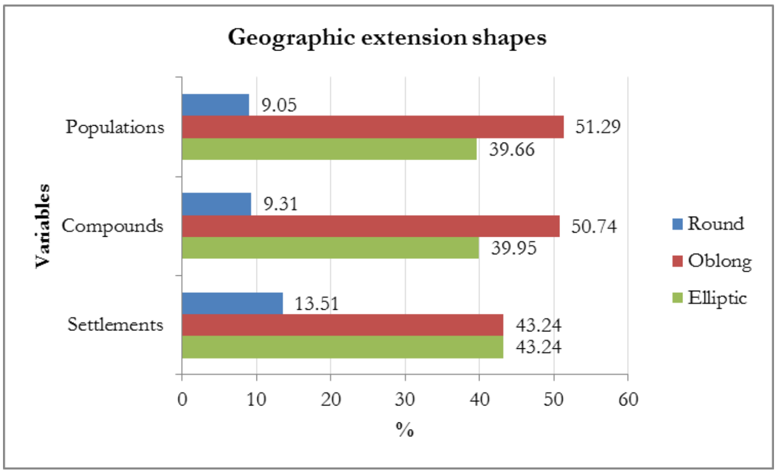


Figure 99: Proportions of settlements, compounds and population per geographic extension shapes

No index has been developed to describe the geographic shape of a set of geographic units regarded as a point set. Lefever is known to be the pioneer in measuring geographic concentration by means of the SDE. His ellipse $F = \pi ab$ (Lefever, 1926, p.91) has been discussed by Furfey who suggested $A = \frac{1}{2}\pi\sigma_x^2$ (Furfey, 1927, p.97). Later on Yuill (1971, p.31) attempted to redefine the SDE based on the various objections raised about Lefever's measure. He focused on normal and boundary condition of the SDE to define three cases: a circle ($A = B$), and ellipse ($A > B$) and a line ($B = 0$). Instead of Lefever's concentration of the ellipse: $C_a = \frac{N_e}{F}$, Yuill used the eccentricity ratio defined by Thomas (1954, p.242): $e = \frac{c}{a}$. Then, an $e = 0$ means ellipse = circle, and $e = 1$ means ellipse = line (Yuill, 1971, p.35). Clarifying the SDE, Gong replaced the ellipse by a curve and proposed the circularity index: $0 \leq \frac{\sigma_{min}}{\sigma_{max}} \leq 1$ (Gong, 2002, p.163) which is comparable to what we called R_3. This ratio was found to be limited in demarcating round from oblong. Therefore, in our case, only R'_3 gave us useful indexes and total satisfaction in distinguishing between a round shape (R'_3 <1.3), an oblong shape (1.3 ≤ R'_3 ≤ 1.9) and an elliptic shape (R'_3 > 1.9) as Table 16 shows. The plot of SD polygon (green) and SDE polygon (red) on the same two dimensional graphique helped to validate the three shapes as Figure 98 illustrates.

4.2.3. Residential units' locational distances with respect to the main stream

Table 17 shows outcomes of settlements classification into four locational distances with respect to the main stream within the study area. Compounds were distributed per ring buffer with a χ^2 = 16097.83 (p-value < 0.001). 51% of settlements had 100% of their compounds that fell into only one ring buffer and only one distance class. About 8% of settlements had their compounds that spread into two different ring buffers but belonging to the same distance class. The rest (41%) of settlements had compounds which fell into different ring buffers of different distance classes. The geographic extension shape of compounds within settlements explains this multi-rings and –classes. Most of them had a $\overline{SDE}_{x,y}$ above 500 m (Table 16). Figure 100 summarizes Table 17 and indicates that the majority of settlements, compounds and populations (40.54, 68.39 and 67.83%, respectively) were located close to the main stream. Figure 101 shows the spatial distribution of settlements according to their proximity to the main stream.

Table 17: Proportions (%) of Compounds per Settlements and per Locational Distances from the Main Stream

Area of Interest: Proportions (%) of Compounds per Settlement per Distance from the Main Stream		Distances from the main stream						
Class	**Settlement**	***1km***	***2km***	***3km***	***4km***	***5km***	***6km***	***7km***
1. Very close	Badala	100						
	Bossola	100						
	Dabokitila	100						
	Lanfièra-Koura	100						
	Ouèrin	100						
	Toma-Île	100						
	Touroukoro	100						
	Watinoma	100						
	Yayo	100						
	Yaran	62.05	37.95					
2. Close	Illa		83.53	16.47				
	Di	5.89	83.29	10.82				
	Débé	1.17	81.92	16.91				
	Niassan	12.84	62.28	19.18	5.71			
	Toumani	4.08	2.04	93.88				
	Kouri			100				
	Ouèrin-Koura			100				
	Toma-Koura			100				
	Winrèbèrè			100				
	Guièdougou			94.36	5.64			
	Leri			74.48	25.52			
	Gouran			69.96	22.92	7.11		
	Bissan			59.70	40.30			
	Benkadi			52.44	47.56			
	Toma			50.00	50.00			
3. Distant	Nion			10.53	83.16	6.32		
	Koubè				100	0.00		
	Lô				100	0.00		
	Oué				65.93	34.07		
	Lanfièra				23.91	73.91	2.17	
	Bantombo					100	0.00	
	Bouna					100	0.00	
	Sono					88.75	11.25	
4. Very distant	Soro					20.00	80.00	
	Koumbara						91.85	8.15
	Yayo-Koura						100	
	Zampana						100	
Total Area of Interest		**10.35**	**30.79**	**31.24**	**11.40**	**11.67**	**4.31**	**0.23**

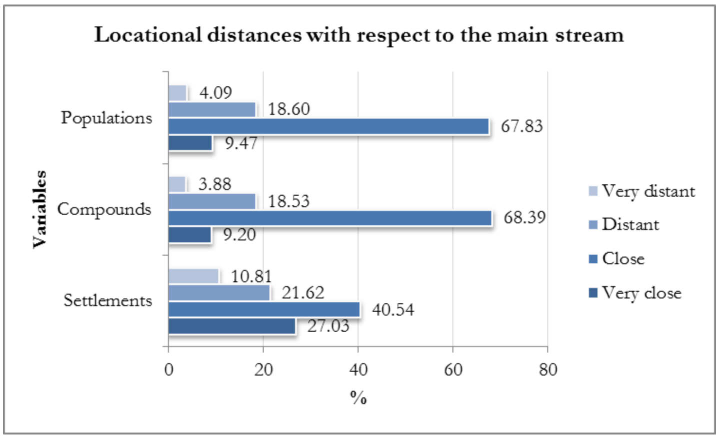


Figure 100: Proportions of settlements, compounds and population per locational distances from the main stream

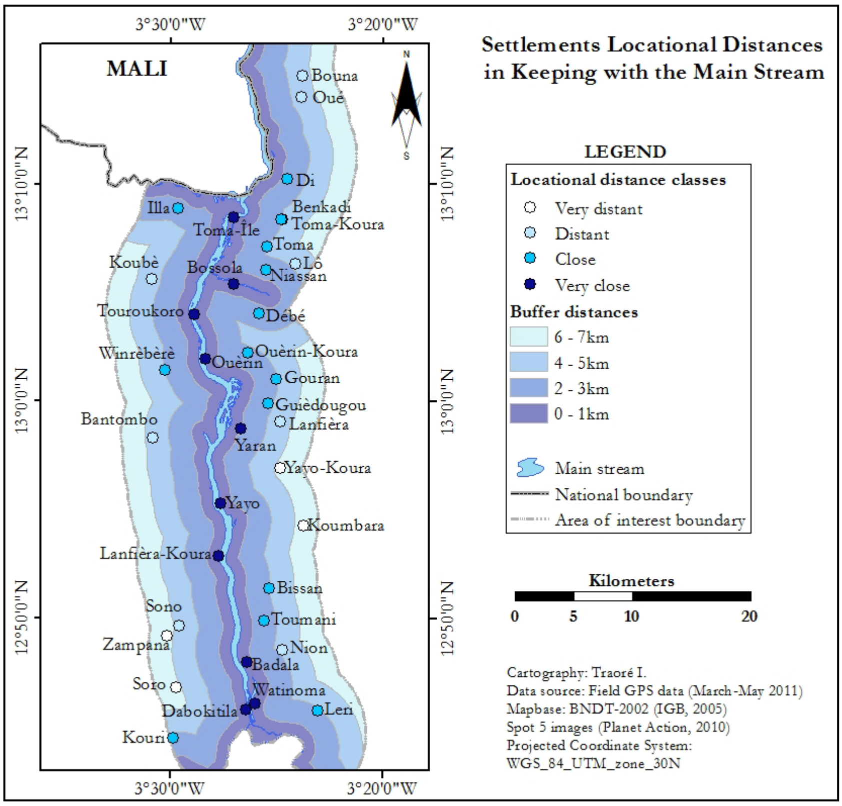


Figure 101: Settlements' locational distance classes in keeping with the main stream

4.3. Environmental aspects of settings

4.3.1. Global environmental data

Out of a total of 82430.28 ha of land cover/use data in the area of interest, the vegetation covered 87.52% while the freshwater and modern irrigation fields covered 7.85% and 4.63%, respectively. Figure 102 shows that the east bank is less covered than the west does in terms of vegetation. This may be linked to the high demographic pressure on the environment, beauce the east bank is more peopled than the west one.

A total of 11 environmental layers were derived from the satellites images (Figure 102). Figure 103 shows their pre-dominance and bare soils not took into account. This later layer was not used in the settlement classification.

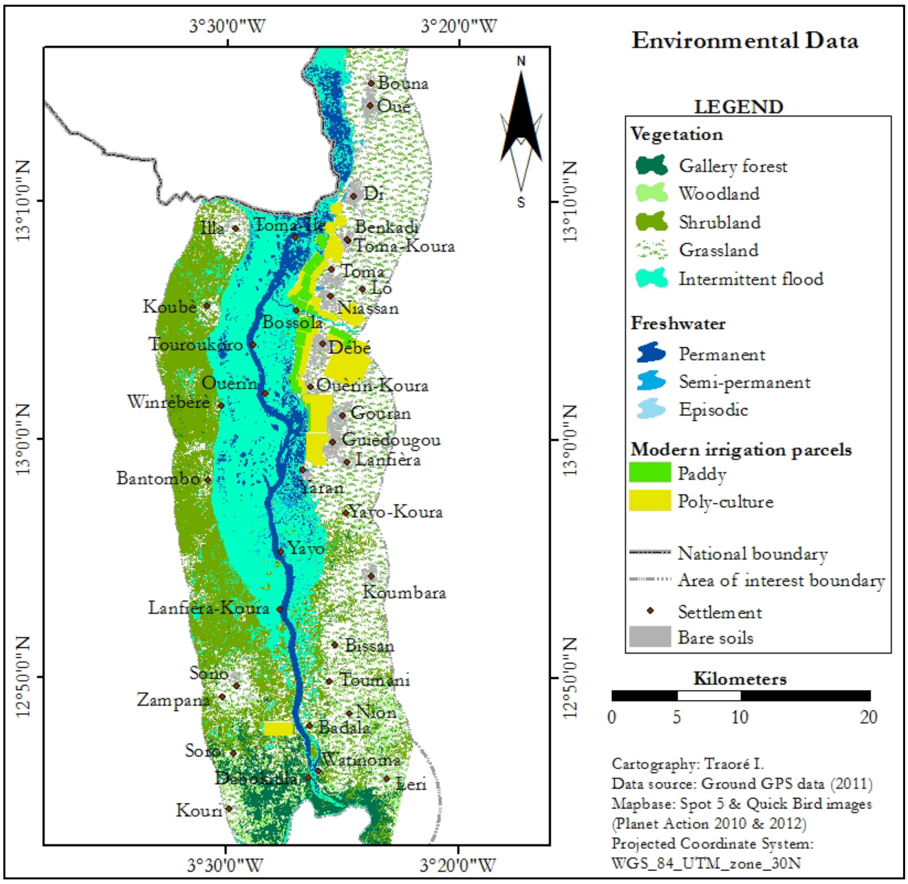


Figure 102: Environmental Data Derived from Satellite Imageries

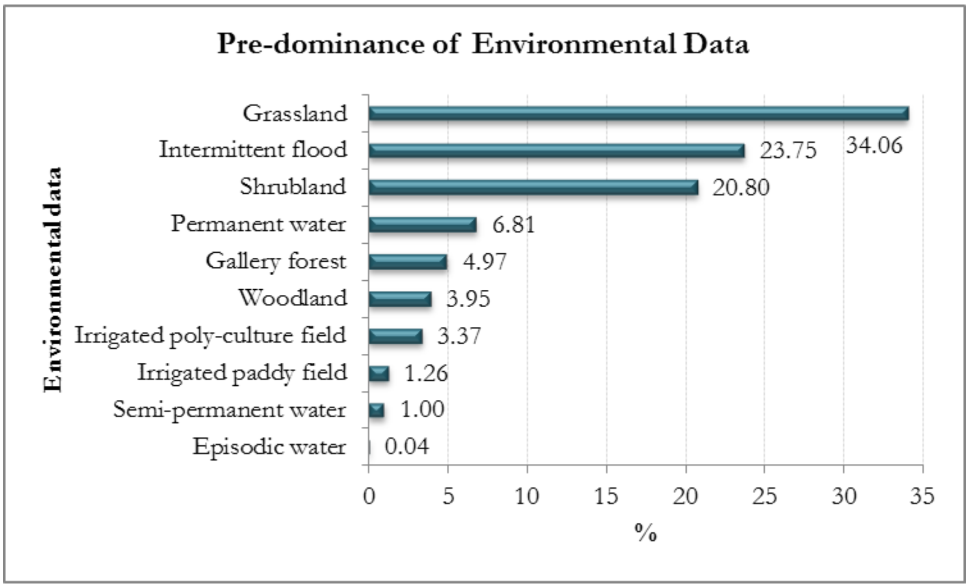


Figure 103: Dominance per type of envioronmental layers

4.3.2. Freshwater bodies potential

Figure 104 shows result of settlements categorization into three freshwater bodies' classes. Then, 32.43% of settlements fell into the lakeside category (Figure 105). The potential of permanent water bodies varied in this group from 18 to 2.5%. Lakeside settlements concentrated 84% of the area covered by permanent water bodies (Figure 106). The majority of settlements (40.54%) fell into the lowlands class (Figure 105). The potential of permanent water bodies varied between 2 and 0.03%. Together, lowlands settlements accounted for the rest (16%) of the total area covered by the permanent water bodies (Figure 106). The third and last class grouped 27.02% of settlements whose nearest neighboring did not contain any permanent water body (Figure 106). The majority of compounds and populations (51.25 and 51.04%, respectively) were concentrated into the lowlands class (Figure 105).

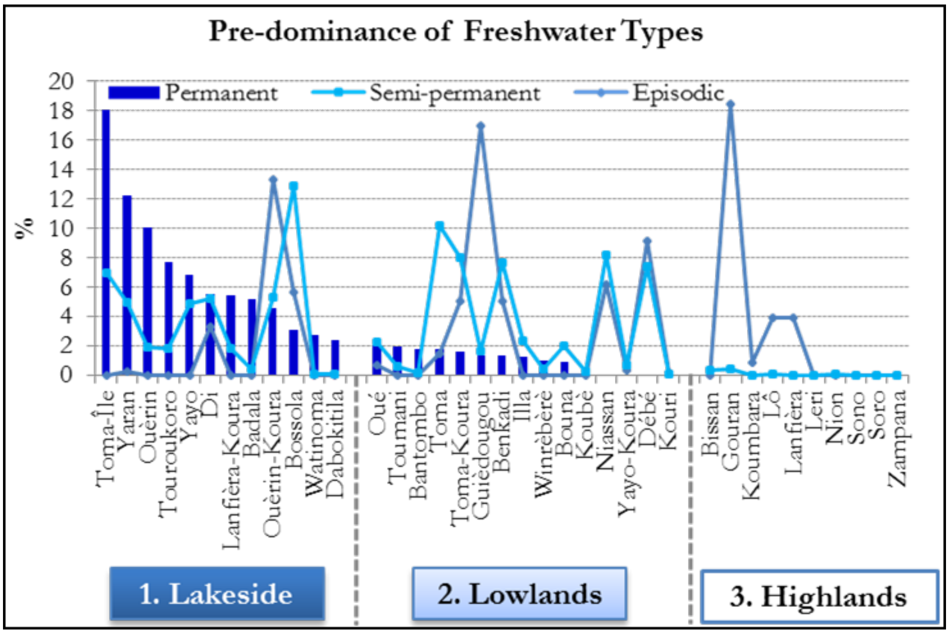


Figure 104: Settlements categorized into three classes based on permanent water

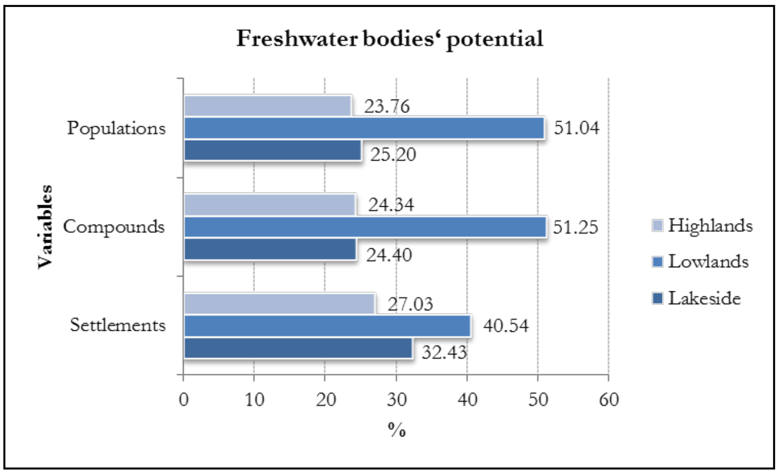


Figure 105: Proportions of settlements, compounds and populations per freshwater class

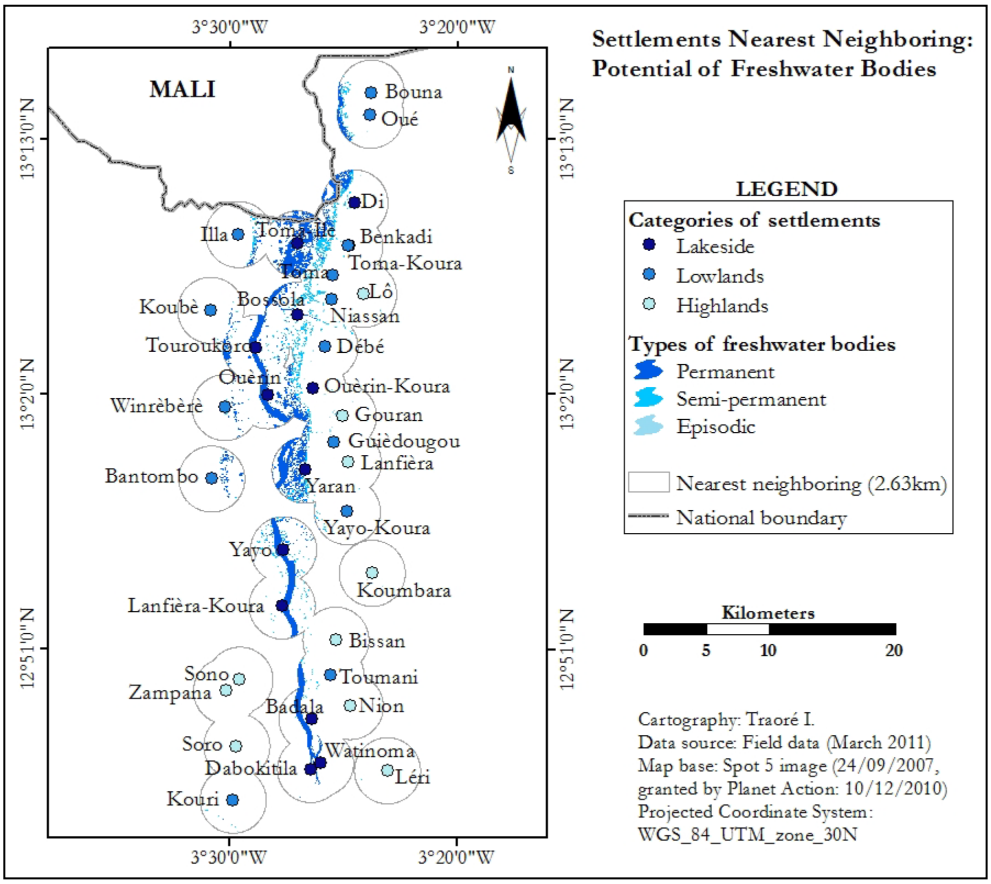


Figure 106: Plot of categories of settlements and freshwater data

4.3.3. Vegetation cover potential

Figure 107 shows result of settlements classification into four vegetation groups. The majority of settlements (51.35%) fell into the degraded land cover where the grassland layer dominated others (Figure 107 and Figure 108 and Figure 109). Proportions of compounds and populations were 77.53 and 79.29%, respectively.

The dense cover included on 8.11% of settlements where the gallery forest dominated other vegetation layers (Figure 107 and Figure 108 and Figure 109).

The shrubland remained minor in all buffer zones. That explains why we had four classes instead of five (Figure 107).

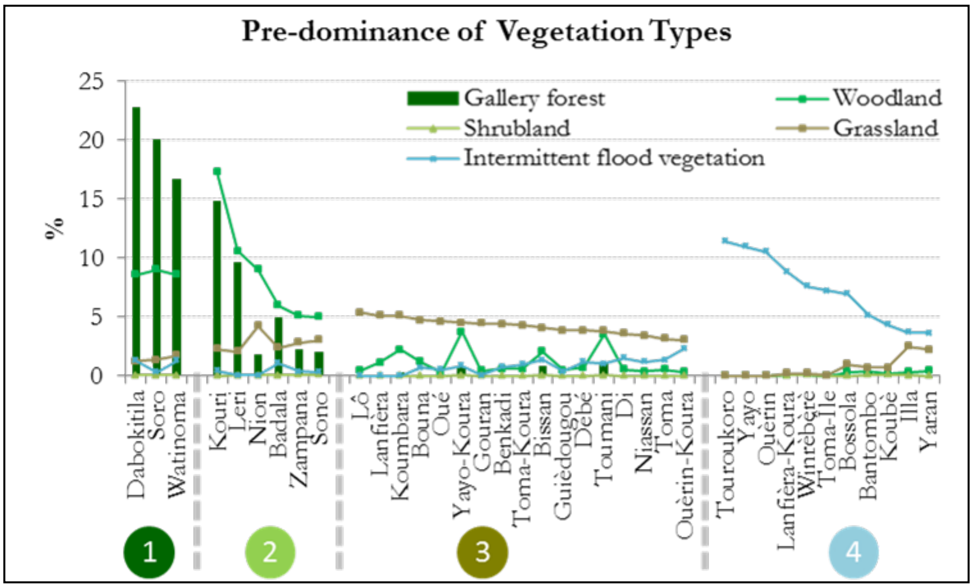


Figure 107: AOI settlements categorized into four claases using vegetation layers

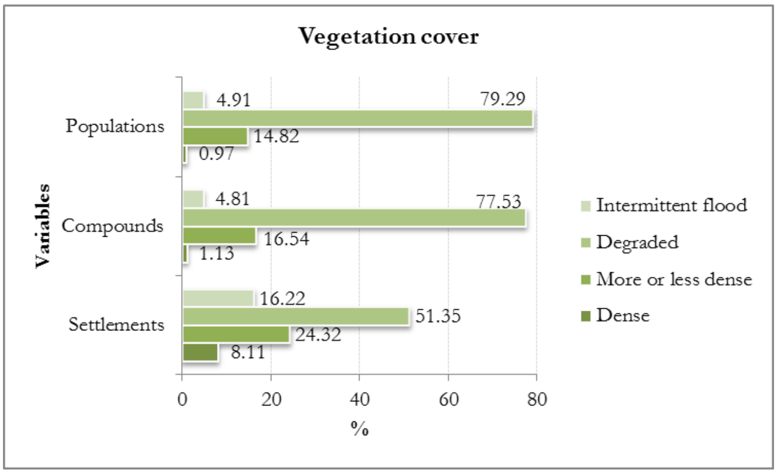


Figure 108: Proportions of settlements, compounds and populations per vegetation class

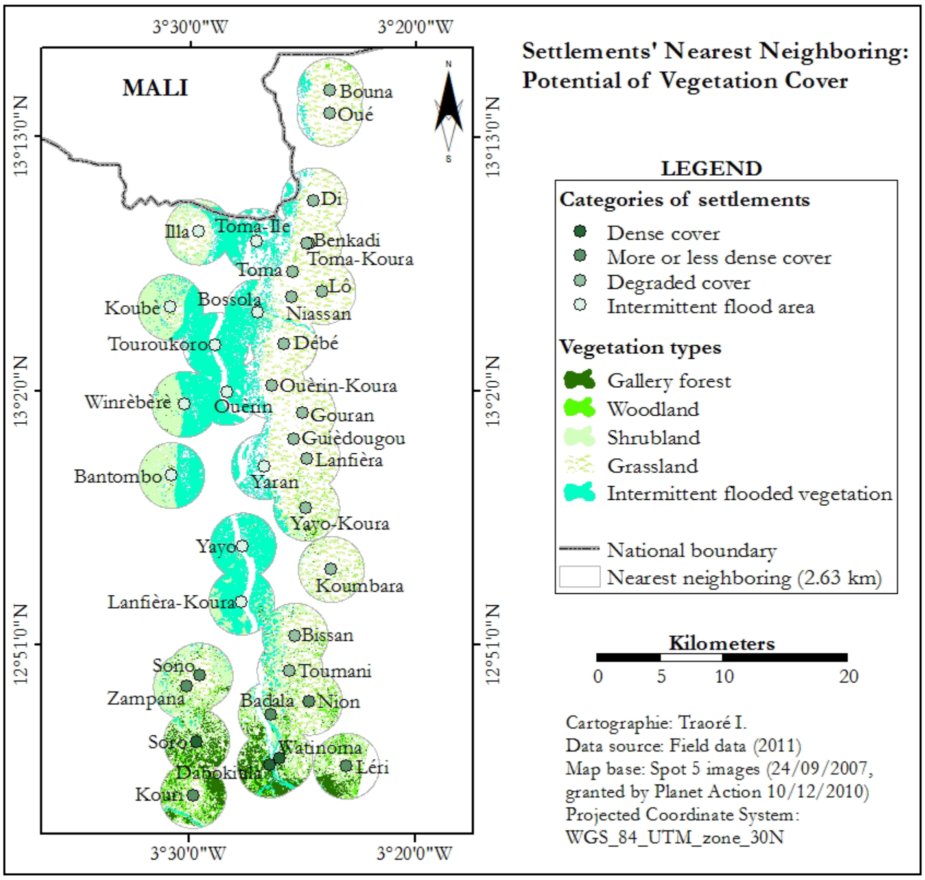


Figure 109: Plot of categories of settlements and vegetation cover data

4.3.4. Modern irrigated fields potential

Figure 110 shows outcomes of settlements categorization into three classes with respect to the presence/absence of modern irrigation parcels with their nearest environment. Results showed that 27.03% of settlements had both paddy and poly-culture parcels within their nearest neighboring areas (heterogenous environment) while 16.22% of settlement observed either paddy or poly-culture parcels (semi-natural environment) (Figure 110, Figure 111 and Figure 112). The majority of settlements (56.76%) did not have any modern irrigation field within their nearest neighboring buffer zone (natural environment) (Figure 110, Figure 111 and Figure 112). However, the majority of compounds and population (43.08 and 43.23%, respectively) were concentrated into the heterogenous environment (Figure 111).

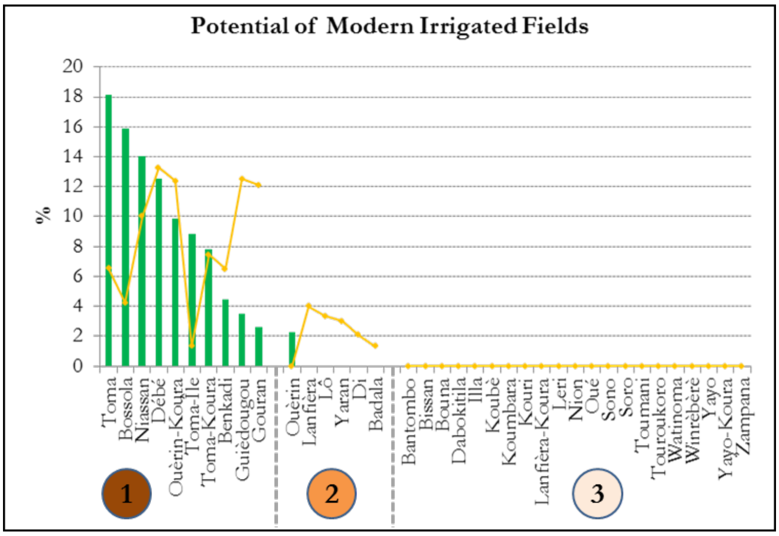


Figure 110: Settlements categorization into three classes using modern irrigation layers

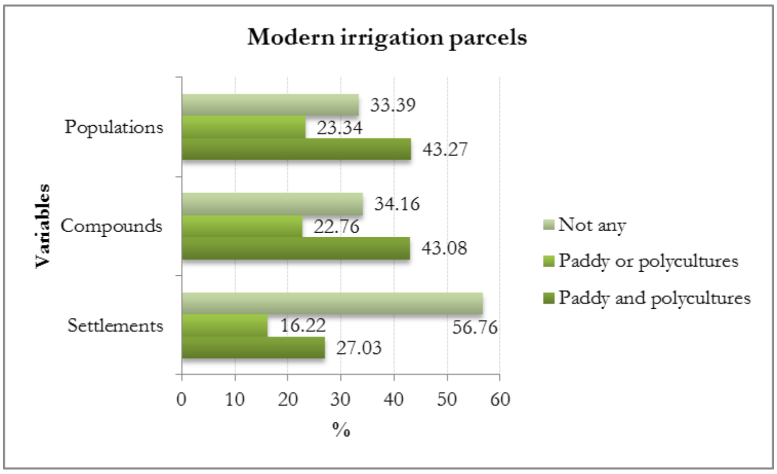


Figure 111: Proportions of settlements, compounds and populations per modern irrigation class

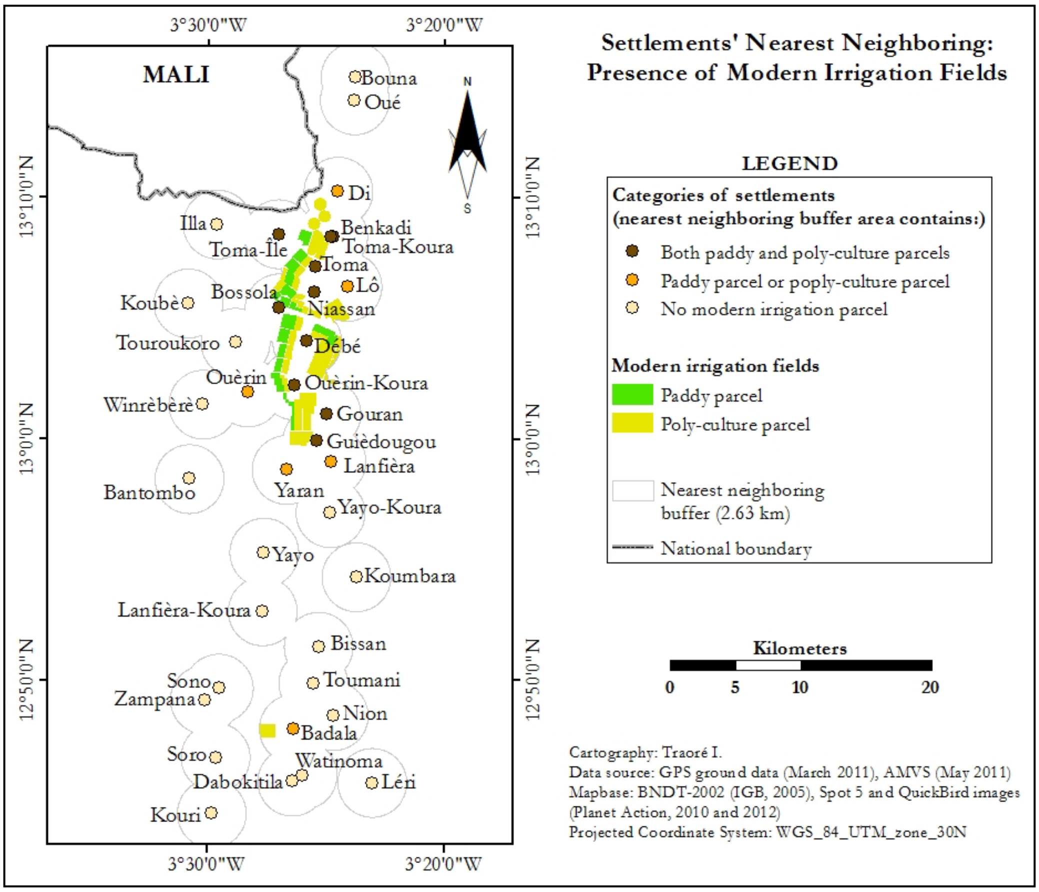


Figure 112: Plot of categories of settlements according to the potential of modern irrigation parcel

4.4. Settlements' functions

The theme on settlements functions has been investigated within a number of conceptual frameworks, including central place theory and the urban economic base (Haggett, 1968; Hudson, 1969). According to Smith (1965):

"Cities serve manifold functions in the economy and culture of a people. All cities have some functions in common; all cities have some functions that are peculiar to their site and situation, to the people whom they serve; and all cities have some functions peculiar to their development and their history; hence cities may be classified more effectively on the basis of their functions as criteria than perhaps according to any other attribute."

This is to say that one must relativize the rational for functional classification. However, in the present study the focus was put on the agricultural and the administrative functions.

4.4.1. Agricultural function

Figure 113 shows that the majority of settlements (76%) was classified into the traditional agricultural function which means that they did not receive any input of population through irrigation development projects. However, the majority of compounds (47%) and populations (45%) belonged to the semi-modern agricultural function. Figure 114 shows that except Sono, all settlemens categorized into the complete modern and semi-moder agricultural functions were located next to modern irrigation fields.

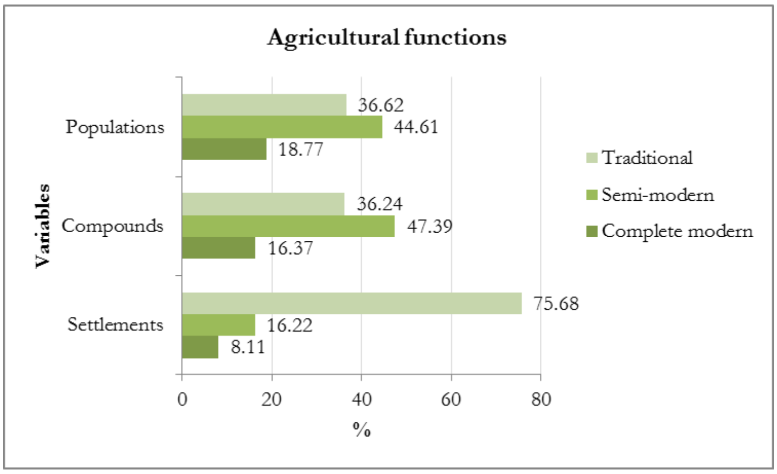


Figure 113: Proportions of settlements, compounds and populations per agricultural function

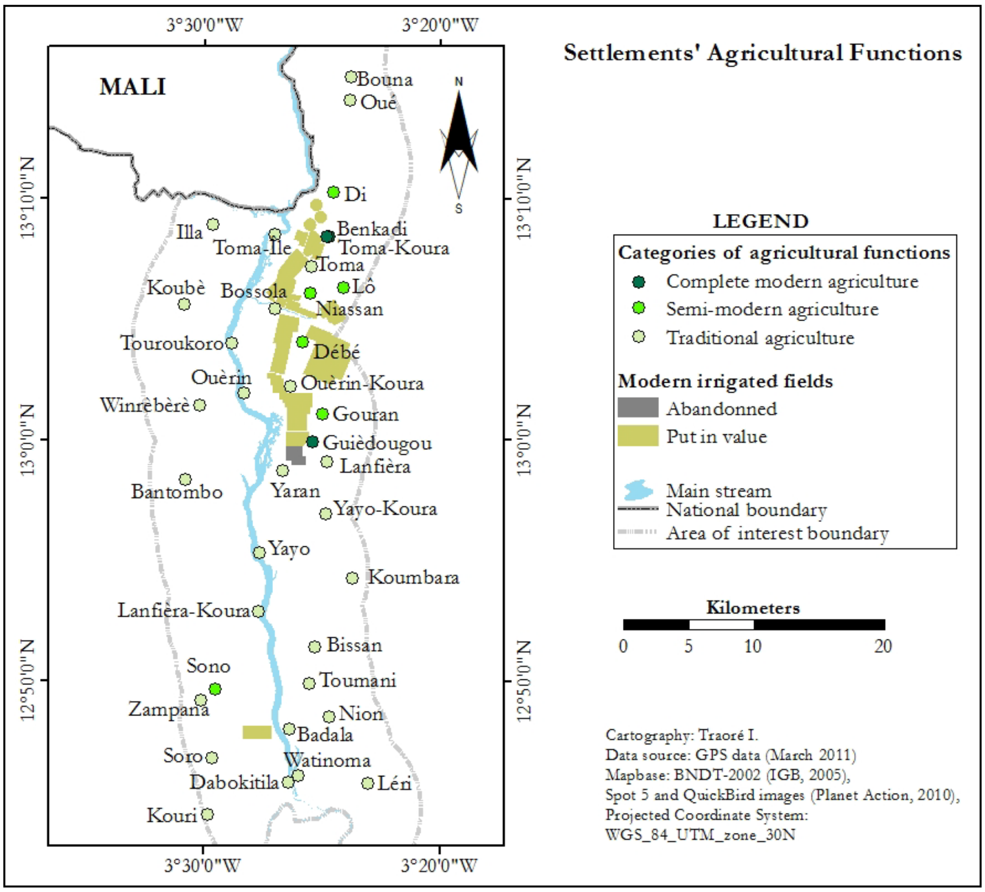


Figure 114: Spatial distribution of AOI settlements according to the agricultural function

4.4.1.1. Complete modern agriculture settlements

- Guièdougou: the first complete modern agriculture village in the Sourou Valley

Table 18 summarizes demographic data of Guièdougou in March 2011. At its creation in 1966, Guièdougou counted four quarters whose inhabitants were coming from Sourou and Yatenga provinces in majority, and from Kossi, Mouhoun and Sanguié provinces in minor number. Seventeen years later, in 1983, news farmers from Mouhoun, Sourou and Yatenga provinces have been resettled. These farmers formed Yinyinkin, the fifth quarter (Table 18). Guièdougou remains by far the most populated in the AOI and a good example of the power of migration as input of populations.

Table 18: Guièdougou demographic data, 2011

Demographic data of Guièdougou in March 2011						
Resettlement years	Quarters		Compounds		Populations	
	1st spelling	*2nd spelling*	*N*	*%*	*N*	*%*
1966	Al-Hamdililayi	St Michel II	313	45.23	3216	38.83
	Bèrèkan	St Pierre	125	18.06	1709	20.64
	Dougoutiguikin	St Michel I	33	4.77	558	6.74
	Ouahigouyakin	St Paul	76	10.98	1344	16.23
1983	Yinyinkin	Alfred Diban	145	20.95	1455	17.57
Total	**5**		**692**	**100**	**8282**	**100**

- Benkadi and Toma-Koura

The second complete agricultural village was created 19 years after Guièdougou. In 1985 farmers recruited in Sourou, Passoré and Yatenga provinces have been resettled in Benkadi. Two years later, in 1987, farmers from Sourou and Nayala provinces joined Benkadi and formed the quarter Sababougnouma.

For Toma-Koura there was not input of population. In 1985 21 families were given plots of irrigated field and as condition of attribution the beneficiaries should move from Toma-Île to resettle on highlands, thus the name Toma-Koura (meaning New-Toma). Therefore, it emerged only from colonizing a new site, without any increase of the population of the AOI.

4.4.1.2. Input of population through migration of farmers in semi-modern agriculture settlements

- Niassan and Débé

Table 19a shows demographic data of Niassan per quarter in March 201. Migrant farmers are spread into all eight quarters of Niassan. Three quarters were totally inhabited by migrant farmers: Sorokadi, Silamèkin and Niassan-Koura (meaning New-Niassan). Table 19a demonstrated that 81 and 75% of compounds and populations in Niassan were constituted by migrant farmers linked to irrigation projects.

Table 19b summarizes demographic data of Débé in March 2011. Six quarters out of eight were created by new farmers: Zone 1 to Zone 5 and Bassinéré. Débé became a quarter and took the spelling of Débé-Koro (meaning Old-Débé). The avoidance of flood resulted in the creation of Télékorokin in 1998 whose inhabitant originated from Touroukoro (Table 19b). Table 19b also demonstrated that 87 and 85% of compounds and populations were constituted by migrant farmers through irrigation projects.

Table 19: Inputs of populations through irrigation projects immigrations in Niassan and Débé

a) Demographic data of Niassan in March 2011					
				Via irrigation projects	
Setting years	Quarters	Nbr. of compounds	Population sizes	% *compounds*	% *populations*
-	Gakina	56	553	28.57	26.40
-	Gorakina	46	488	41.30	33.40
-	Soukina	93	988	47.31	45.04
-	Pèrekin	34	208	97.06	95.67
-	Kouroukan	44	288	95.45	95.49
1987	Sorokadi	108	729	100	100
1992	Silamèkin	93	540	100	100
1993	Niassan-Koura	157	1394	100	100
Total	**8**	**631**	**5188**	**81.14**	**75.00**

b) Demographic data of Débé in March 2011					
				Via irrigation projects	
Setting years	Quarters	Nbr. of compounds	Population sizes	% *compounds*	% *populations*
-	Débé-Koro	30	421	0.00	0.00
1990	Zone 1	27	410	100	100
	Zone 2	23	214	100	100
	Zone 3	73	832	100	100
	Zone 4	72	698	100	100
	Zone 5	57	587	100	100
1997	Bassinéré	45	372	100	100
1998	Télékorokin	16	130	0.00	0.00
Total	**8**	**327**	**3534**	**86.59**	**84.96**

- Situation in Lô, Di, Gouran and Sono

Figure 115 summarizes inputs of compounds and populations linked to irrigation development projects in March 2011. The input in Lô is not due to farmers' resettlement but rather the village served to build as estate for agriculture co-operatives managers of the AMVS. Concerning Di, former workers of the *Société Coopérative de Di* (SOCADI) represented the main input. Similarly, the development of agro-business perimeters led to slight inputs in Gouran and Sono.

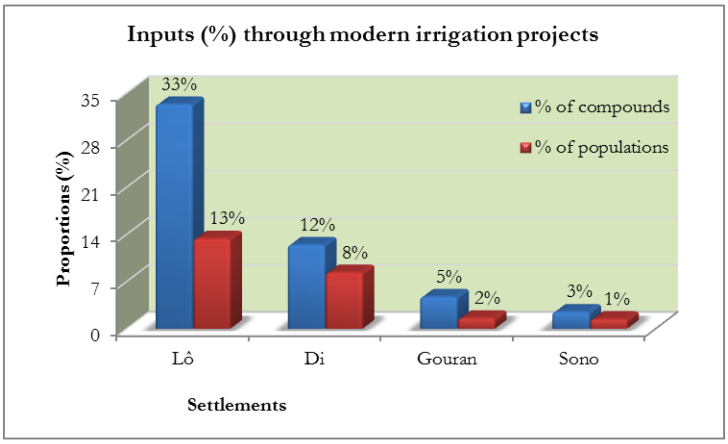


Figure 115: Proportions of immigrants compounds and populations in Lô, Di, Gouran and Sono

The presence of agricultural co-operatives' stores and the pigeon hole architecture are the main characteristics of complete and mixed agricultural settlements as Figure 116 shows in Guièdougou and Débé.

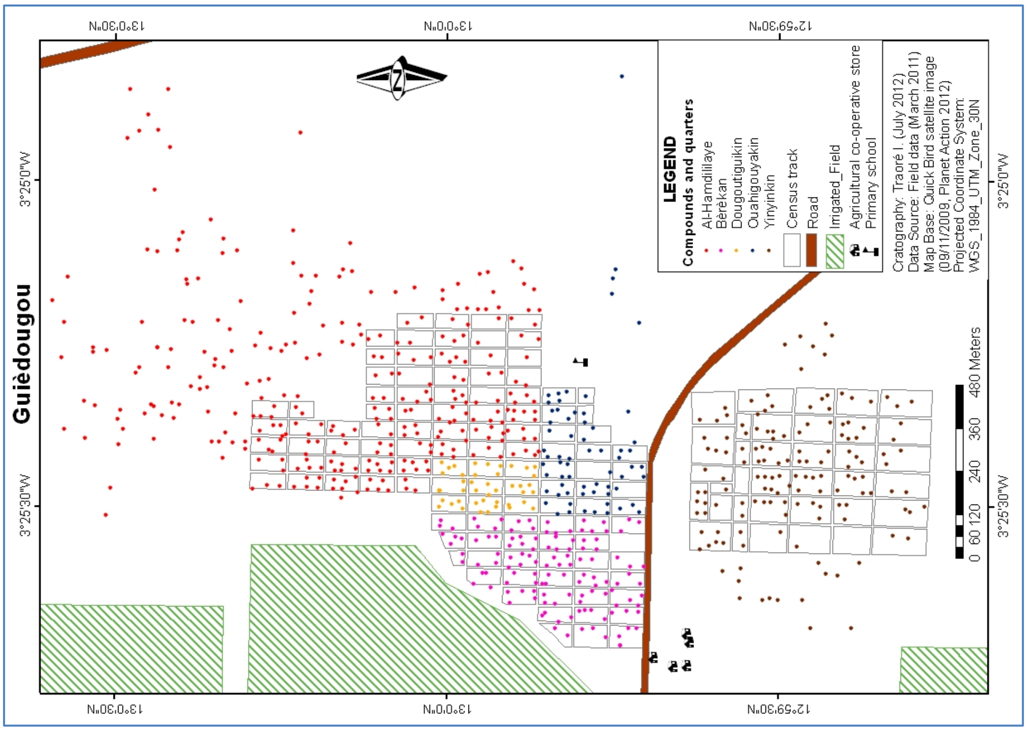


Figure 116: Architecture of complete and mixed agricultural settlemens

4.4.2. Administrative functions

Settlements were categorized into three administrative functions as indicated in Figure 117. The highest ranked function refers to the capital of rural commune which differs from the others by the presence of the town hall office. Our area of interest straddles five rural communes but only Di, Lanfièra and Sono (8.11%) were categorized into this particular function (Figure 118). The two others (Barani and Gassan) were located outside the study area. Administrative villages are autonomous geographic entities vis-à-vis others but remain under the responsibility of the capital of rural commune. In this administrative function fitted 72.97% of settlements (Figure 117). The nearest neighbor settlement distance (2.63km) (see Annex 2 for settlements connectivity matrix) was used to define hamlets. Then, all quarters found beyond 2.63km from the centroid of their administrative villages were classified as hamlets of villages and accounted for 18.92% of settlements (Figure 117).

Administrative villages concentrated 75.04% of compounds and 75.27% of populations of the area of interest. Proportions for capitals of rural communes were 23.46% and 23.22% while, those for hamlets of villages were 1.50% and 1.15%, respectively.

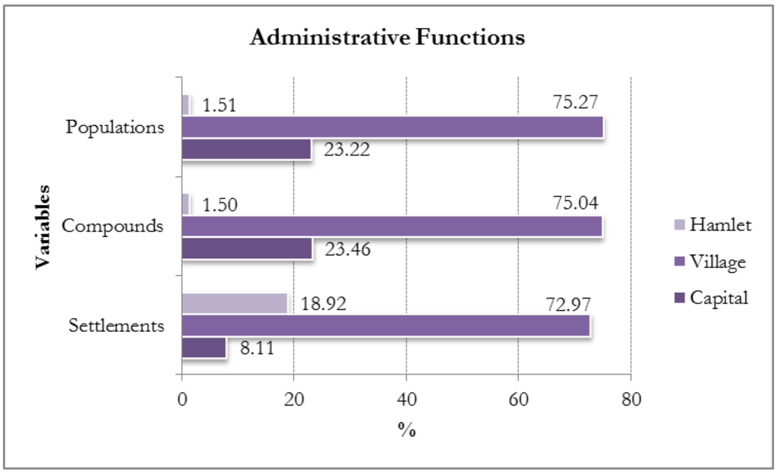


Figure 117: Proportions of settlements, compounds and populations per administrative function

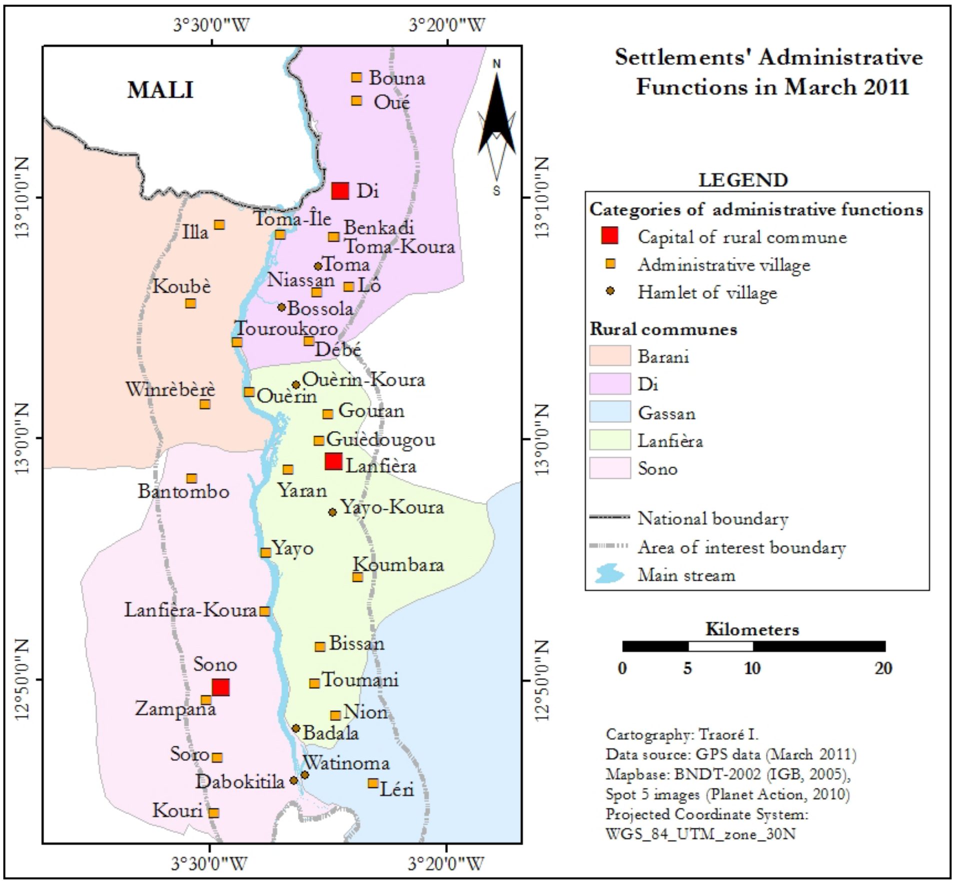


Figure 118: Settlements categorization into three administrative functions (in 2011)

4.4.2.1. *Capital of rural commune: the example of Lanfièra*

Before the event of independences in 1960s, Di and Lanfièra were capitals of cantons. The warrior bravery of Di and the religious power of Lanfièra are well known in the Sourou Valley and have drawn the attention of the colonizer. Compared to Di, considered as the first center of gravity in the area, Lanfièra is a youth settlement created in 1785. The politico-administrative leadership of Lanfièra is embedded in its religious dominance background on the other settlements in the Sourou Valley. From a two pages typed minutes of the meeting of lands border demarcation within the framework of preliminary studies of the physical development of the Sourou Valley (Circle of Tougan, Canton of Lanfièra and Di) dated on June 2nd 1958, we can conclude that Lanfièra was created later after Gouran, Yaran and Koumbara. It means that Lanfièra do not have its own lands. At their arrival in 1785, they have been resettled on the lands of Yaran.

However, Lanfièra became rapidly, under the domination of Ahmadou Baba, also known as *Karamogo Ba* (meaning big marabout), and third son of Mahamoudou Sanogo the founding father of Lanfièra (former Saaba), the radiating center of the Islam in the area (Massa, 1995). On November 24th 1896, the colonial mission Voulet and Chanoine executed *Karamogo Ba* by a high treason of one of his competitor Ouidi Sidibé of Barani. This act was totally refuted by the Colonel Archinard (former

Superior commander of the French Soudan). Thus, in 1922, for manifesting their deep regret the French named Moussa Souleymane, the elder son of Ahmadou Baba, as chief of the canton of Lanfièra. Since then and despite its status of new comer, Lanfièra became a radiating center in politico-administrative terms.

Visibly Di and Sono have imposed their supremacy on other settlements through their status of first occupants and their overwhelming population size. Sono was decreed capital in December 1997.

4.4.2.2. Administrative villages

- Example of complete modern agricultural villages

All complete modern agricultural settlements were erected in autonomous administrative villages. They do not have their own lands, thought. It could be that the legal security be the main reason. Guièdougou was officially created by decree on December 8th 1966 as an administrative village. This political willingness to give the autonomy to complete agricultural villages led to the erection of quarters into administrative village. It is the case of Benkadi and Toma-Koura which formed two quarters on the same site at their resettlement. But they became two administrative villages since 1986. The distance separating their centroids of compounds is less than ½ km. What is more, Toma-Île was duplicated into two autonomous entities with the erection of Toma-Koura as village. In the mind of the community the second is seen as a quarter of the former, thought.

- Example of immigrants village: Case from Lanfièra-Koura

Lanfièra-Koura was erected in autonomous village when its occupants, came from the Republic of Mali, decided to naturalize themselves in 1990.

4.4.2.3. Hamlets of villages

About 43% of hamlets, Ouèrin-Koura, Toma and Yayo-Koura (Table 20), were imposed sites by the government willing to resettle, Ouèrin, Toma-Île and Yayo, on highlands more accessible. Before 1986, attempts were made to displace lakeside villages and resettle them on highlands easier to reach in all season. The erection of new sites by a minority of families was materialized by the spatial duplication of these villages. The agglomeration of the human geography population on ancient sites may be synonymous of big failure. The rest of hamlets were created through migration movements from the country and even international (Republic of Mali) toward the study area (Table 20). Reasons were needs of fertile lands for traditional farming, except Bossola which was created by professional fishermen or *Bosso* in local language, thus the name Bossola.

Table 20: AOI settlements classified as hamlets of autonomous villages

Village	Hamlet	Distance (km)	Setting year	Geographic origin	% of compounds	% of populations
Débé	Bossola	3.31	1983	- Republic of Mali	1.44	1.19
Nion	Badala	3.20	1968	- Goursi (Zandoma Province)	8.65	11.71
	Watinoma	5.11	1984	- Ouahigouya (Yatenga Province)	12.84	9.96
Ouèrin	Ouèrin-Koura	3.64	1997	- Ouèrin	16.13	18.38
Sono	Dabokitila	9.11	1982	- Sono, - Bangassogo (Nayala Province)	3.32	3.16
Toma-Île	Toma	4	1986	- Toma-Île	31.03	32.05
Yayo	Yayo-Koura	5.89	1997	- Yayo	6.38	4.33

4.5. Access to socio-educative and health infrastructures

4.5.1. Access to clean water

4.5.1.1. Hydraulic works availability

- Outcome of hydraulic works inventory

A total of 382 functional hydraulic works was made an inventory in March 2011 in our AOI as indicated Table 21. Community hydraulic works included four different types: Traditional wells, modern wells, hand pumps and water fountains (Table 21 and Figure 119). Traditional wells (n = 214) are easily distinguishable by their common non-cemented interior walls, with diameters between 1 and 1.20m, and depth varying from 5 to 10m in general (Figure 119a). They are supplied by streaming, infiltration, or artesian water table. Individually dug at the compound level or collectively carry out in the village, traditional wells can be or not equipped with coping. Modern wells (n = 40) are large diameter hydraulic works destined to harness the water table. They are qualified as modern because their walls are made up of reinforced concrete ducts on all its depth (Figure 119b). Those ducts are composed of a casing and of a capture, of a basis slab and of an average 0.8-meter-high concrete coping and having an interior diameter of 1.80m in general. As a consequence, a modern well is not supplied by streaming. Hand pumps or boreholes (n = 64) are characterized by a small diameter (≥ 4 inch) and destined to harness deep water-bearings. HP are equipped of tubing and of a superstructure, and are foreseen to receive an apparatus of pumping (the drilling is then "equipped"). The pumping apparatus can be the *Volanta* model (wheel) or the *India* one (Figure 119c). Water fountains (n = 19) are service points of a mini-network of safe water canalization which is a system of safe water supply adapted to small agglomerations and consisting in general, a source of water production whose output is superior or equal to 5 m^3/h, an exhaust system, a power source, a water tower, network of pipe of adduction and of water distribution (Figure 119d). Always located on public domains, WF are equipped each by a single water-meter and managed by a water vendor who sells the water to households.

Table 21: Spatial distribution of hydraulic works per type per settlement

Functional Hydraulic Works per Type and per Settlement (March-May 2011)							
Settlement	Private tapwater connections	Water fountains	Hand pumps	Modern wells	Hydraulic works recognized by the PN-AEPA-2015	Traditional wells	Total hydraulic works
Badala	0	0	0	0	0	0	0
Bossola	0	0	0	0	0	0	0
Dabokitila	0	0	0	0	0	0	0
Lanfièra-Koura	0	0	0	0	0	0	0
Ouèrin	0	0	0	0	0	0	0
Toma-Île	0	0	0	0	0	0	0
Touroukoro	0	0	0	0	0	0	0
Toma-Koura	0	0	0	0	0	2	2
Watinoma	0	0	0	0	0	2	2
Zampana	0	0	0	0	0	2	2
Koubè	0	0	1	0	1	7	8
Nion	0	0	0	1	1	7	8
Soro	0	0	1	0	1	4	5
Toma	0	0	1	0	1	0	1
Winrèbèrè	0	0	0	1	1	2	3
Yayo	0	0	1	0	1	0	1
Kouri	0	0	2	0	2	31	33
Ouèrin-Koura	0	0	1	1	2	0	2
Toumani	0	0	1	1	2	1	3
Bantombo	0	0	2	1	3	0	3
Benkadi	0	0	2	1	3	3	6
Bouna	0	1	1	1	3	4	7
Leri	0	0	3	0	3	14	17
Yayo-Koura	0	0	3	0	3	0	3
Bissan	0	0	1	3	4	21	25
Gouran	0	0	2	2	4	13	17
Yaran	0	0	2	3	5	9	14
Débé	0	0	4	2	6	11	17
Oué	0	0	6	0	6	10	16
Illa	0	0	2	5	7	3	10
Sono	0	3	4	0	7	20	27
Koumbara	0	3	1	4	8	7	15
Lanfièra	0	3	4	2	9	5	14
Lô	9	0	0	0	9	1	10
Di	4	3	4	5	16	18	34
Guièdougou	0	5	6	5	16	7	23
Niassan	32	1	9	2	44	10	54
Total Area of Interest	**45**	**19**	**64**	**40**	**168**	**214**	**382**

Figure 119: Typology of hydraulic works found in our AOI and took into account in this thesis

- Hydraulic works availabilaity classes

Table 22 shows results for both water demand indexes (WDI) and similations of the balanced normalized water demand index (BNWDI) per settlements.

First of all, results in Table 22 revealed three differents water demand index (WDI) which were less than 300, 300-500 and greater than 500 persons per units of hyraulic work. Proportions of settlements were 32.43, 21.62, and 16.22%, respectively, for works recognized by the PN-AEPA-2015; and 75.67, 2.70 and 2.70%, respectively for all works together with traditional wells. Settlements without any works recognized by PN-AEPA-2015 accounted for 29.73% while those without any hydraulic works constituted the remaining (18.92%) of settlements.

Specifically, Table 22 shows categories of settlements depending on the number of positive/negative simulations of BNWDI. Figure 120 summarizes settlements (in Table 22) and indicates that the majority of settlements (32.43%) fell into the normal availability class (6BNWDI<0) (Table 22). However, the bulk of 45.15 and 48.01% of compounds and populations, respectively, were concentrated into the insufficient availability class (3-4 BNWDI>0). Figure 121 shows a characteristic spatial distribution of settlements per hydraulic work availability class. It depicts clearly that both the too insufficient and the not available classes were constituted only by likeside settlements. Figure 121 also points to an insufficient availability condition in very large population size settlements (Di, Guiѐdougou).

Table 22: Settlements' Hydraulic Works Availability Categories

Categories of Settlements according to the Availability of Hydraulic Works (March-May 2011)												
			Hydraulic works recognized by PN-AEPA-2015					All hydraulic works together with traditional wells				
Class	Settlement	Total population	*Number of works*	*WDI*	*BNWDI_1 300 persons*	*BNWDI_2 400 persons*	*BNWDI_3 500 persons*	*Number of works*	*WDI*	*BNWDI_1 300 persons*	*BNWDI_2 400 persons*	*BNWDI_3 500 persons*
1. Normal	Lanfièra	984	9	109.33	-5.72	-10.72	-6.54	14	70.29	-11.54	-7.03	-12.03
	Koumbara	1631	8	203.88	-2.56	-9.56	-3.92	15	108.73	-10.92	-4.74	-11.74
	Illa	1729	7	247.00	-1.24	-4.24	-2.68	10	172.90	-5.68	-3.54	-6.54
	Bissan	652	4	163.00	-1.83	-22.83	-2.37	25	26.08	-23.37	-2.70	-23.70
	Yayo-Koura	40	3	13.33	-2.87	-2.87	-2.90	3	13.33	-2.90	-2.92	-2.92
	Bantombo	579	3	193.00	-1.07	-1.07	-1.55	3	193.00	-1.55	-1.84	-1.84
	Bouna	893	3	297.67	-0.02	-4.02	-0.77	7	127.57	-4.77	-1.21	-5.21
	Ouèrin-Koura	125	2	62.50	-1.58	-1.58	-1.69	2	62.50	-1.69	-1.75	-1.75
	Toumani	458	2	229.00	-0.47	-1.47	-0.86	3	152.67	-1.86	-1.08	-2.08
	Winrèbèrè	190	1	190.00	-0.37	-2.37	-0.53	3	63.33	-2.53	-0.62	-2.62
	Toma	217	1	217.00	-0.28	-0.28	-0.46	1	217.00	-0.46	-0.57	-0.57
	Soro	289	1	289.00	-0.04	-4.04	-0.28	5	57.80	-4.28	-0.42	-4.42
2. Close to normal	Niassan	5099	12	424.92	5.00	-5.00	0.75	22	231.77	-9.25	-1.80	-11.80
	Sono	3005	7	429.29	3.02	-16.98	0.51	27	111.30	-19.49	-0.99	-20.99
	Oué	2462	6	410.33	2.21	-7.79	0.16	16	153.88	-9.85	-1.08	-11.08
	Yaran	2145	5	429.00	2.15	-6.85	0.36	14	153.21	-8.64	-0.71	-9.71
	Benkadi	1036	3	345.33	0.45	-2.55	-0.41	6	172.67	-3.41	-0.93	-3.93
	Leri	1343	3	447.67	1.48	-12.52	0.36	17	79.00	-13.64	-0.31	-14.31
	Kouri	811	2	405.50	0.70	-30.30	0.03	33	24.58	-30.97	-0.38	-31.38
	Koubè	398	1	398.00	0.33	-6.67	-0.01	8	49.75	-7.01	-0.20	-7.20
3. Insufficient	Guiѐdougou	8282	16	517.63	11.61	4.61	4.71	23	360.09	-2.30	0.56	-6.44
	Di	7967	12	663.92	14.56	-3.44	7.92	30	265.57	-10.08	3.93	-14.07
	Débé	3664	6	610.67	6.21	-4.79	3.16	17	215.53	-7.84	1.33	-9.67
	Gouran	2929	4	732.25	5.76	-7.24	3.32	17	172.29	-9.68	1.86	-11.14
	Nion	1040	1	1040.00	2.47	-4.53	1.60	8	130.00	-5.40	1.08	-5.92
	Watinoma	115	0	-	0.38	-1.62	0.29	2	57.50	-1.71	0.23	-1.77
	Zampana	150	0	-	0.50	-1.50	0.38	2	75.00	-1.63	0.30	-1.70
	Toma-Koura	357	0	-	1.19	-0.81	0.89	2	178.50	-1.11	0.71	-1.29
	Lô	197	0	-	0.66	-0.34	0.49	1	197.00	-0.51	0.39	-0.61
4. Too insufficient	Yayo	884	1	884.00	1.95	1.95	1.21	1	884.00	1.21	0.77	0.77
5. Not available	Badala	138	0	-	0.46	0.46	0.35	0	-	0.35	0.28	0.28
	Bossola	44	0	-	0.15	0.15	0.11	0	-	0.11	0.09	0.09
	Dabokitila	98	0	-	0.33	0.33	0.25	0	-	0.25	0.20	0.20
	Lanfièra-Koura	92	0	-	0.31	0.31	0.23	0	-	0.23	0.18	0.18
	Ouèrin	555	0	-	1.85	1.85	1.39	0	-	1.39	1.11	1.11
	Toma-Île	460	0	-	1.53	1.53	1.15	0	-	1.15	0.92	0.92
	Touroukoro	352	0	-	1.17	1.17	0.88	0	-	0.88	0.70	0.70
Total Area of Interest		51410	123	417.97	48.37	-165.63	5.53	337	152.55	-208.48	-20.18	-234.18

BNWDI: Balanced Normalized Water Demand Index (>0 means deficit; <0 means exces); **WDI:** Water Demand Index

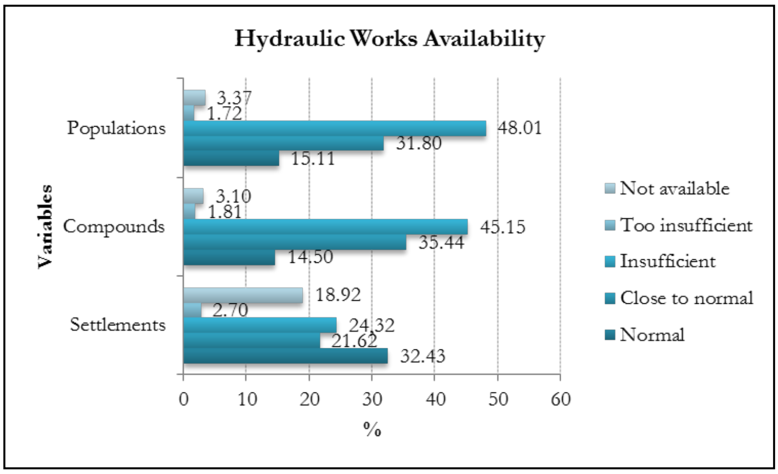


Figure 120: Proportions of AOI settlements, compounds and populations per hydraulic work availability level

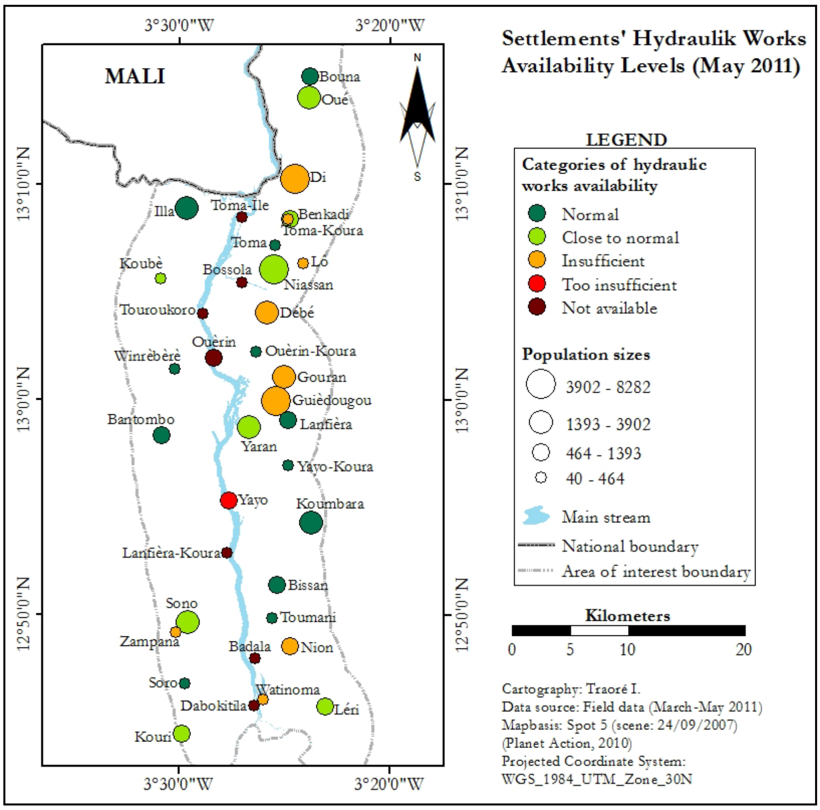


Figure 121: Spatial distribution of AOI settlements per level of water availability

4.5.1.2. Hydraulic works accessibility

- Difference and similarity among compounds within the same settlement

Table 23 shows that 62% of settlements had 100% of compounds under the same accessibility conditions. Among them, the fairly-good condition represented 43% of communities, while appalling and no access accounted for 3% and 16%. Table 23 also shows unequal accessibility to HW within the same community. On the one hand, it opposes peasants to government employees in terms of very good accessibility condition. Lô shows the highest inequality where 88% of local population had no access to CHW and were served with only one TW, and 12% representing AMVS agricultural managers dwelling in the Cité AMVS Lô are provided with private taps.

The agricultural engineers and researchers dwelling in the Cité INERA Di represented the 0.18% of very good condition in Di. In Niassan, private taps were found within every compound in the Cité AMVS Niassan accommodating agricultural managers; and also compounds located within the Catholic parish. These governmental workers and religious people accounted for 1.72%.

On the other hand, Table 23 opposes compounds within the same community in terms of their spatial distribution. Except for Lô, 27% of settlements had their populations divided into two different accessibility conditions. About 8% of settlements recorded the most pronounced states of inequality of accessibility due to compounds' geographic extension. Four different conditions were observed in Di, while Niassan and Gouran spread on three different accessibility classes, each (Table 23). These three settlements had the longest SD and SDE in the AOI.

Table 23 also shows that 57% of settlements had the majorities of their compounds falling in the fairly-good accessibility condition, thus a theoretical rate of served population of 54.86%. About 16% of settlements had the majority of their compounds located in the good condition with 40.21% of populations. With the same proportion of settlement, the no access group represented 3.31% of AOI populations. The appalling condition accounted for 11% of communities, that is to say, 1.37% of populations. None of the settlements had their majority located into the very good accessibility condition recording the lowest theoretical rate of 0.25% of AOI inhabitants.

Table 23: Settlement's Accessibility to Hydraulic Works in 2011

Proportions (%) of Compounds per Settlement per Type of Accessibility to Hydraulic Works in 2011						
Class	Settlement	Private tapwater (0m)	Within a double buffer area of a water fountain and a modern water point (500m)	Within only a buffer area of a modern water point (1000m)	Within 1000m buffer area of a Traditional well	Beyond 1000m from any hydraulic work
1. Good	Lanfièra		99.39	0.61		
	Bouna		99.22	0.78		
	Sono		90.73	9.27		
	Koumbara		87.06	12.94		
	Guièdougou		84.44	15.56		
	Di	0.18	68.39	29.58	1.85	
2. Fairly-good	Niassan	1.72	43.29	54.99		
	Bantombo			100		
	Benkadi			100		
	Bissan			100		
	Débé			100		
	Illa			100		
	Koubè			100		
	Kouri			100		
	Leri			100		
	Oué			100		
	Ouèrin-Koura			100		
	Toma			100		
	Toma-Koura			100		
	Winrèbèrè			100		
	Yaran			100		
	Yayo			100		
	Yayo-Koura			100		
	Soro			99.27	0.73	
	Gouran			98.43	0.24	1.33
	Toumani			96.72		3.28
	Nion			95.77	4.23	
3. Appalling	Zampana			29.33	70.67	
	Watinoma				100	
	Dabokitila				89.80	10.20
	Lô	12.05			87.95	
4. No access	Badala					100
	Bossola					100
	Lanfièra-Koura					100
	Ouèrin					100
	Toma-Île					100
	Touroukoro					100
Total Area of Interest		**0.25**	**40.21**	**54.86**	**1.37**	**3.31**

- Accessibility to water at the settlement level

Attributing the status showed by the majority of compounds to the settlement, Figure 122 shows proportions of settlements, compounds and populations per concerned accessibility levels. Results indicate highest proportions for the fairly-good accessibility level with 57%, 54% and 51% of AOI settlements, compounds and populations, respectively. Figure 123 shows the concentration of lakeside settlements in the no access class. Figure 123 also demonstrates that a good availability doesn't always mean good accessibility. The nearest neighboring status (see Annex 2 for settlements connectivity matrix) played an important role in Toma-Koura and Dabokitila which were influenced by the accessibility conditions of their nearest neighbors, Benkadi and Watinoma, respectively. Although with an insufficient quantitative availability Di and Guièdougou showed a good accessibility status (Figure 123).

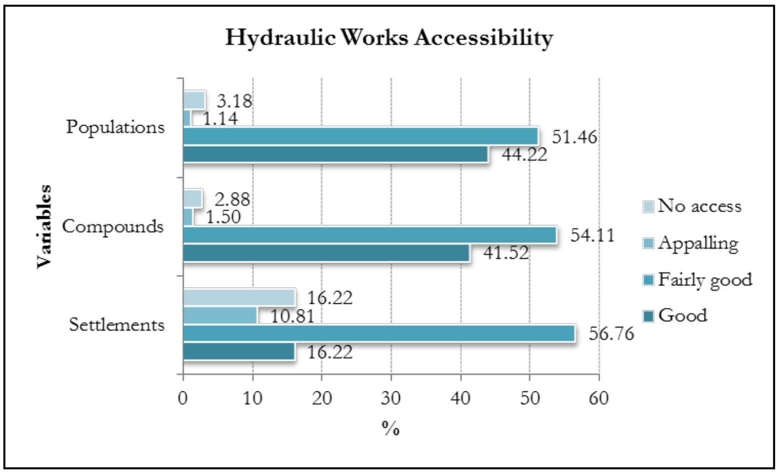


Figure 122: Proportions settlements, compounds and populations per level of accessibility to hydraulic works

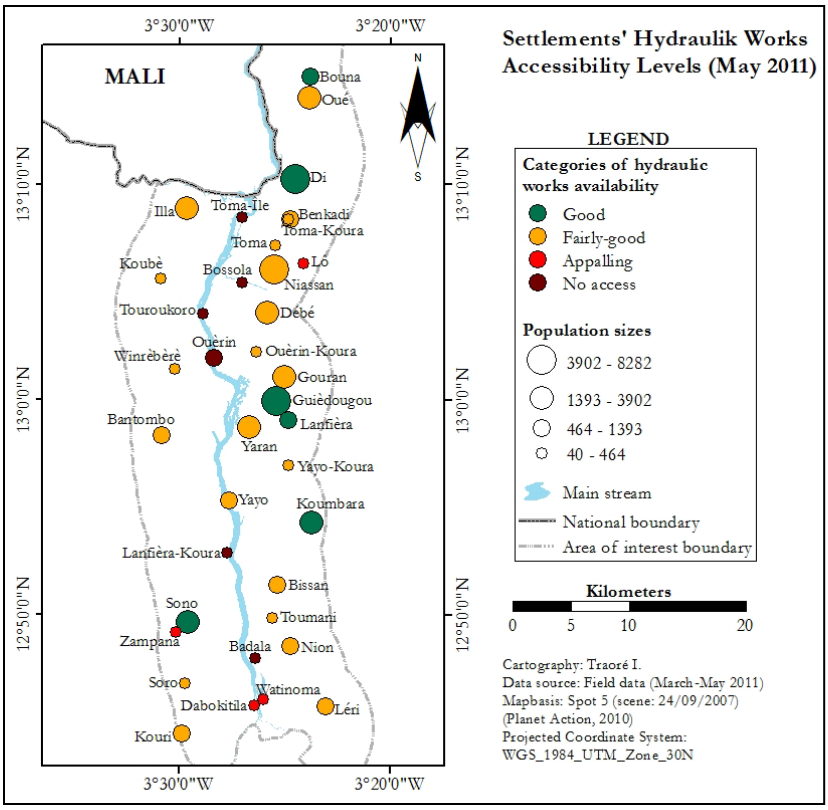


Figure 123: Spatial ditribution of AOI settlements per level of accessibility to hydraulic works

4.5.1.3. Access to familial latrines

Using a descriptive statistics cross table in SPSS (20), the goodness to fit of the spatial distribution of familial latrines' availability was tested by quarter (see Annex 1 for number of quarter per settlements) at the settlement level and by settlement within the study area (Table 24). The Chi-square (χ^2) test worked only for settlements with more than one quarter and with presence of latrine. The influence of the quarter on the distribution of latrines was more significant (p-values < 0.001) in Niassan (χ^2 = 81.52), Guièdougou (55.18), Di (32.56) and Débé (32.31) than in other settlements which observed smaller χ^2 and bigger p-values. Statistics also show that the demand for latrines strongly depended on the settlement within the study area, χ^2 was 703.27 (p-value < 0.001) (Table 24). Odds ratios indicate that the change to find a latrine was at least 12 times higher in the first class and between one and three in the second while; it was less than one for the third and fourth classes. According to Stuart (2006) an odds ratio greater than one implies a positive association between the exposure and the condition of interest; an odds ratio less than one implies a negative association. An odds ratio of one implies no association between the exposure and the condition. According to Figure 125, 2.07%, 31.31%, 49.71%, 11.36% and 5.55% of the study area compounds were concentrated into the very good, good, fairly-good, not good and no access to familial latrines classes. In terms of populations, proportions were 2.18, 33.57, 47.01, 11.76 and 5.49%, respectively.

Table 24: AOI settlements categorized into five classes of familial latrines availability rates

Familial Latrines Availability in March 2011									
			Goodness to fit			Availability			
Class	Settlement	Compounds with latrines	*Chi-Square*	*df*	*p-value*	*Rate (%)*	*Odds ratio*	*95% CI lower*	*95% CI upper*
1. Very good	Lanfièra	73	2.87	1	0.090	79.35	14.76	0.79	0.80
	Badala	7	-	-	-	77.78	12.25	0.76	0.80
2. Good	Guièdougou	445	55.18	4	0.000	64.31	3.25	0.64	0.64
	Toma-Koura	14	-	-	-	60.87	2.42	0.60	0.62
	Di	415	32.56	7	0.000	56.85	1.74	0.57	0.57
	Toumani	27	13.52	4	0.009	55.10	1.51	0.55	0.56
	Lô	15	10.07	3	0.018	50.00	1.00	0.49	0.51
3. Fairly-good	Bouna	24	6.85	4	0.144	46.15	0.73	0.46	0.47
	Toma	8	-	-	-	44.44	0.64	0.43	0.46
	Gouran	105	24.83	7	0.001	41.50	0.50	0.41	0.42
	Niassan	236	81.52	7	0.000	37.40	0.36	0.37	0.37
	Leri	50	7.22	4	0.125	34.48	0.28	0.34	0.35
	Oué	74	7.93	7	0.339	32.74	0.24	0.33	0.33
	Sono	103	21.09	8	0.007	32.19	0.23	0.32	0.32
	Illa	50	6.26	6	0.395	29.41	0.17	0.29	0.30
	Débé	99	32.31	7	0.000	28.86	0.16	0.29	0.29
	Yaran	56	9.29	4	0.054	28.72	0.16	0.29	0.29
	Bissan	19	2.73	3	0.436	28.36	0.16	0.28	0.29
4. Not good	Koumbara	33	1.86	7	0.967	24.44	0.10	0.24	0.25
	Kouri	21	1.79	4	0.775	21.88	0.08	0.22	0.22
	Koubè	5	0.67	1	0.414	16.67	0.04	0.16	0.17
	Bantombo	9	0.59	1	0.441	15.79	0.04	0.16	0.16
	Benkadi	12	5.56	1	0.062	14.63	0.03	0.14	0.15
	Nion	11	13.89	8	0.085	11.58	0.02	0.11	0.12
	Ouèrin-Koura	1	-	-	-	10.00	0.01	0.09	0.11
	Zampana	1	0.41	1	0.523	5.56	0.00	0.05	0.06
	Soro	1	2.41	3	0.491	3.33	0.00	0.03	0.03
5. No access	Bossola	0	-	-	-	0.00	-	0.00	0.00
	Yayo-Koura	0	-	-	-	0.00	-	0.00	0.00
	Lanfièra-Koura	0	-	-	-	0.00	-	0.00	0.00
	Dabokitila	0	-	-	-	0.00	-	0.00	0.00
	Watinoma	0	-	-	-	0.00	-	0.00	0.00
	Winrèbèrè	0	-	-	-	0.00	-	0.00	0.00
	Touroukoro	0	-	-	-	0.00	-	0.00	0.00
	Toma-Île	0	-	-	-	0.00	-	0.00	0.00
	Ouèrin	0	-	-	-	0.00	-	0.00	0.00
	Yayo	0	-	-	-	0.00	-	0.00	0.00
Total Area of Interest		**1914**	**703.27**	**36**	**0.000**	**39.32**	**0.42**	**0.39**	**0.39**

df: degree of freedom; **CI:** Confidence Interval

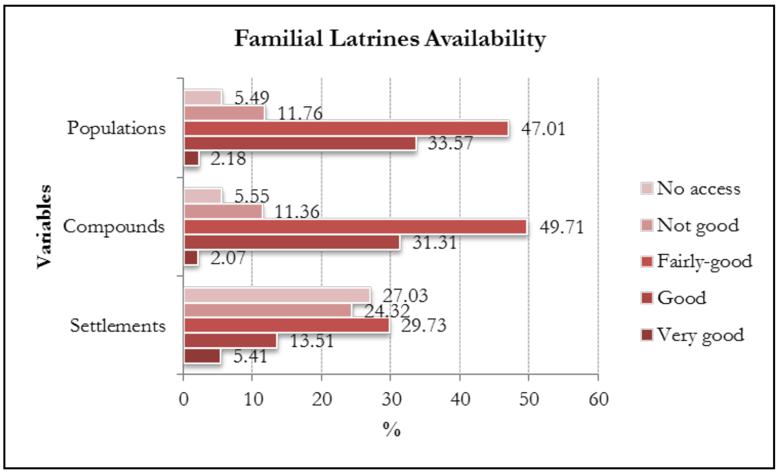


Figure 124: Proportions settlements, compounds and populations per

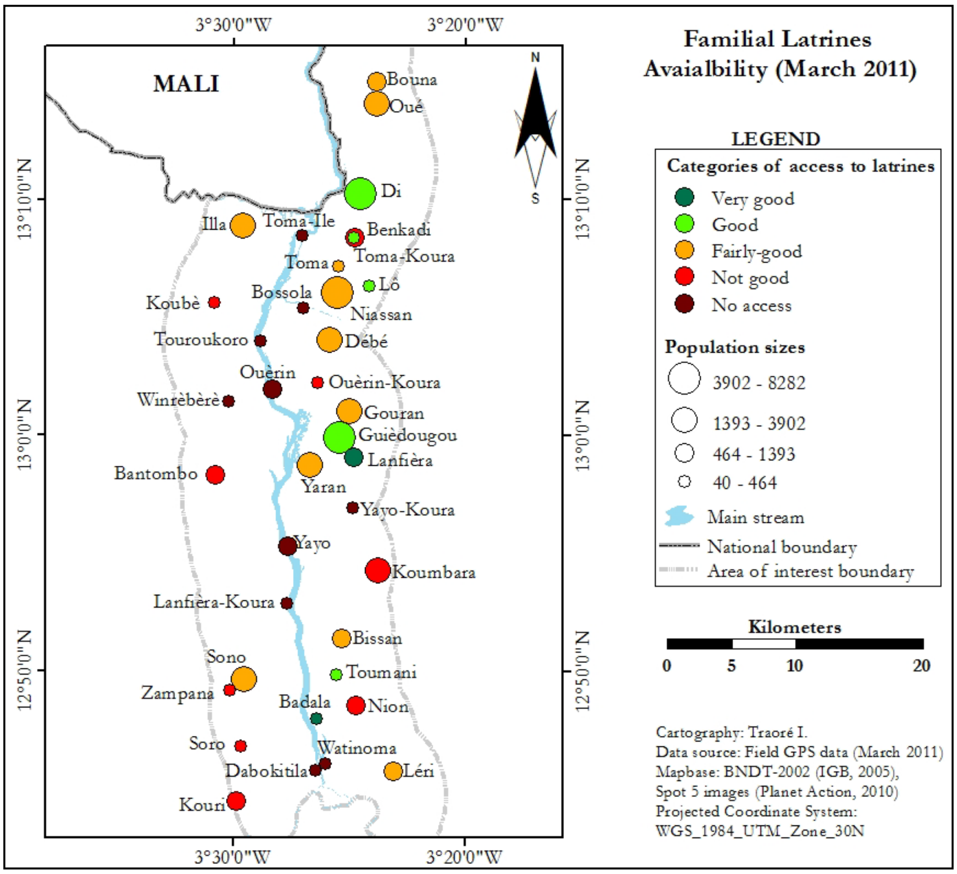


Figure 125: Spatial ditribution of AOI settlements per familial latrines availability class

4.5.1.4. *Access to modern health care services*

- Availability in time and space

The totality of settlements within the study area was covered by nine sanitary areas, each formed by a peripheral modern health care service, CSPS (*Centre de Santé et de Promotion Sociale*) as summarized in Table 25. Seven out of the nine CSPS were located within the area of interest which concentrated about 55% of villages of the sanitary areas and 70% of served populations. Population data in Table 25 are projected data based on the general population census of 2006. This explains why the population of the area of interest slightly superior to that we get from the field compounds survey: 52531 vs. 51540 (a difference of 991 persons). Table 25 also raises the link between the administrative function played by the settlement and the supply of CSPS. None of hamlets had a CSPS while, 100% of capitals of rural communities were supplied with CSPS.

Table 25: Modern health care provision in time and space

Modern Health Care Infrastructures Provision in Time and Space								
Modern healthcare center (CSPS)			Administrative villages of the sanitary area			Served populations (Projections of CSPS for 2011)		
N°	*Location*	*Opening year*	*All villages*	*Area of interest*	*% Area of interest*	*All populations*	*Area of interest*	*% Area of interest*
1	Di	1960	5	4	80	9640	9436	97.88
2	Lanfièra	1960	6	4	66.67	13418	12258	91.35
3	Koumbara	1984	7	4	57.14	7606	5484	72.1
4	Niassan	1991	3	2	66.67	9246	7829	84.67
5	Wèrèbèrè	1998	7	3	42.86	6783	2836	41.81
6	Sono	2003	11	7	63.64	9003	4615	51.26
7	Moara Grand	2005	7	1	14.29	7852	1379	17.56
8	Oué	2007	5	2	40	5811	3630	62.47
9	Débé	2008	4	3	75	5315	5064	95.28
TOTAL	**9**	**-**	**55**	**30**	**54.55**	**74674**	**52531**	**70.35**

- Accessibility to the closest CSPS

Table 26 shows the distribution of compounds per settlements depending on the distance to the closest CSPS. The good accessibility accounted for 48.06% of settlements had the majority of their compounds located within the 0 – 4 km buffer from a CSPS (Figure 126 and Figure 127). The more or less good accessibility to health services, grouped 43.24% of settlements with majority of compounds concentrated within the 5 – 9 km distance from a CSPS (Table 26 and Figure 127). Only 8.10% of settlements fell into the appalling accessibility to health services (Table 26 and Figure 126 and Figure 127). In terms of populations, the good accessibility class concentrated 80.20% while the more or less good and appalling accounted for 13.80 and 6% of the total populations (Figure 126).

(See Annex 2 for settlements connectivity matrix)

Table 26: Settlements accessibility to the closest CSPS

Proportions (%) of Compounds per Buffer Distances to the Closest CSPS per Category of Settlements						
Class	**Settlement**	**0 – 4 km**	**5 – 9 km**	**10 km and more**	**CSPS of reference**	**Closest CSPS**
1. Good	Benkadi	100			Di	
	Bossola	100			Débé	Niassan
	Bouna	100			Oué	
	Débé	100			Débé	
	Di	100			Di	
	Guièdougou	100			Lanfièra	
	Koumbara	100			Koumbara	
	Lanfièra	100			Lanfièra	
	Lô	100			Niassan	
	Niassan	100			Niassan	
	Oué	100			Oué	
	Ouèrin-Koura	100			Débé	
	Sono	100			Sono	
	Toma	100			Di	Niassan
	Toma-Koura	100			Di	
	Yaran	100			Lanfièra	
	Zampana	100			Sono	
	Gouran	99.60	0.40		Lanfièra	
2. More or less good	Badala		100		Koumbara	Sono
	Bissan		100		Koumbara	
	Dabokitila		100		Sono	
	Koubè		100		Wèrèbèrè	
	Lanfièra-Koura		100		Sono	
	Leri		100		Moara Grand	
	Nion		100		Koumbara	Moara Grand
	Ouèrin		100		Débé	
	Toma-Île		100		Di	
	Toumani		100		Koumbara	Sono
	Touroukoro		100		Débé	
	Watinoma		100		Koumbara	Sono
	Winrèbèrè		100		Wèrèbèrè	
	Yayo		100		Koumbara	
	Soro	3.30	96.70		Sono	
	Yayo-Koura		71.43	28.57	Koumbara	
3. Appalling	Bantombo			100	Sono	Lanfièra
	Illa		5.30	94.70	Wèrèbèrè	Di
	Kouri		42.71	57.29	Sono	
Total Area of Interest		**79.20**	**15.11**	**5.69**		

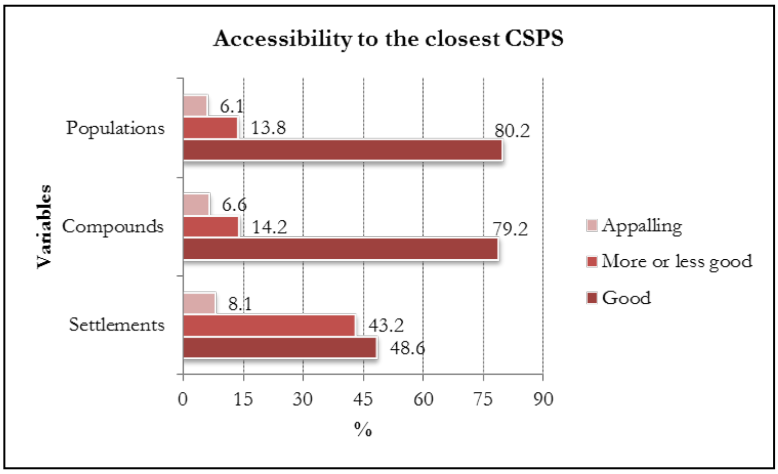


Figure 126: Proportions settlements, compounds and populations per class of accessibility to closest CSPS

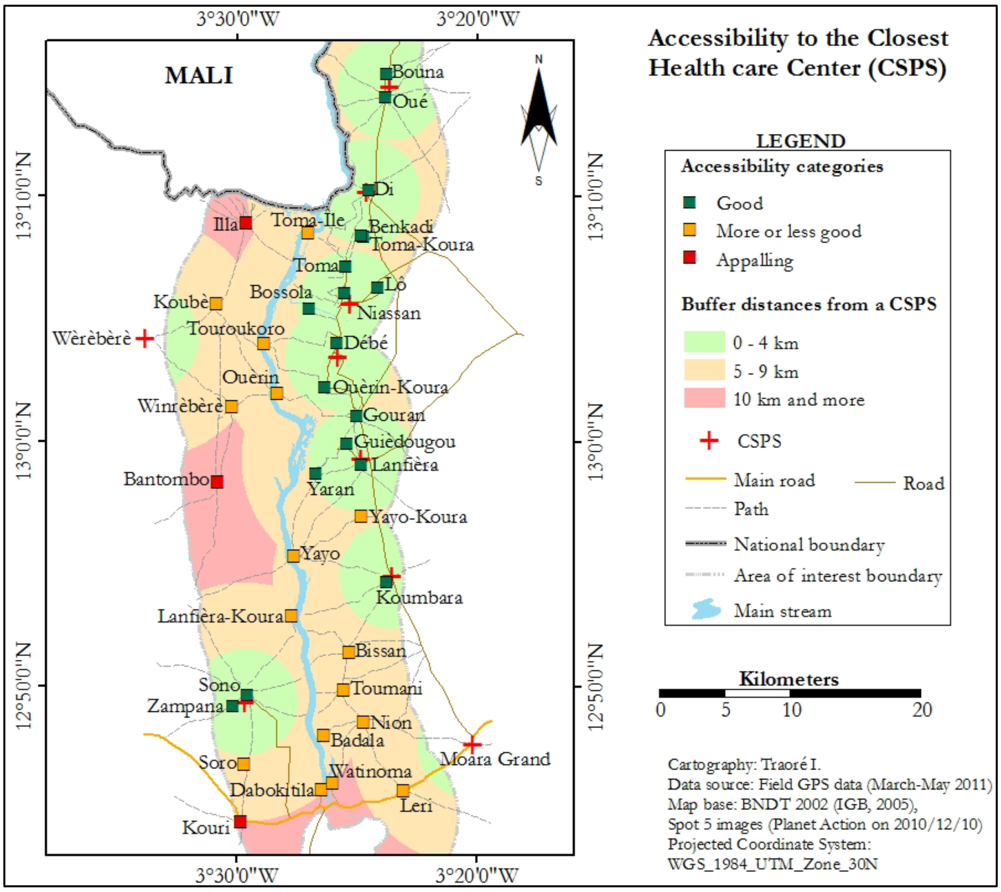


Figure 127: Spatial ditribution of settlements per category of accessibility to a health center

4.5.1.5. Access to Educational infrastructures

- Availability in time and space in the AOI

Table 27 summarizes data on the availability of school per level in our area of interest. Out of 26 schools found in 2011, 88% were primary schools while secondary schools constituted 12%. Table 27 also shows that 80% of primary schools, opened until 1996, was normalized (meaning 6 classrooms: Year 1 to Year 6) while only 20% was not normalized (≤ 3 classrooms). Conversely, 100% of primary schools opened after 1996 was not normalized. In general, only 35% of primary school was normalized, against 22% in normalization process and 43% not normalized. Table 27 points out the influence of the administrative function played by the settlement on the availability of schools. Secondary schools were found only in the three capitals of rural communes. On the other hand, primary schools were found in 51% of settlements (including 100, 59 and 0% of capitals of rural communes, administrative villages and hamlets of villages).

Two different primary schools “A” and “B” were found in 21% of settlements with primary education buildings. Schools “B” were located within settlements categorized into the very large population size class. Table 27, therefore, pointed out the relationship between the number of primary schools within a settlement and its population size. About 57, 39 and 4% of primary schools observed more boys than girls, more girls than boys and as many boys as girls, respectively. While all secondary schools showed more boys than girls. In general, boys outnumbered girls in 62% of schools. Fifty attendants per classroom is the standard in the country. Therefore, Table 27 indicates that 78 and 67% of primary and secondary schools, respectively, showed more than 50 attendants per classroom (Figure 128). Overally, this plethoric number of attendants per classroom concerned 77% of schools in the study area. The ratio number of attendants/classroom raises an insufficiency of classrooms. Without Leri, data in Table 27 showed that 89% of primary education attendants and 85% of secondary education pupils were interviewed to gather additional data; that is to say about 89% of all school attendants. Participation rates below 100% in other schools are explained by absences from classes.

Table 27: Data on primary and secondary schools in our AOI

Statistics data of schools within the area of interest (school year 2010-2011)									
Level	**Locality or school's name**	**Opening Year**	**Room**	**Size**	**% of boys**	**% of girls**	**Sex ratio**	**Size/ room**	**% of pupils interviewed**
Primary	Di "A"	1957	6	694	49.71	50.29	0.99	115.67	96.69
	Lanfièra	1957	6	242	54.55	45.45	1.20	40.33	93.39
	Sono	1982	6	366	44.26	55.74	0.79	61.00	80.33
	Guièdougou "A"	1985	6	793	55.61	44.39	1.25	132.17	94.07
	Koumbara	1986	3	206	43.69	56.31	0.78	68.67	94.66
	Gouran "A"	1987	6	478	44.77	55.23	0.81	79.67	52.72
	Niassan "A"	1989	6	633	52.13	47.87	1.09	105.50	99.84
	Oué	1992	3	334	48.80	51.20	0.95	111.33	89.52
	Benkadi	1993	6	344	49.42	50.58	0.98	57.33	94.19
	Débé	1996	6	643	51.63	48.37	1.07	107.17	76.52
	Leri	1998	5	194	51.03	48.97	1.04	38.80	0.00
	Bantombo	1999	3	99	64.65	35.35	1.83	33.00	100
	Illa	1999	3	185	66.49	33.51	1.98	61.67	97.30
	Koubè	1999	3	80	50.00	50.00	1.00	26.67	93.75
	Yaran	1999	4	173	54.72	45.28	1.21	43.25	99.42
	Kouri	2000	4	213	44.13	55.87	0.79	53.25	93.43
	Di "B"	2005	5	477	51.57	48.43	1.06	95.40	96.23
	Niassan "B"	2005	5	323	49.23	50.77	0.97	64.60	99.38
	Guièdougou "B"	2007	3	296	51.35	48.65	1.06	98.67	72.30
	Nion	2007	2	113	48.67	51.33	0.95	56.50	100
	Bissan	2009	1	66	54.55	45.45	1.20	66.00	100
	Bouna	2009	1	85	55.29	44.71	1.24	85.00	97.65
	Gouran "B"	2010	1	67	53.73	46.27	1.16	67.00	95.52
Total 1	***23***	**-**	***94***	***7104***	***50.64***	***49.36***	***1.04***	***75.57***	***86.94***
Secondary	Lanfièra	2004	6	495	56.16	43.84	1.28	82.50	86.87
	Di	2006	5	519	65.32	34.68	1.88	103.80	79.77
	Sono	2007	4	140	67.14	32.86	2.04	35.00	96.43
Total 2	***3***	**-**	***15***	***1154***	***61.61***	***38.39***	***1.60***	***76.93***	***84.84***
TOTAL (1+2)	**26**	**-**	**109**	**8258**	**52.48**	**47.52**	**1.10**	**75.76**	**86.64**

Figure 128: Primary school children

- School attendants' age and gender distribution

Figure 129 shows the age and gender distribution of attendants interviewed according to the educational level. Primary school children age varied between 5 and 16 years old with peaks located at 8 and 9 years old for girls (17.23%) and boys (18.05%), respectively. The age of secondary school attendants varied from 12 to 23 years old with peaks appearing at 15 and 16 years old for females (20.65%) and males (24.57%), respectively. The intermediate age between primary and secondary schools was located at 13 years old (Figure 129).

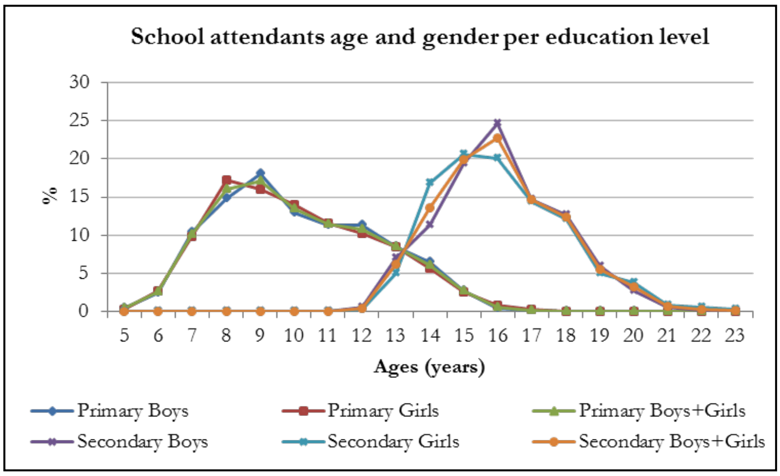


Figure 129: School attendants' age and gender distribution per educational level

- Decreasing trend of numbers of attendants year after year

Figure 130 plots numbers of classrooms and sizes of school attendants per gender and according to the educational level. There was a strong linear correlation between number of classrooms and size of attendants ($r = 0.80$, $r^2 = 63\%$, p-value <0.001). This could explain the decreasing trend of attendants from lower level to higher educational levels. Figure 130 shows that, with more than 1400 children for the first two years of primary education, sizes were below 90 attendants for the two last plots the number of school attendants per educational level. Figure 130 also raises failure issues from lower to upper grades for both primary and secondary educations. This problem affects more girls than boys, because the former overtake the latter at the first year of the enrolment to school (CP1), but proportions change from the second year of primary education and remained unchanged.

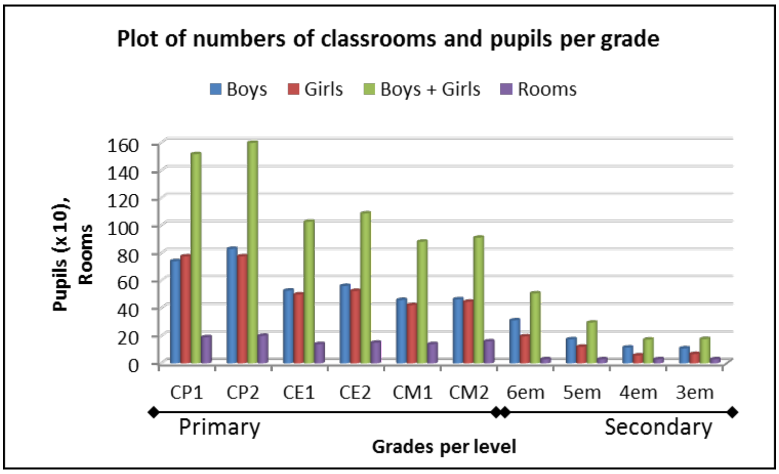


Figure 130: Decreasing trend of schools attendants with increase in grades

CP: Cours Préparatoire; **CE:** Cours Elémentaire ; **CM:** Cours Moyen

- Geographic origin of school attendants interviewed

Three geographic origins were distinguished as shown in Table 28. 54.54% of primary education presented a spatial homogenous sample of attendants characterized by a unique geographic origin. In this case 100% of primary schools children were from the village within which the school building is located (within-village). 31.82% of primary schools showed a spatial heterogeneous sample of attendants characterized by the presence of attendants from one or more neighbouring settlements within our area of interest (AOI-village). However and except for Gouran "A", more than 79% of children belong to the within-village group. The rest (13.64%) of primary schools observed attendants from outside frontiers of our area of interest (outside-AOI).

The distribution of geographic origins of secondary school attendants showed a total different pattern. The majority of attendants fell into the AOI-village group, and even the proportion from outside-AOI was higher than that from within-village at Sono secondary schools.

According to Table 28, 99.5 % of primary schools children interviewed was from our AOI. Therefore, the spatial scope of primary education infrastructures was too local and limited to the village scale. At the opposite, the spatial scope of secondary education infrastructures was wider and covered the AOI scale.

Table 28: Proportions of school attendants according to three types of geographic origins

Geographic origins of pupils per school and educational level					
Level	Name	Within-village	AOI-village	Outside-AOI	Sum
Primary	Bantombo	100	0.00	0.00	100
	Bissan	100	0.00	0.00	100
	Bouna	100	0.00	0.00	100
	Di "B"	100	0.00	0.00	100
	Gouran "B"	100	0.00	0.00	100
	Guiėdougou "A"	100	0.00	0.00	100
	Guiėdougou "B"	100	0.00	0.00	100
	Illa	100	0.00	0.00	100
	Koubè	100	0.00	0.00	100
	Koumbara	100	0.00	0.00	100
	Niassan "B"	100	0.00	0.00	100
	Yaran	100	0.00	0.00	100
	Di "A"	99.85	0.15	0.00	100
	Débé	98.00	2.00	0.00	100
	Sono	94.90	5.10	0.00	100
	Nion	87.60	12.40	0.00	100
	Oué	82.61	17.39	0.00	100
	Benkadi	79.01	20.99	0.00	100
	Gouran "A"	50.79	49.21	0.00	100
	Niassan "A"	98.74	0.79	0.47	100
	Lanfièra	84.10	13.70	2.20	100
	Kouri	85.15	2.97	11.88	100
Total 1	***22***	***94.24***	***5.26***	***0.50***	***100***
Secondary	Di	36.23	47.83	15.94	100
	Sono	28.90	35.56	35.56	100
	Lanfièra	13.80	73.20	13.49	100
Total 2	***3***	***25.36***	***57.26***	***17.38***	***100***
TOTAL (1+2)	**25**	**84.81**	**12.38**	**2.81**	**100**

- Details on the geographic origin for the AOI-village group

Table 29a shows details on geographic origins of primary school children of the AOI-village group. It demonstrates that despite the two different primary schools in Guiėdougou, this village represented 49.21% and 13.30% of children of Gouran “A” and Lanfièra Schools. We can therefore conclude that the pressure of Guiėdougou on Gouran lead to the erection of Gouran “B”. Table 29b shows details on geographic origins of secondary school attendants of the AOI-village group. It points out the overwhelming proportion of attendants from Guiėdougou representing 42% of attendants of Lanfièra Secondary School while Niassan accounted for 25.60% of participants of the Di Secondary School.

Table 29: Origins of school attendants of the AOI-village group

a) Geographic origins of primary school pupils of AOI-village group

School	Badala	Benkadi	Bouna	Débé	Di	Gouran	Guièdougou	Kouri	Lanfièra	Lô	Niassan	Nion	Oué	Ouèrin-Koura	Sono	Soro	Toma-Koura	Zampana
Benkadi	0	79.01	0	0.31	13.89	0	0	0	0	0	0	0	0	0	0	0	6.79	0
Débé	0	0	0	98.00	0	0	0	0	0	0	0	0	0	2.00	0	0	0	0
Di "A"	0	0	0	0	99.85	0	0	0	0	0	0	0	0.15	0	0	0	0	0
Gouran "A"	0	0	0	0	0	50.79	49.21	0	0	0	0	0	0	0	0	0	0	0
Kouri	0	0	0	0	0	0	0	85.15	0	0	0	0	0	0	0	2.97	0	0
Lanfièra	0	0	0	0	0	0	13.30	0	84.10	0	0.40	0	0	0	0	0	0	0
Niassan "A"	0	0	0	0	0	0	0	0	0	0.79	98.74	0	0	0	0	0	0	0
Nion	12.39	0	0	0	0	0	0	0	0	0	0	87.61	0	0	0	0	0	0
Oué	0	0	17.39	0	0	0	0	0	0	0	0	0	82.61	0	0	0	0	0
Sono	0	0	0	0	0	0	0	0	0	0	0	0	0	0	94.90	3.74	0	1.36

b) Geographic origins of secondary school pupils of AOI-village group

School	Bantombo	Benkadi	Bouna	Débé	Di	Gouran	Guièdougou	Illa	Koubè	Koumbara	Kouri	Lanfièra	Lô	Niassan	Oué	Ouèrin-Koura	Sono	Soro	Toma-Île	Toma-Koura	Yaran	Yayo-Koura	Zampana
Di	0	6.76	1.21	5.07	36.23	0	0.24	2.90	0.72	0	0	0	1.21	25.60	2.90	0	0	0	0.24	0.97	0	0	0
Lanfièra	0.23	0.23	0	8.39	0.93	8.16	42.00	0.70	1.17	2.56	0	13.75	0	2.56	0	0.23	0	0.47	0	0	5.36	0.23	0
Sono	17.78	0	0	0	0	0	0.74	0	0	0	11.85	0	0	0	0	0	28.89	4.44	0	0	0	0	0.74

- Communities representativeness through school attendants

Table 30 shows proportions obtained by dividing the number of pupils interviewed by the total number of populations of the settlement multiplied by 100. Proportions varied between 0.22% (in Toma-Île) and 27.51% (in Benkadi). The first class, defined as high school attendance, grouped settlements (62.16%) with at least 5% of the total population being school attendants (Table 30 and Figure 131). The second class concerned settlements (10.81%) with pupils but representing less than 5% of the population, and qualified as low school attendance (Table 30 and Figure 131). The third and last class categorized the rest (27.03%) of settlements found without any school attendant during the school year 2010-2011 (Table 30 and Figure 131).

Leri was classified into the first class because it has a primary school and also because all settlements having primary schools observed at least 5% of the population enrolled in school attendance. Figure 132 indicates that 18.91% of settlements were found without school buildings but had school attendants. Among them, 42.86% observed a high school attendance. Therefore, the school attendance expressed the access to school better than the simple presence/absence of school within the settlement. This explains the reason why we choose the school attendance rate as criterion for categorizing settlements into the three classes of access to educational infrastructures.

Table 30: Proportions of population enrolled in school attendance

Proportions of populations enrolled in school attendance (School year 2010-2011)				
Class	Settlement	Total population	School attendants	% school attendants
1. High attendance	Benkadi	1036	285	27.51
	Lanfièra	984	249	25.30
	Kouri	811	185	22.81
	Bantombo	579	124	21.42
	Koubé	398	83	20.85
	Niassan	5188	1063	20.49
	Di	7981	1328	16.64
	Bouna	893	140	15.68
	Guièdougou	8282	1295	15.64
	Débé	3664	540	14.74
	Koumbara	1631	206	12.63
	Illa	1729	195	11.28
	Sono	3005	318	10.58
	Oué	2462	260	10.56
	Badala	138	14	10.14
	Bissan	652	66	10.12
	Nion	1040	99	9.52
	Yaran	2145	195	9.09
	Ouérin-Koura	125	11	8.80
	Soro	289	25	8.65
	Gouran	2929	227	7.75
	Toma-Koura	357	26	7.28
2. Low attendance	Lô	224	10	4.46
	Zampana	150	5	3.33
	Yayo-Koura	40	1	2.50
	Toma-Île	460	1	0.22
3. No school attendants	Bossola	44	0	0.00
	Dabokitila	98	0	0.00
	Lanfièra-Koura	92	0	0.00
	Ouèrin	555	0	0.00
	Toma	217	0	0.00
	Toumani	458	0	0.00
	Touroukoro	352	0	0.00
	Watinoma	115	0	0.00
	Winrèbèrè	190	0	0.00
	Yayo	884	0	0.00

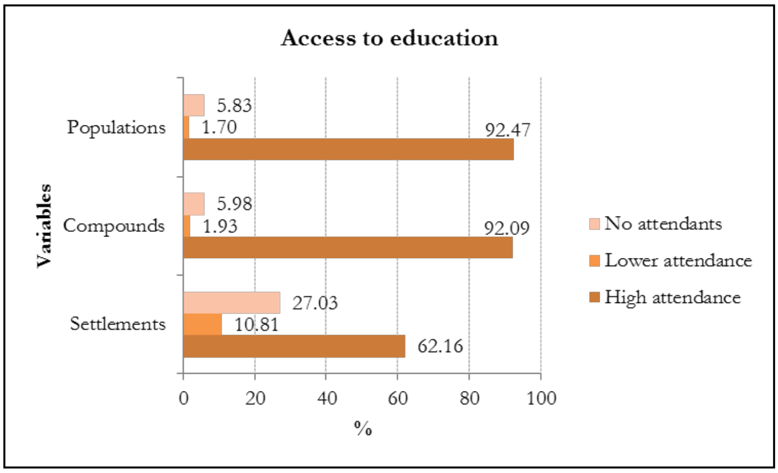


Figure 131: Proportions of settlements, compounds and populations per class of access to education

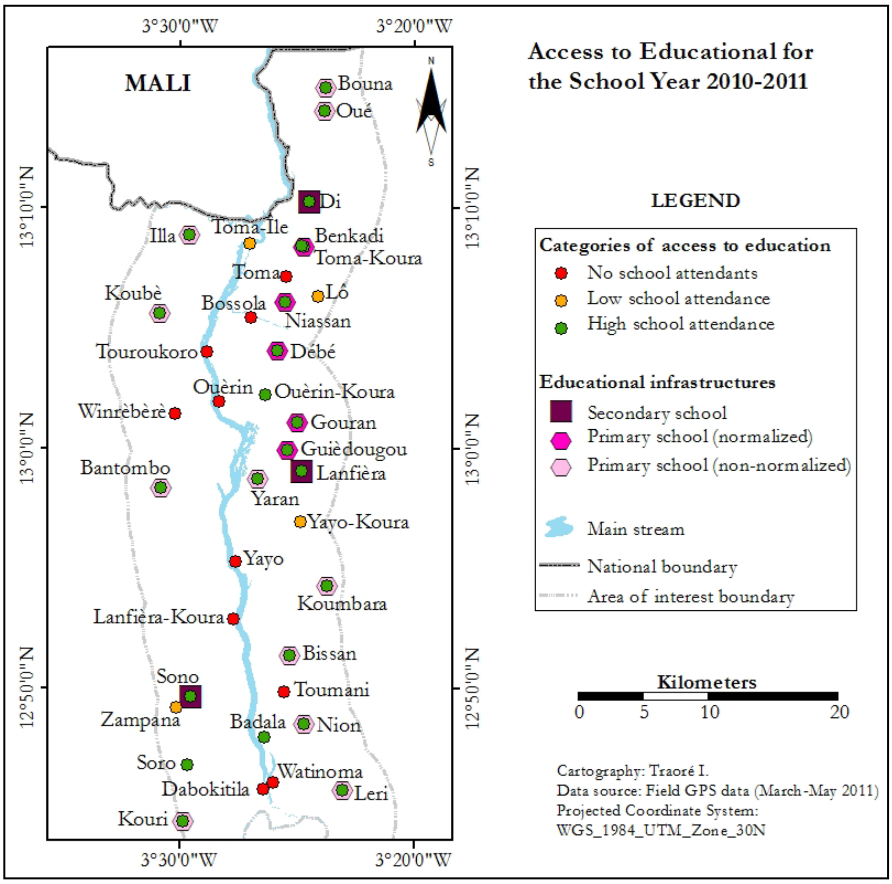


Figure 132: Spatial ditribution of AOI settlements per class of access to education

4.6. Modern and traditional occupational activities

4.6.1. Distribution of compounds per activity status

Table 31 shows the distribution of compounds per settlement in a manner that a compound belonged to only one possible activity status. Height combianation of activities were expected whit irrigation (IRR) constituted alone 45.93% of AOI compounds. While in about 26% of AOI compounds, members were neither involved in IRR, TFP (traditional fishing in ponds) nor WBG (water lily bulbs gathering). These compounds were codified NTA (non-targeted activities) (Table 31).

4.6.2. Spatial distribution of AOI settlements per activity status

Based on the location of the majority of compounds per settlement, six combinations of activities were highlighted (orange cells in Table 31). Figure 133 shows that 35% of settlements felt into NTA. IRR, alone, accounted for 60% of compounds. Figure 134 visualizes the status of settlement involvement in targeted activities. Then, all settlements with majority of compounds involved in IRR were located on the East bank where is the bulk of modern irrigation fields in the AOI.

Table 31: Proportions of compounds per activity per settlement

Proportions (%) of compounds involved in targeted traditional and modern water activities per settlement grouped into six combinations									
Class	**Settlements**	**IRR+TFP+WBG**	**IRR+TFP**	**IRR+WBG**	**TFP+WBG**	**IRR**	**TFP**	**WBG**	**NTA**
1.	Toma-Île	52.50	25.00		2.50	17.50			2.50
	Ouèrin	25.00	3.85	3.85	25.00	13.46	3.85	9.62	15.38
2.	Toma-Koura		95.65			4.35			
	Illa	26.47	60.00	0.59	1.18	4.12	4.12		3.53
	Bouna		28.85		1.92	21.15	15.38	3.85	28.85
	Koubè	26.67	30.00		10.00	3.33	16.67		13.33
3.	Touroukoro	18.52	7.41		40.74	3.70	14.81		14.81
4.	Benkadi	2.44	2.44			91.46			3.66
	Débé	2.92	1.17		0.87	91.25	0.29		3.50
	Niassan	1.58	6.50		0.16	85.26	0.16	0.16	6.18
	Guièdougou		10.69			76.45	0.72		12.14
	Watinoma					71.43			28.57
	Lô		3.33			70.00			26.67
	Ouèrin-Koura	20.00				70.00			10.00
	Lanfièra		5.43			57.61			36.96
	Badala		44.44			55.56			
	Gouran	1.98	24.11	0.79		51.78	1.58		19.76
	Di	0.55	24.93	0.14		46.16	0.82		27.40
	Toma	22.22	22.22	11.11		33.33	5.56		5.56
5.	Bantombo		3.51		17.54		71.93		7.02
	Winrèbèrè		5.00		5.00		60.00		30.00
	Zampana					22.22	55.56		22.22
	Yayo-Koura						50.00		50.00
	Leri		1.38			2.07	49.66		46.90
6.	Bossola								100
	Lanfièra-Koura								100
	Kouri				1.04	4.17	12.50	2.08	80.21
	Koumbara		2.96			0.74	21.48		74.81
	Soro					23.33	3.33		73.33
	Toumani		4.08				32.65		63.27
	Yayo			1.14	12.50	1.14	11.36	18.18	55.68
	Sono	1.56	3.44		4.69	10.00	24.69	0.63	55.00
	Dabokitila					45.45			54.55
	Bissan				11.94		34.33	1.49	52.24
	Nion		15.79			33.68	6.32		44.21
	Yaran	1.54	5.64		1.54	33.33	11.79	5.13	41.03
	Oué	4.87	18.58		6.19	9.73	23.45	2.65	34.51
Total Area of Interest		**3.04**	**12.94**	**0.18**	**2.01**	**45.93**	**8.92**	**0.92**	**26.05**

IRR: Irrigation; **TFP:** Traditional Fishing in Ponds; **WBG:** Water lily Bulbs Gathering; **NTA:** Non-Targeted Activity

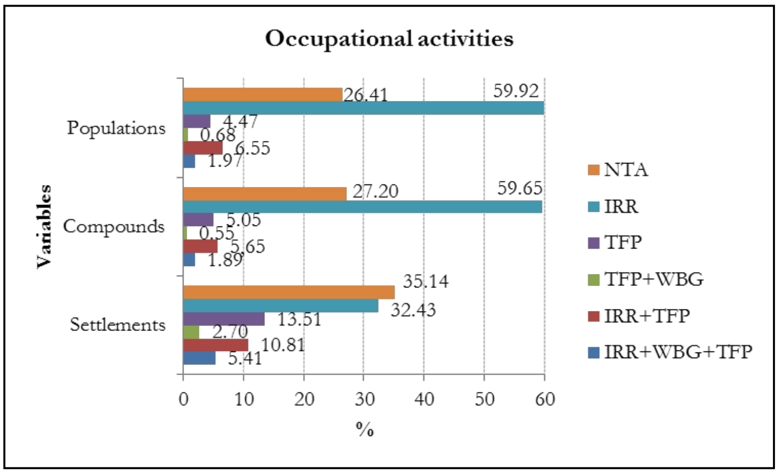


Figure 133: Proportion of AOI settlements, compounds and populations per activity status

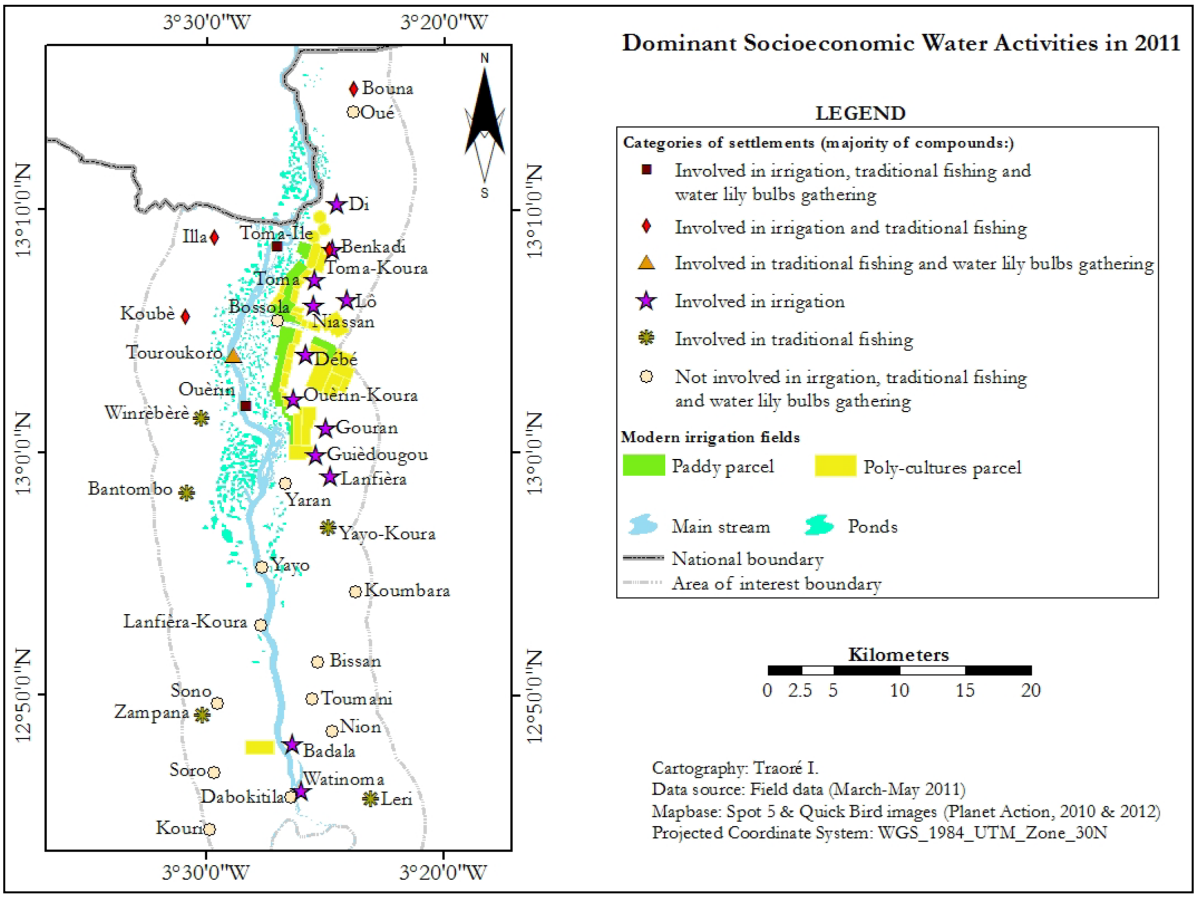


Figure 134: Spatial distribution of AOI settlements according to their dominant activity status

4.7. Schistosomiasis morbidity in our AOI

4.7.1. Schistosomiasis-disease cases

Table 32a shows five years (2006-2010) statistics, which are worrying and speak for themselves. Out of a total of 220526 all cases of diseases, schistosomiasis weighted for 0.10% all forms together. Table 32b shows that in this time lag, a total of 75 different pathologies were among which urinary schistosomiasis was ranking 41st while the intestinal form came at the 65th place. However, at CSPS of Lanfièra, Di and Oué, the urogenital form came before 39, 29 and 21 other pathologies.

Table 32: Schistosomiasis-diseases recorded at the CSPS level

a) Schistosomiasis-diseases cases from 2006 to 2010

CSPS	All diseases		Schistosomiasis				
	All cases	*Annual means*	*All forms*	*Annual means*	*% Urinary*	*% Intestinal*	*% (at all cases)*
Débé	17038	5679.33	2	0.67	100	0.00	0.01
Sono	10377	1297.13	2	0.40	100	0.00	0.02
Koumbara	36319	1345.15	8	1.60	100	0.00	0.02
Di	31898	625.45	23	4.60	95.65	4.35	0.07
Niassan	28382	1419.10	28	5.60	85.71	14.29	0.10
Moara Grand	12535	2089.17	13	2.60	100	0.00	0.10
Wèrèbèrè	13397	1030.54	15	3.00	100	0.00	0.11
Lanfièra	49563	971.82	72	14.40	98.61	1.39	0.15
Oué	21017	5254.25	47	11.75	100	0.00	0.22
Total	**220526**	**44105.20**	**210**	**42.00**	**97.14**	**2.86**	**0.10**

b) Rank of schistosomiasis-disease in six CSPS (2006-2010)

CSPS	All diseases	Schistosomiasis	
		Urinary	*Intestinal*
Débé	45	41st	-
Oué	53	32nd	42nd
Niassan	61	40th	-
Koumbara	63	45th	-
Lanfièra	65	26th	63rd
Di	68	39th	63rd
Total	**75**	**41st**	**65th**

4.7.2. Characteristics of patients

Through archives searches at CSPS level, we could find 67.62% of the total of 210 cases. The analyzing of characteristics of patients concern only these found cases.

4.7.2.1. Patients' age group and occupational status per gender

Table 33a shows that 65% of AOI patients was adults persons and 73% was males. This age and gender distribution was similar to that observed at the country scale. Table 33b shows that in 52% of cases the occupational status of the patient was not informed. Schools attendants accounted only for 4%.

Table 33: Characteristics of schistosomiasis patients from archive searches

a) Age Group and Gender of Patients

Age (years)	Gender (%)		Total
	Male	*Female*	(n = 142)
< 1	0.70	0.00	**0.70**
1 – 4	5.63	0.70	**6.34**
5 – 14	12.68	7.04	**19.72**
≥ 15	47.89	17.61	**65.49**
Unknown	5.63	2.11	**7.75**
Total (n = 142)	**72.54**	**27.46**	**100**

b) Occupational Status of Patients

Occupation	Gender (%)		Total
	Male	*Female*	(n = 142)
Shepherd	3.52	0.00	**3.52**
Pupil	4.23	0.00	**4.23**
Child	5.63	0.70	**6.34**
Housewife	0.00	9.86	**9.86**
Farmer	21.83	0.70	**22.54**
Unknown	37.32	16.20	**53.52**
Total (n = 142)	**72.54**	**27.46**	**100**

4.7.2.2. Geographic origins of patients

Archive searches reveal that 63% (n = 89) of patients was dwelling in our AOI, not only but also 6% was from the neighbor country as indicated in Figure 135a. Patients from Mali were recorded only in border CSPS: Oué and Wèrèbèrè. Figure 135b shows the spatial distribution of AOI patients with 23.60% of patients from Guièdougou, 15.73% from Oué and 10.11% from Leri.

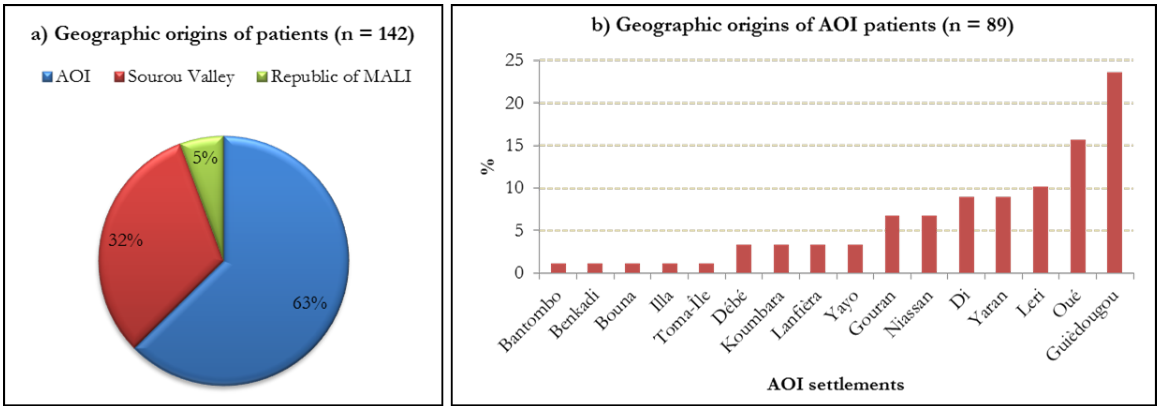


Figure 135: Schistosomiasis patients' geographic origins

4.7.3. Schistosomiasis-illness cases reported at schools level

4.7.3.1. Prevalence rates distribution per school

According to Table 34, 1886 school attendants interviewed reported symptoms related to urinary Schistosomiasis. 98.57% of cases was reported by primary school children. Prevalence rates varied between 90 and 0.70%. The prevalence rate in primary school level was about 11 times higher than in the secondary school.

4.7.3.2. Urinary schistosomiasis-illness prevalence rates distribution per gender according to attendants geographic origin

Out of 1886 school-goers having reported illness cases, 1882 dwelled in 26 settlements within our area of interest for which Table 35 shows the spatial distribution per gender. The highest prevalent settlements were Zampana and Illa with respect to boys (100%) and girls (84.13%), respectively. Regarding both male and female together, Illa observed the highest prevalence rate (84.10%). However, 58% of settlements showed higher prevalence rates for boys than for girls.

Table 34: Urinary schistosomiasis-illness prevalence rates per school

Outcomes of the school-based questionnaire survey (May 2011)						
School		Reported illness				
Level	*Name*	*Cases*	*Prevalence (%)*	*Odds ratio*	*95% CI lower*	*95% CI upper*
Primary	Illa	162	90.00	81.00	0.90	0.90
	Bouna	65	78.31	13.04	0.78	0.79
	Benkadi	194	59.88	2.23	0.60	0.60
	Oué	176	58.86	2.05	0.59	0.59
	Yaran	91	52.91	1.26	0.53	0.53
	Gouran "A"	111	44.05	0.62	0.44	0.44
	Bantombo	34	34.34	0.27	0.34	0.35
	Gouran "B"	21	32.81	0.24	0.32	0.33
	Niassan "B"	96	29.91	0.18	0.30	0.30
	Di "A"	190	28.32	0.16	0.28	0.28
	Niassan "A"	172	27.22	0.14	0.27	0.27
	Koumbara	49	25.13	0.11	0.25	0.25
	Sono	67	22.79	0.09	0.23	0.23
	Bissan	15	22.73	0.09	0.22	0.23
	Débé	101	20.53	0.07	0.20	0.21
	Di "B"	94	20.48	0.07	0.20	0.21
	Lanfièra	39	17.26	0.04	0.17	0.17
	Guièdougou "B"	35	16.36	0.04	0.16	0.16
	Kouri	31	15.58	0.03	0.16	0.16
	Koubè	11	14.67	0.03	0.15	0.15
	Guièdougou "A"	93	12.47	0.02	0.12	0.12
	Nion	12	10.62	0.01	0.11	0.11
Total1	22	1859	30.10	0.19	0.30	0.30
Secondary	Sono	13	9.63	0.01	0.10	0.10
	Di	11	2.66	0.00	0.03	0.03
	Lanfièra	3	0.70	0.00	0.01	0.01
Total2	3	27	2.76	0.00	0.03	0.03
TOTAL (1+2)	**25**	**1886**	**26.36**	**0.13**	**0.26**	**0.26**

Table 35: Reported urinary schistosomiasis-illness prevalence rates per origin and gender

Urinary schistosomiasis-illness reported by pupils interviewed in schools per geographic origin and gender																		
	Boys						Girls						Boys+Girls					
Origins	*Number*	*Case*	*Prevalence (%)*	*Odds ratio*	*95% CI lower*	*95% CI upper*	*Number*	*Case*	*Prevalence (%)*	*Odds ratio*	*95% CI lower*	*95% CI upper*	*Number*	*Case*	*Prevalence (%)*	*Odds ratio*	*95% CI lower*	*95% CI upper*
Di	680	175	25.74	0.12	0.26	0.26	648	126	19.44	0.06	0.19	0.19	1328	301	22.67	0.09	0.23	0.23
Guiédougou	694	108	15.56	0.03	0.16	0.16	601	89	14.81	0.03	0.15	0.15	1295	197	15.21	0.03	0.15	0.15
Niassan	545	159	29.17	0.17	0.29	0.29	518	112	21.62	0.08	0.22	0.22	1063	271	25.49	0.12	0.25	0.26
Débé	286	51	17.83	0.05	0.18	0.18	254	49	19.29	0.06	0.19	0.19	540	100	18.52	0.05	0.18	0.19
Sono	159	44	27.67	0.15	0.28	0.28	159	23	14.47	0.03	0.14	0.15	318	67	21.07	0.07	0.21	0.21
Benkadi	149	100	67.11	4.16	0.67	0.67	136	68	50.00	1.00	0.50	0.50	285	168	58.95	2.06	0.59	0.59
Oué	134	75	55.97	1.62	0.56	0.56	126	65	51.59	1.14	0.51	0.52	260	140	53.85	1.36	0.54	0.54
Lanfièra	129	18	13.95	0.03	0.14	0.14	120	14	11.67	0.02	0.12	0.12	249	32	12.85	0.02	0.13	0.13
Gouran	104	35	33.65	0.26	0.33	0.34	123	39	31.71	0.22	0.32	0.32	227	74	32.60	0.23	0.33	0.33
Koumbara	89	29	32.58	0.23	0.32	0.33	117	20	17.09	0.04	0.17	0.17	206	49	23.79	0.10	0.24	0.24
Illa	132	111	84.09	27.94	0.84	0.84	63	53	84.13	28.09	0.84	0.84	195	164	84.10	27.99	0.84	0.84
Yaran	124	52	41.94	0.52	0.42	0.42	71	39	54.93	1.49	0.55	0.55	195	91	46.67	0.77	0.47	0.47
Kouri	80	21	26.25	0.13	0.26	0.26	105	8	7.62	0.01	0.08	0.08	185	29	15.68	0.03	0.16	0.16
Bouna	76	64	84.21	28.44	0.84	0.84	64	39	60.94	2.43	0.61	0.61	140	103	73.57	7.75	0.73	0.74
Bantombo	78	22	28.21	0.15	0.28	0.28	46	15	32.61	0.23	0.32	0.33	124	37	29.84	0.18	0.30	0.30
Nion	46	6	13.04	0.02	0.13	0.13	53	6	11.32	0.02	0.11	0.12	99	12	12.12	0.02	0.12	0.12
Koubé	41	6	14.63	0.03	0.14	0.15	42	5	11.90	0.02	0.12	0.12	83	11	13.25	0.02	0.13	0.13
Bissan	36	7	19.44	0.06	0.19	0.20	30	8	26.67	0.13	0.26	0.27	66	15	22.73	0.09	0.22	0.23
Toma-Koura	13	6	46.15	0.73	0.44	0.48	13	5	38.46	0.39	0.37	0.40	26	11	42.31	0.54	0.41	0.43
Soro	12	1	8.33	0.01	0.08	0.09	13	3	23.08	0.09	0.22	0.24	25	4	16.00	0.04	0.15	0.17
Badala	9	0	0.00	-	0.00	0.00	5	0	0.00	-	0.00	0.00	14	0	0.00	-	0.00	0.00
Ouèrin-Koura	7	0	0.00	-	0.00	0.00	4	1	25.00	0.11	0.20	0.30	11	1	9.09	0.01	0.08	0.10
Lô	6	0	0.00	-	0.00	0.00	4	1	25.00	0.11	0.20	0.30	10	1	10.00	0.01	0.09	0.11
Zampana	1	1	100	-	1.00	1.00	4	3	75.00	9.00	0.70	0.80	5	4	80.00	16.00	0.77	0.83
Toma-Île	1	0	0.00	-	0.00	0.00	0	0	-	-	-	-	1	0	0.00	-	0.00	0.00
Yayo-Koura	0	0	-	-	-	-	1	0	0.00	-	0.00	0.00	1	0	0.00	-	0.00	0.00
Total	**3631**	**1091**	**30.05**	**0.18**	**0.30**	**0.30**	**3320**	**791**	**23.83**	**0.10**	**0.24**	**0.24**	**6951**	**1882**	**27.08**	**0.14**	**0.27**	**0.27**

4.7.3.3. Prevalence rates distribution per age group and gender

Table 36 shows reported urinary schistosomiasis-illness prevalence rates per school attendants' age group and gender. The highest prevalence rate among boys and girls were shown by age groups between 10-14 years old and 5-9 years old, respectively. Therefore, results in Table 36 showed a classical pattern of illness prevalence rates which increases up to a peak located between 10-14 years old and then decreases with increase in subjects' age. In general males reported more cases than did females. It could be that males observed easily symptoms than females.

Table 36: AOI school attendants' urinary schistosomiasis-illness prevalence rates per age group and gender

Reported illness at schools level per age group and gender						
Age (years)	**Number**	**Case**	**Prevalence (%)**	**Odds ratio**	**95% CI Lower**	**95% CI Upper**
Boys						
5 – 9	1459	447	30.64	0.20	0.31	0.31
10 – 14	1690	596	35.27	0.30	0.35	0.35
15 – 19	465	47	10.11	0.01	0.10	0.10
20 – 24	17	1	5.88	0.00	0.06	0.06
Boys	**3631**	**1091**	**30.05**	**0.18**	**0.30**	**0.30**
Girls						
5 – 9	1379	376	27.27	0.14	0.27	0.27
10 – 14	1563	390	24.95	0.11	0.25	0.25
15 – 19	359	24	6.69	0.01	0.07	0.07
20 – 24	19	1	5.26	0.00	0.05	0.06
Girls	**3320**	**791**	**23.83**	**0.10**	**0.24**	**0.24**
Boys + Girls						
5 – 9	2838	823	29.00	0.17	0.29	0.29
10 – 14	3253	986	30.31	0.19	0.30	0.30
15 – 19	824	71	8.62	0.01	0.09	0.09
20 – 24	36	2	5.56	0.00	0.05	0.06
Boys+Girls	**6951**	**1882**	**27.08**	**0.14**	**0.27**	**0.27**

4.7.3.4. Assessment of school children statements about illness symptoms

- Constancy in reporting symptoms

Figure 136 shows that more than 1250 school-goers interviewed ready observed urinary Schistosomiasis symptoms, because they were able to report it the first day of the survey "D0". Since, participants to the survey started paying attention to symptoms, reported cases never went below 1300 for the remaining seven days of survey. However, data show slight input/output of report symptoms between "D1" and "D7". This means that some ill subjects did not see every day the blood passing in urine.

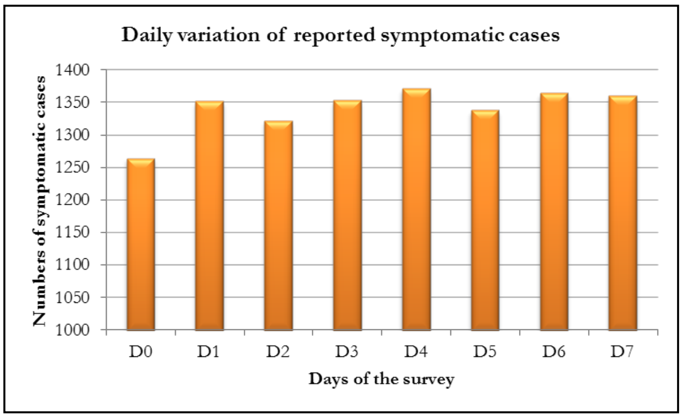


Figure 136: Symptomatic reported cases per day of survey (Traoré et al., 2012)

- Specificity and sensitivity of pupils' statements about urinary schistosomiasis

Figure 137 plots urinary schistosomiasis-illness and –disease prevalence rates. Out of 60 urine samples of self-reported illness cases, the parasitological examinations revealed that 21.70% contained *S. haematobium* eggs. Therefore, the sensitivity of the reporting illness was 65% (95% CI = 44% – 86%). Results of the parasitological examinations also revealed that 89.06% of the 64 children who reported no symptom had no *S. haematobium* eggs in their urine samples. Therefore, the specificity of the illness reporting was 55% (95% CI = 46% – 64%). Figure 137 also shows that in general urinary schistosomiasis-disease prevalence rates were lower compared to the self-reported illness.

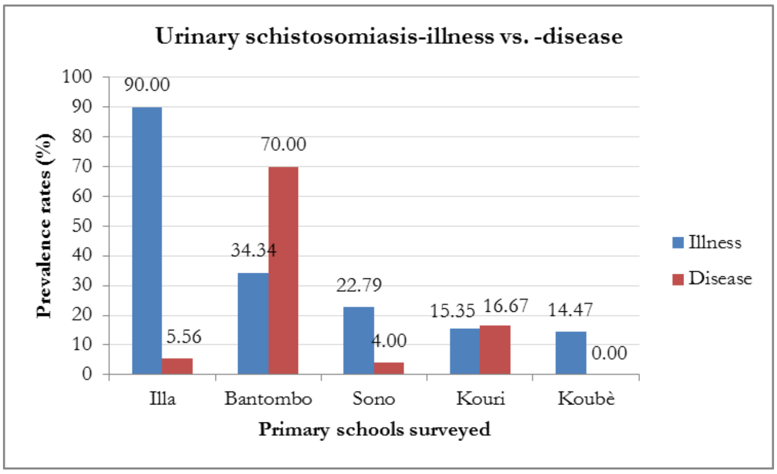


Figure 137: Plot of illness and disease prevalence rates and their difference (after Traoré et al., 2012)

Two main reasons could explain the moderate sensitivity and specificity we observed about pupils self-reported symptoms and the presence of schistosomes eggs in their urine (Traoré et al., 2012). First, the use of the centrifugation method instead of filtering has probably diminished the chance to detect more infected cases during the laboratory examinations. Second, the small number of urine samples, coupled with a single testing day. Even by urine filtration, one misses about one-third of the egg-positive people on a single testing day (Lengeler, 1989, cited Lengeler et al., 1991a). This is because of the circadian variation of eggs excretion (McMahon, 1976; Doehring et al., 1985).

4.7.4. Urinary schistosomiasis-illness cases reported at compounds level

4.7.4.1. Global outcomes

Outcomes of the awareness of heads of compounds of the presence/absence in their compounds of members suffering from urinary schistosomiasis are indicated in Figure 138. Out of the 4868 interviewed heads of compounds only 6% was not aware of the illness status members. Conversely, about the quarter of heads reported the presence of symptomatic cases in their compounds while, the large majority stated that nobody was complaining about seeing blood in urine.

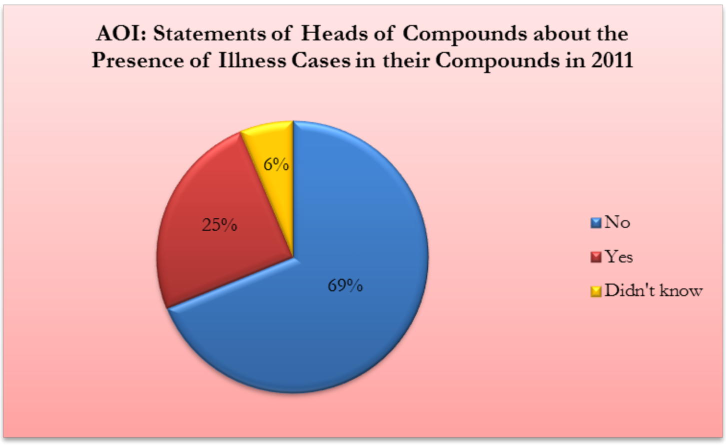


Figure 138: Proportion of AOI compounds having reported urinary schistosomiasis-illness

4.7.4.2. Using compounds illness prevalence rates for categorizing settlements

The influence of the quarter on the distribution of compounds with illness within the settlements observed significant χ^2 test of the goodness to fit in Gouran, Niassan and Oué (p-value <0.001). Conversely, in Bantombo there was no relationship between quarter and the frequency of report of illness within the compound (p-value=1). Number of compounds having reported illness cases ranged from zero (Badala) to 199 (Guièdougou) and the highest ranked prevalence rate was recorded in Bossola (100%). Only Ouèrin and Toma-Île observed a positive association (Odds ratio>1) (Stuart, 2006). Based on the work of Ansell et al. (1997), it was recommended that a prevalence of self-reported urinary schistosomiasis of 30% be used to define communities where the true prevalence is expected to be above 50% (Clements et *al.*, 2008). Adapting these endemic thresholds, AOI settlements were categorized as indicated in Figure 89, using urinary schistosomiasis-illness status reported by head of compounds. Figure 139 shows that the majority of AOI settlements (67%), compounds and populations (88%, each) fell into the medium prevalence rate setting. Figure 140 indicated settlements spatial distribution.

Table 37: Urinary schistosomiasis-illness prevalence rates reported at compounds level per settlement

Area of Interest: Urinary Schistosomiasis-illness Prevalence in March 2011									
			Goodness to fit			Prevalence			
Class	**Settlement**	**Compounds with illness**	χ^2	*df*	*p-value*	*Rate (%)*	*Odds ratio*	*95% CI lower*	*95% CI upper*
1. Low	Badala	0	-	-	-	0.00	-	0.00	0.00
	Zampana	1	0.41	1	0.523	5.56	0.00	0.05	0.06
	Watinoma	1	-	-	-	7.14	0.01	0.07	0.08
2. Moderate	Gouran	32	111.48	14	0.000	12.65	0.02	0.13	0.13
	Sono	41	20.23	8	0.010	12.81	0.02	0.13	0.13
	Soro	4	1.10	6	0.981	13.33	0.02	0.13	0.14
	Kouri	15	4.04	8	0.853	15.63	0.03	0.15	0.16
	Yayo-Koura	1	-	-	-	16.67	0.04	0.14	0.19
	Lô	5	10.42	6	0.108	16.67	0.04	0.16	0.17
	Lanfièra	16	0.13	2	0.937	17.39	0.04	0.17	0.18
	Toumani	9	7.46	4	0.114	18.37	0.05	0.18	0.19
	Bissan	13	1.30	3	0.730	19.40	0.06	0.19	0.20
	Niassan	123	73.02	14	0.000	19.49	0.06	0.19	0.20
	Koumbara	27	5.45	7	0.606	20.00	0.06	0.20	0.20
	Leri	29	5.47	4	0.243	20.00	0.06	0.20	0.20
	Nion	20	7.46	8	0.488	21.05	0.07	0.21	0.21
	Toma-Koura	5	-	-	-	21.74	0.08	0.21	0.22
	Koubè	7	0.19	1	0.666	23.33	0.09	0.23	0.24
	Débé	81	36.71	14	0.001	23.62	0.10	0.24	0.24
	Winrèbèrè	5	-	-	-	25.00	0.11	0.24	0.26
	Di	192	30.02	14	0.008	26.30	0.13	0.26	0.26
	Bouna	14	23.24	8	0.003	26.92	0.14	0.27	0.27
	Yaran	54	10.03	8	0.263	27.69	0.15	0.28	0.28
	Lanfièra-Koura	2	-	-	-	28.57	0.16	0.26	0.31
	Guièdougou	199	8.21	8	0.413	28.76	0.16	0.29	0.29
	Touroukoro	8	0.84	2	0.659	29.63	0.18	0.29	0.30
	Oué	67	50.29	14	0.000	29.65	0.18	0.30	0.30
	Ouèrin-Koura	3	-	-	-	30.00	0.18	0.28	0.32
3. high	Yayo	32	2.09	4	0.720	36.36	0.33	0.36	0.37
	Illa	66	22.77	12	0.030	38.82	0.40	0.39	0.39
	Benkadi	36	5.56	2	0.062	43.90	0.61	0.44	0.44
	Toma	8	-	-	-	44.44	0.64	0.43	0.46
	Dabokitila	5	-	-	-	45.45	0.69	0.43	0.48
	Bantombo	27	0.00	1	1.000	47.37	0.81	0.47	0.48
	Toma-Île	22	8.15	12	0.773	55.00	1.49	0.54	0.56
	Ouèrin	35	3.82	2	0.148	67.31	4.24	0.67	0.68
	Bossola	5	-	-	-	100	-	1.00	1.00
Total Area of Interest		**1210**	**817.66**	**72**	**0.000**	**24.86**	**0.11**	**0.25**	**0.25**

df: degree of freedom; **CI:** Confidence Interval

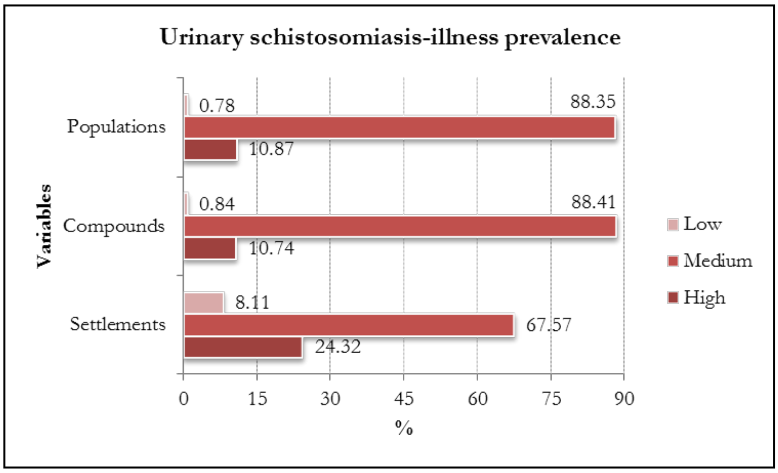


Figure 139: Proportions of settlements, compounds and population per class of urinary schistosomiasis-illness prevalence rate

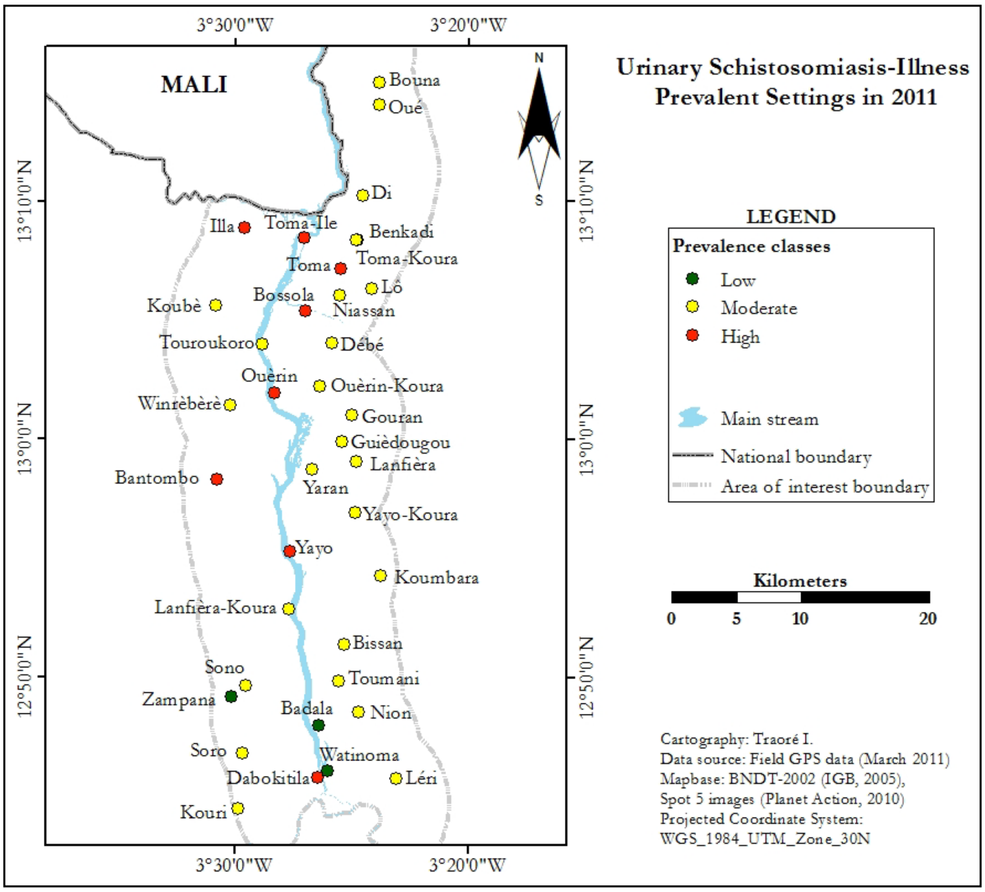


Figure 140: Spatial distribution of AOI settlements according to urinary schistosomiasis-illness prevalence rate

4.8. Summary of the interrelation of geogreaphic parameters identified

Figure 141 shows the complex interrelation between geographic parameters identified within the framework of this study. Local populations, active actors of schistosomiasis transmission, are at the center of the whole system. Settlements function had a strong influence on infrastructures availability and socio-professional occupations. The environmental aspects determined which communities were more likely in contact with contaminative water bodies as well as the residential units' spatial distribution. Results also showed a clear pattern between proximity to perennial water bodies and schistosomiasis prevalence. Without local populations, all others geographic parameters have no importance in terms of schistosomiasis transmission risk and vice-versa.

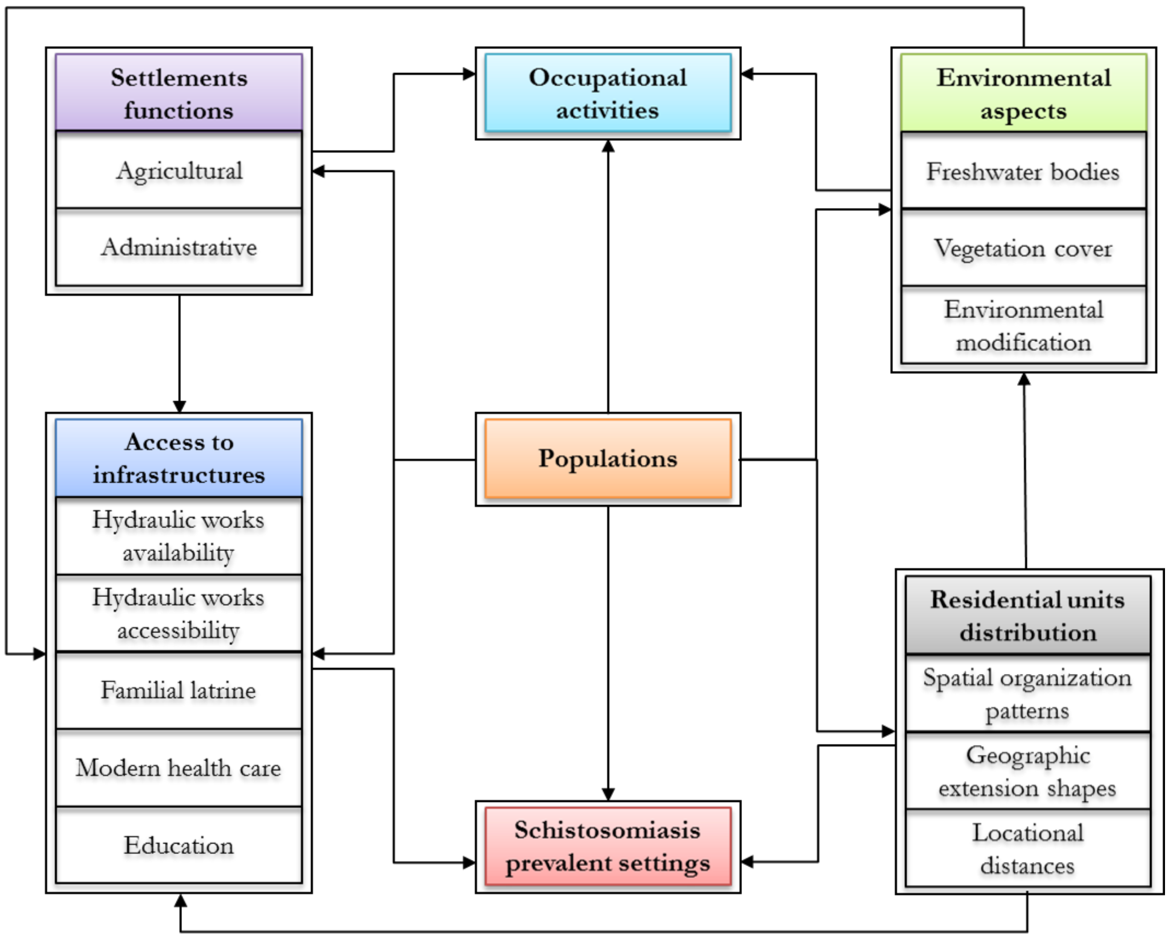


Figure 141: Interrelation between local geographic parameters

Chapter 5. Complex geographic determinants of human infestation in the Sourou Valley

In this chapter we deal with the role and place of local natural and social geographic determinants in human infestation. We analyzed ways through which local populations enter into contact with contaminated water bobies.

5.1. Water contacts through domestic activities within a context of absence of hydraulic works: Case study from Toma-Île

5.1.1. Characteristics of women followed up in Toma-Île

Table 38 summarizes characteristics of the 40 women followed up during the direct field observation of domestic activities in Toma-Île. 35% of the women were between 20 and 24 years old while 55% of women were breast-feeding and 72% had no co-wife. Table 38 also shows that the majority, 45% of followed up women had two under 5 (U5) children.

Table 38: Characteristics of women followed up in Toma-Île

Characteristics of women followed up in Toma-Île			
Characteristics	Number	Woman ID	%
Age groups			
15-19	2	7-38-	5.00
20-24	14	2-3-4-6-8-11-13-15-16-19-20-30-31-34	35.00
25-29	9	12-14-17-25-28-29-32-33-35	22.50
30-34	3	21-37-40	7.50
35-39	5	1-5-18-22-24	12.50
40-44	5	23-26-27-36-39	12.50
45-49	1	9	2.50
50-54	1	10	2.50
Mother status			
Breast-feeding	22	2-3-5-6-12-19-21-22-23-25-26-28-30-31-32-33-34-35-36-37-39-40	55.00
Pregnant	8	4-7-8-11-14-16-20-29	20.00
Not breast-feeding/ not pregnant	10	1-9-10-13-15-17-18-24-27-38	25.00
Marital status			
Without any co-wife	29	1-2-3-6-7-9-10-11-12-13-15-16-17-19-20-21-24-25-27-28-29-30-31-32-33-34-36-38-39	72.50
With co-wives	11	4-5-8-14-18-22-23-26-35-37-40	27.50
Number of U5 children			
Zero	6	1-10-13-16-27-38	15.00
One	15	2-5-7-8-9-14-15-18-23-26-29-31-32-39-40	37.50
Two	18	3-4-6-11-12-17-19-20-21-24-25-28-30-33-34-35-36-37	45.00
Three	1	22	2.50

5.1.2. Nature and frequency of domestic activities

5.1.2.1. Global outcomes of recordings

The total number of times the women entered into contact with the river showed 6750 recordings at the end of the 59 days of observation. 54% of observations were done during Period_2. Table 39 shows the spectrum of 19 identified domestic tasks bringing women in contact with the Sourou River in Toma-Île. Based on recordings of Period_1 & 2, 63% of activities were defined as frequent (at least 3 digits) while 37% were classified as non-frequent (less than 3 digits). Figure 142 shows illustrations for activities N° 1, 6, 9 and 18 (Table 39).

Table 39: Complete list of domestic activities observed in Toma-Île

Types and frequencies of occurrence of domestic activities done in the Sourou River in Tomal-Île							
Activities		Period_1		Period_2		Period_1 & 2	
N°	***Type***	***Recording***	***%***	***Recording***	***%***	***Recording***	***%***
1	Dishes	722	23.39	668	18.24	1390	20.59
2	Woman having a bath	514	16.65	533	14.55	1047	15.51
3	Drink water collection	459	14.87	399	10.89	858	12.71
4	Laundry	389	12.60	376	10.26	765	11.33
5	Cereals washing	346	11.21	158	4.31	504	7.47
6	Cooking water collection	200	6.48	288	7.86	488	7.23
7	Gathering fish out of boat	25	0.81	316	8.63	341	5.05
8	Performing one's ablutions	191	6.19	138	3.77	329	4.87
9	Bathing children	63	2.04	220	6.01	283	4.19
10	Fish cleaning water collection	0	0.00	224	6.12	224	3.32
11	Bathing water collection	63	2.04	136	3.71	199	2.95
12	Fish cleaning	75	2.43	77	2.10	152	2.25
13	Ablutions water collection	4	0.13	69	1.88	73	1.08
14	House building water collection	4	0.13	32	0.87	36	0.53
15	Animal watering water collection	27	0.87	1	0.03	28	0.41
16	Fruits and potatoes cleaning	0	0.00	15	0.41	15	0.22
17	Hair cleaning	2	0.06	8	0.22	10	0.15
18	Pick up firewood	2	0.06	5	0.14	7	0.10
19	traditional medicine cleaning	1	0.03	0	0.00	1	0.01
Total		**3087**	**100**	**3663**	**100**	**6750**	**100**

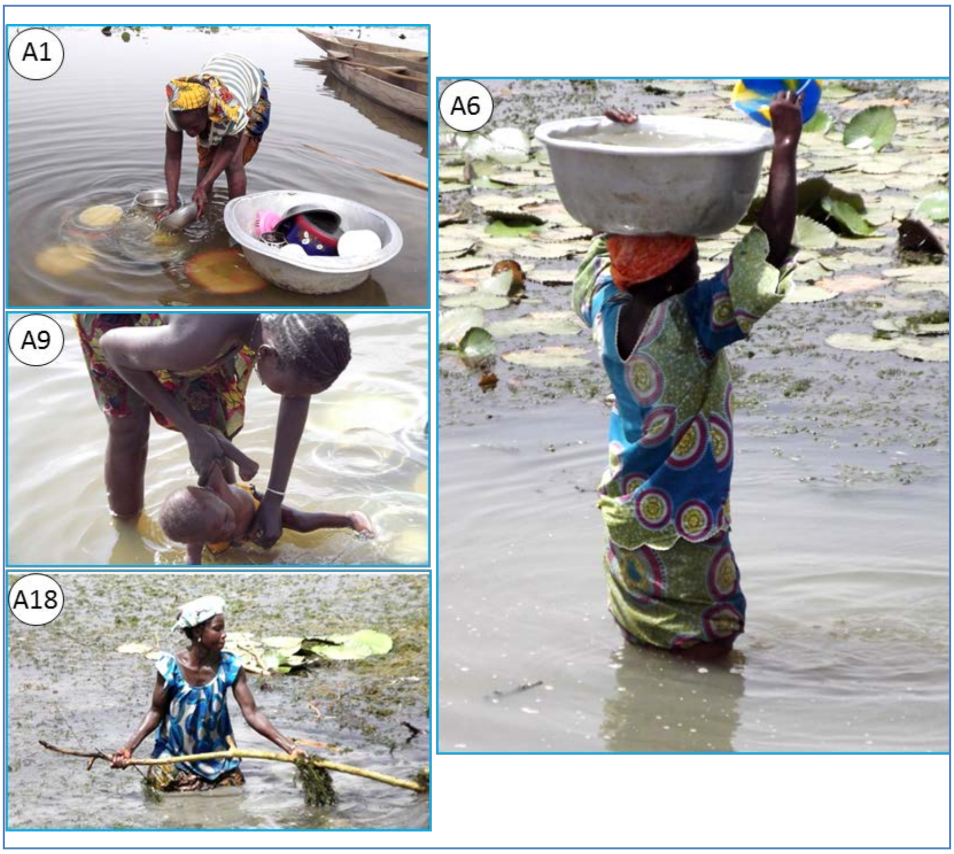


Figure 142: Illustration of four domestic activities observed in Toma-Île

A1: Dish washing; **A6:** Cooking water collection; **A9:** Bathing children; **A18:** Pick up firewood

5.1.2.2. Water contact indexes (WCI) per characteristics of women followed up

- Water contact indexes (WCI) according to age group

Figure 143a shows, for each group of characteristics of women followed up, the ratio between number of recordings and total number of women belonging to the given group. Similarly, Figure 143b shows, for each of the first 12 frequent activities, the index between cumulative values of the two periods of observation (Period_1 & Period_2) and the number of women grouped under a particular characteristic.

Figure 143a shows that WCI increased from 172.00 for 15-19 years old up to the peak of 222.60 observed for 35-39 years old, that is to say, about two times higher than that of 50-54 years old (116.00). Figure 143b shows that 12 reported activities were observed in women between 15 and 44 years old. Fish cleaning in the river (A12) was not observed for women within 45-49 years age group while gathering fish out of the canoe (A7), collection of water for fish cleaning (A10) and fish cleaning in the river (A12) were not recorded for women within 50-54 years age bracket. Bars representing 35-39 years old dominated in 75% of activities.

- WCI per marital status

Figure 144a shows a slight difference in WCI between women without any co-wife and those with co-wives: 158.93 vs. 159.09. According to Figure 144b, the latter dominated the former in 58% of concerned activities. Activities such as A1, A3, A6, A7 and A10 were most common among WCI for women without co-wives.

- WCI per mothering status

Figure 145a shows that the lowest WCI was recorded by pregnant women (133.00) while breast-feeding and non-pregnant not breast feeding women recorded a WCI of 162.00 and 173.10, respectively; hence, the latter groups presented a higher WCI than the former. The non-pregnant not breast-feeding group, according to Figure 145b, dominated the breast-feeding group in 83% of activities. WCI was higher in pregnant women due to bathing in the river (A2) and water collection for bathing (A11). This means that pregnant women had less contact with the river for domestic activities.

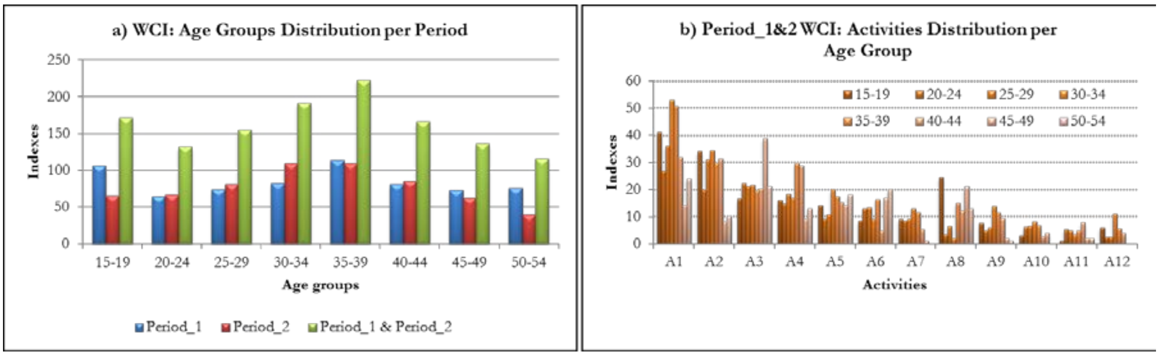


Figure 143: Pattern of domestic activities according to age group of followed up women

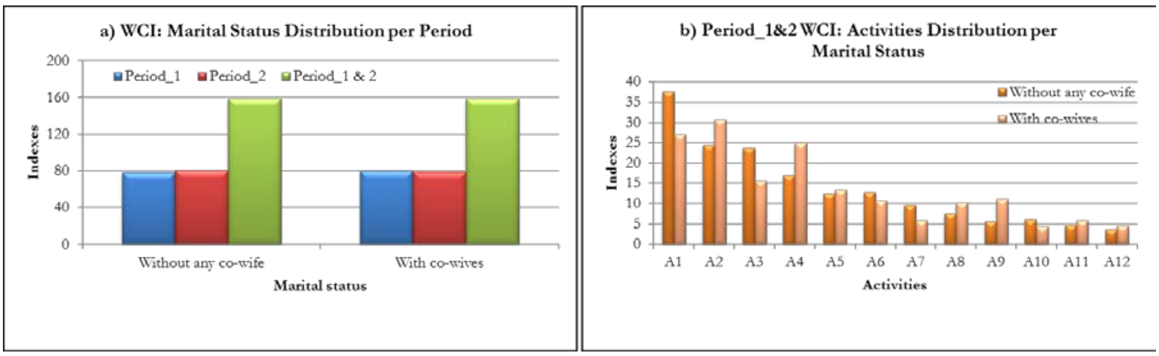


Figure 144: Pattern of domestic activities according to marital status of followed up women

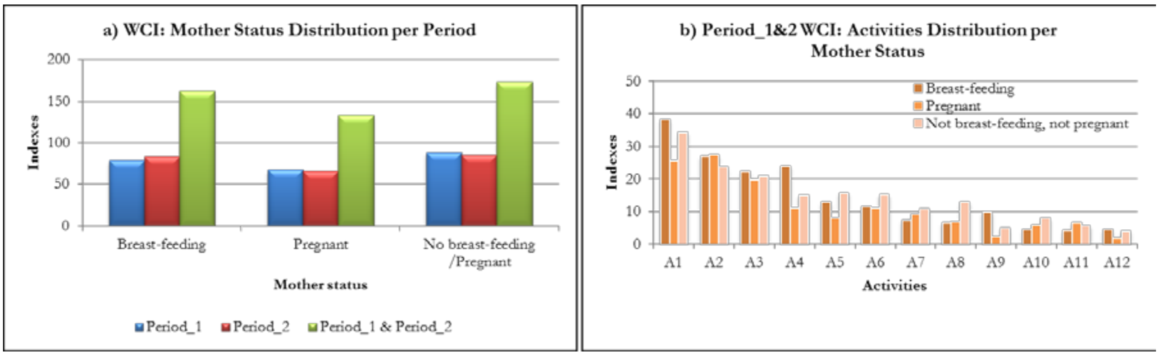


Figure 145: Pattern of domestic activities according to mothering status of followed up women

- Water contact indexes (WCI) according to the number of children per woman

Figure 146a show WCI patterns of women according to number of children with an index of 165.17 for women without children, 148.20 for women with 1 child, 160.67 for women with 2 children and 253.00 for women with three children. Figure 146b shows that a woman having three U5 children dominated others in 75% of concerned activities. Note that in WCI for A4, A9 decreased evenly with decrease in the number of U5 children.

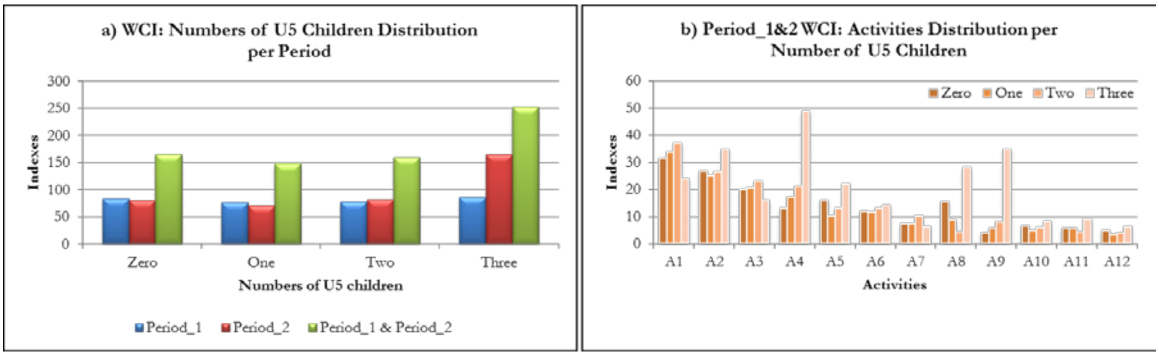


Figure 146: Pattern of domestic activities according to the number of U5 children per followed up woman

5.1.2.3. Individual water contact indexes (IWCI) of followed up women

Figure 147a shows IWCI per woman obtained by dividing the total number of recordings by 28 for Period_1; by 31 for Period_2, and by 59 for Period_1 & 2. Globally, individual water contact frequencies varied between 1 and 5. Due to the large interval in observed frequencies, the risk could be explained as possibly emanating from an individual behaviour within the same community.

Figure 147b shows IWCI per day per woman obtained by dividing the total number of recording of the period by 40. Results showed that for the same woman the water contact frequency varied from one day to another during the same period of time. In general, indexes varied between 2 and 3 per day in the first and second periods, respectively; and between 5 and 6 contacts per day (cumulative) for both periods of observation.

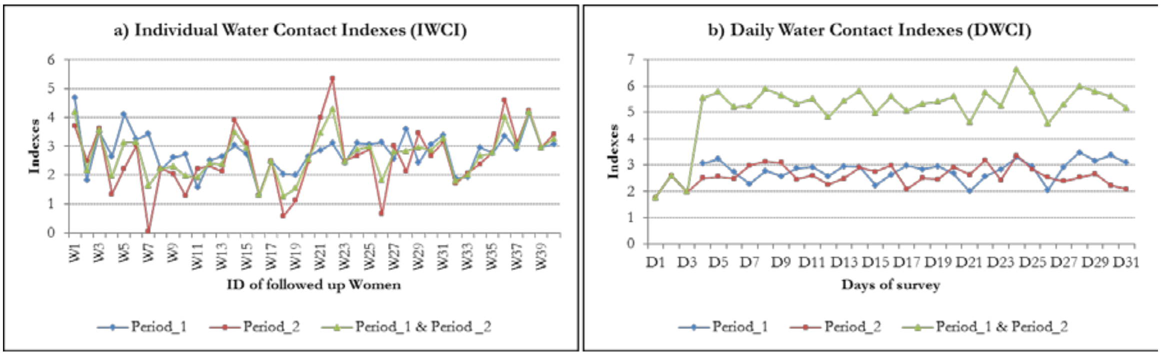


Figure 147: Profiles of water contact through domestic activities per period

5.1.2.4. Additional reasons of the unequal DWCI

- Mobility of women followed up beyond Toma-Île frontiers

Figure 148 highlights the fluctuation of the daily water contact indexes. In fact, a total of 240 recordings were related to days without domestic activity. About 39% occurred during the Period_1 and 61% during the Period_2, that is to say, an average absence rate of two and three days per woman, respectively. The curve of Period_1 and Period_2 in Figure 148a shows two peaks with 6.79% of absences observed for W18 and W35, each followed by W19 with 5.36%. Conversely, W7 and W13 recorded the lowest proportions, 0.36%, each; followed by W37 with 0.71%.

- Diverse reasons explained the mobility

Figure 148b shows the main reasons in descending order according to motivations. As expected for M3, M5, M9 and M11, results showed that 64% of reasons for absences was due to movement of followed up women outside frontiers of Toma-Île.

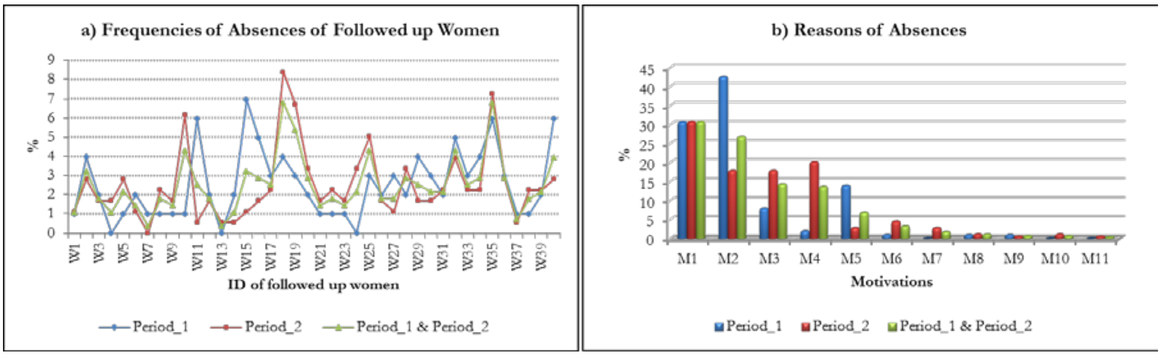


Figure 148: Domestic activities interruption per period

M1: Trip, **M2**: Local market, **M3**: Have not seen, **M4**: Funeral, **M5**: Illness, **M6**: Fieldworks, **M7**: Wedding, **M8**: Consultation at the CSPS, **M9**: Death, **M10**: Visit a sick person, **M11**: Birth given

5.1.2.5. Domestic activities, hourly occurrence patterns and durations

Figure 149 shows concentrations (%) of the contacts at a particular hour on the basis of the total number of contact recorded in the hour divided by the total number of recording for the period or activity multiplied by 100. Similarly, Figure 150 shows duration of contacts.

- Hourly profile

Figure 149a points out two peak hours of women exposure to the river, irrespective of the period. The first occurred earlier in the morning at 6H (12%) and the second 10 hours later at 16H with 11% of observations. Mid-day (12H) remained a break time with only few contacts occurring (4%). Figure 149b shows that in 33% of activities observed, single peaks of 16.6, 36.5, 16.10 and 30.90% occurred at 15, 6, 16, and 10H for A1, A2, A3 and A12, respectively. On the other hand, peaks of 67% of activities coincided at the same time. These overlapped peaks were formed by A4 – A5, A7 – A10, A8 – A9 and A6 – A11; with 14.60% – 14.70%, 46.00% – 40.20%, 28.30% – 14.10% and 26.60 – 24.10% of recordings observed at 7, 9, 14 and 17H, respectively. Figure 149b also shows that 58% of activities (A1, A2, A4, A5, A6, A9 and A11) took place at any time from 6H to 18H. Drinking water collection (A3) and fish cleaning in river (A12) were not observed after 17H. A7 and A10 recorded four and three breaks observed at 6, 14, 16 and 17H; and 6, 14 and 18H, respectively.

- Duration profile

Figure 150a points out that the majority (54.74%) of activities lasted between one and five minutes (1-5min) in general. It demonstrates that most of water contacts were due to short occurrence of activities. Because of the closeness of the water, women do not keep any water reserve. They get, for each single need, in contact with the river. Figure 150b demonstrates that the same activity done by the same woman did not last always the same time. Among those that occurred within 60mn and more, A4 showed the highest proportion (22.22%) followed by A3 (20.63%). In case of the latter, women usually collect the water from the middle area of the river using canoe. The duration of activity also depends on the volume in terms of quantity the women have to fetch. With lot of dirty clothes the laundry will last longer.

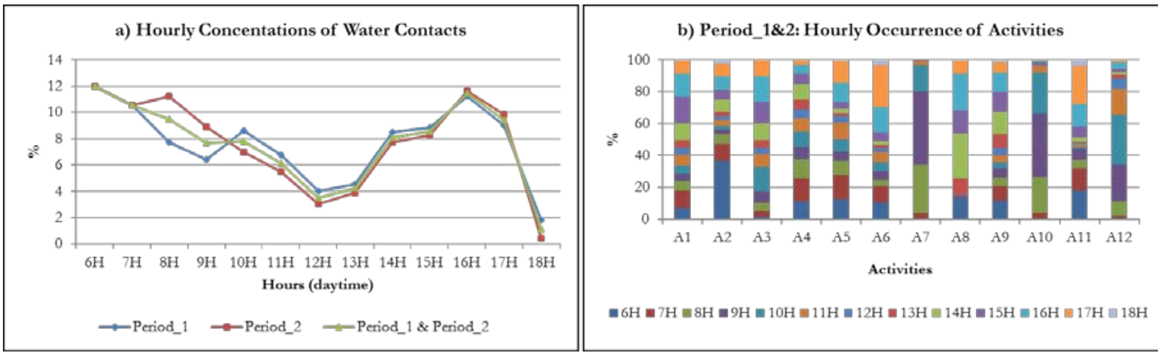


Figure 149: Hourly occurrence pattern of domestic activities of followed up women

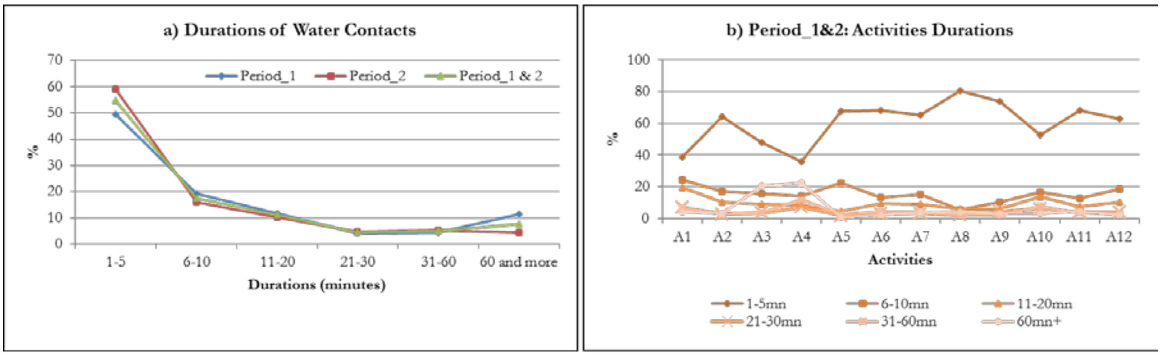


Figure 150: Duration of activities of followed up women

5.1.3. Relationship between air temperature and frequency of domestic activities of followed up women

We put the focus on two observed activities: women having a bath and children bathing directly in the river for assessing the influence of air temperature on domestic activities in Toma-Île.

Figure 151 shows, on the one hand, that women having a bath had their first highest peaks at 6H irrespective of the period. However, second peaks did not overlap and even showed a gap of 3 hours. During Period_1 the peak occurred at 17H, i.e., 11 hours later, while during Period_2 it occurred at 14H, i.e., 8 hours later and corresponding to the hottest hour of the day. On the other hand, the highest peak for children bathing occurred at 6H during Period_1 while that of Period_2 was observed at 14H.

Gaps were positive within each period at 6H (22.36% vs. 21.12%). It means that there were more women and children and that the same number of mothers took their bath together with their children. Conversely, children bathing overtook women having a bath at 14H (-6.77% vs. -0.02%). This implies that most mothers bath only their children without having a bath themselves during Period_1 while almost all mothers had a bath together with their children during Period_2 (Figure 151).

Table 40 shows that the daily occurrence of A9 was more influenced by the daily mean air temperature than did A2 (38% vs. 4%). This means that U5 children showed less tolerance to higher temperatures than mothers did.

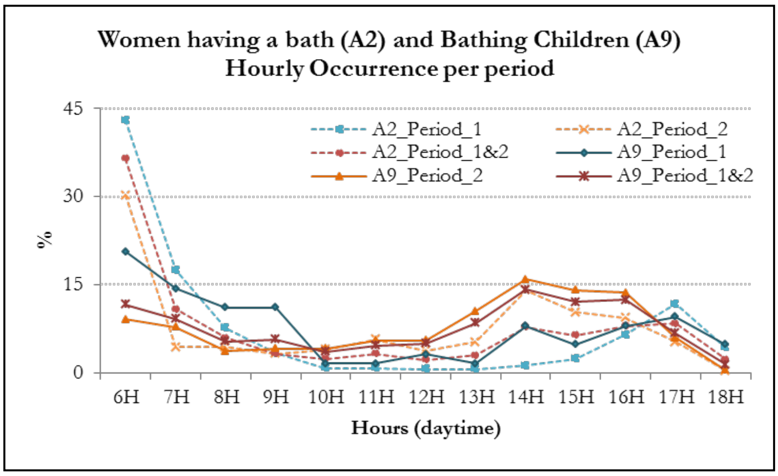


Figure 151: Occurrence pattern per period of women having a bath and U5 children bathing hourly in Toma-Île

Table 40: Linear regression statistics of the influence of air temperature on domestic activities in Toma-Île

	Women having a bath			Bathing children		
Period	**r**	**r^2 (%)**	**p-value**	**r**	**r^2 (%)**	**p-value**
Period_1	0.24	6	0.094	0.49	24	0.003
Period_2	-0.42	18	0.012	-0.48	23	0.005
Period_1&2	-0.19	4	0.075	0.62	38	0.000

5.2. Water contacts through domestic activities within a context of presence of hydraulic works: Case study from Débé, Di, Guièdougou and Niassan

Results from direct field observation of water drawing sites and source selection showed that in the Sourou Valley, clean water supply did not succeed in discouraging people from the use of contaminated freshwater bodies.

5.2.1. Reasons for water site selection by drawers

Figure 152a displays reasons for site selection by water drawers. The proximity to the irrigation canal was the most reported reason (R5) by water drawers interviewed in Débé, DEB1 (70.83%), DEB2 (76.14%) and in Niassan, NSN1 (56.36%). Reasons reported in Guièdougou were the lack of rope (R3) and the ease of drawing water (R7) representing 23.25%each. Also, the ease of drawing water from the Sourou River (DII1) was the most cited in Di (57.28%). Out of 16 different reasons, 87.5% was cited for GDG1. Figure 152b showed reasons reported by water drawers at hydraulic works sites. Two major peaks appeared due to the increase in reporting frequency of clear water (R2) and proximity (R5) as reasons for selection of hydraulic works by water drawers. The peaks then overlapped as a result of citing of R2 and R5 as reasons for selection of hydraulic works by water drawers across all observed hydraulic sites. The others 14 reasons were minor. The free-of-charge reason (R1) was reported only at the modern well site in Guièdougou (GDG2). Figure 152c compares the frequencies of reported reasons for water bodies to those recorded for hydraulic works. The proximity to the water drawing site (R5) was the commonest reported reason. However, the clear water (R2) was specific to hydraulic works while the ease of water drawing (R7) was seen as the advantage of water bodies.

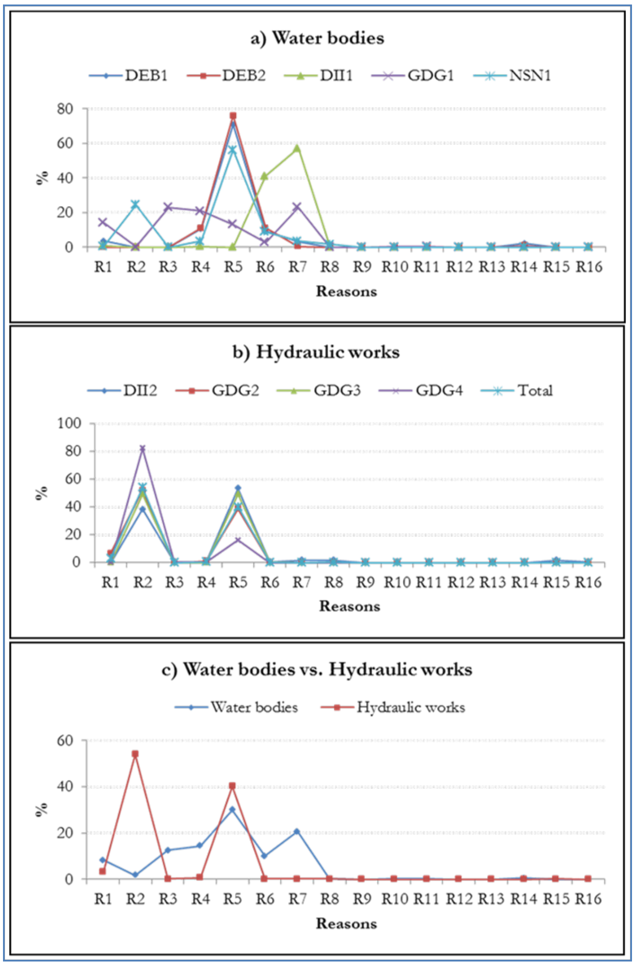


Figure 152: Reasons reported by water drawers

R1: Free of charge, **R2**: Clear water, **R3**: No rope, **R4**: Time saving, **R5**: Proximity, **R6**: Soap saving, **R7**: Ease, **R8**: Water taste, **R9**: No means, **R10**: Cannot draw water from wells, **R11**: Insufficiency of water in the village, **R12**: Large family, **R13**: Do not have any choice, **R14**: Dirty water, **R15**: Hand pump out of condition, **R16**: To resell cold water

5.2.2. Diverse water utilization domains

Figure 153 displays the distribution of utilization domains reported by water drawers. Figure 153a showed that the frequent use of water from water bodies were for laundry and dish washing (U3).

This was reported at the Sourou River in Di (DII1, 70.24%) and the irrigation canal in Guièdougou (GDG1, 32.09%); whereas, house building (U6) was reported by 66.51, 76.14 and 37.17% of drawers at DEB1, DEB2 in Débé and NSN1 in Niassan, respectively. Figure 153b depicts that water from hydraulic works was mostly used for drinking (U1) which was reported by 47.44% of drawers at the water fountain site in Di (DII2), 47.99% for the modern well in Guièdougou (GDG2), and 34.11 and 63.60% for the water fountain and the hand pump, respectively, in Guièdougou (GDG3 and GDG4). The use of water from hydraulic works for cooking (U2), laundry and dish washing (U3) took second and third places, respectively. Figure 153c shows that U1 was peculiar to hydraulic works (45.75%) while U6 is for water bodies (34.92%). U3 was the most reported domain when the two (water bodies and hydraulic works) sources were compared. Figure 153c also shows that all utilization domains employed water from water bodies. It means that freshwater is used for all the reported domains and therefore, convenient or multipurpose for all sectors of use while water from hydraulic works appears to be used for only U1, U2 and U3, and therefore, too restrictive.

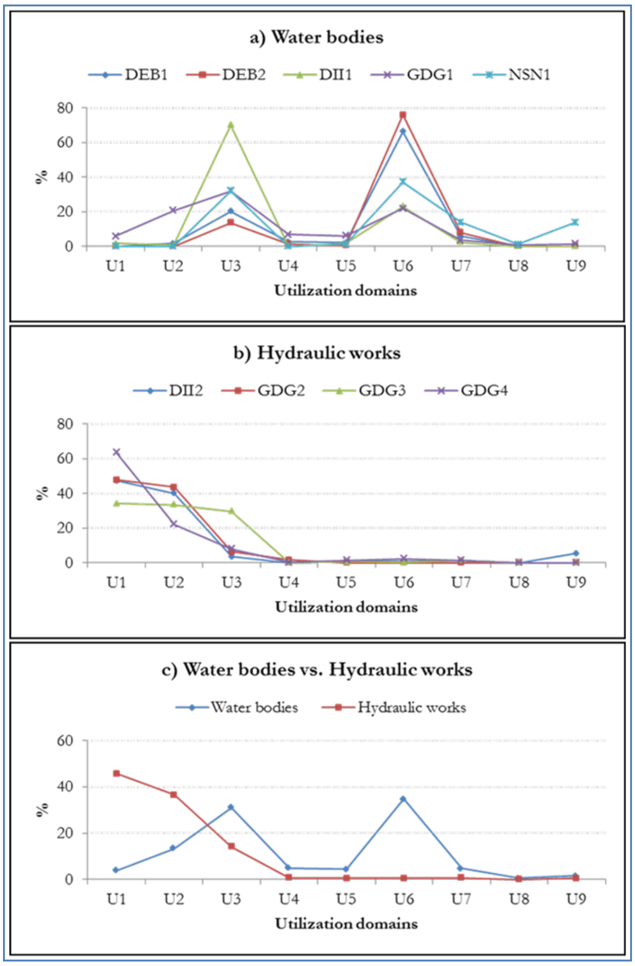


Figure 153: Water use domains

U1: Drinking, **U2**: Cooking food, **U3**: Laundry and dish washing, **U4**: Traditional beer cooking, **U5**: Paddy braising, **U6**: House building, **U7**: Animals watering, **U8**: Plants watering, **U9**: Others

5.2.3. Spatial scopes of observed water drawing sites

5.2.3.1. Travel distances for water drawing in Guièdougou and Di

- Travel distances for reaching water drawing sites in Guièdougou

Figure 154 shows the behavior of water drawers in Guièdougou. Out of 784 recordings, 96.68% of drawers seen at the irrigation canal site (GDG1) were from Guièdougou; where 45.92% and 23.72% were dwelling in Al-Hamdililaye and Dougoutiguikin quarters. Bèrèkan, Ouahigouyakin and Yinyinkin represented 13.01%, 12.63% and 1.40%, respectively. The rest (3.31%) of water drawers seen at GDG1 came from Gouran (2.93%) and Lanfièra (0.38%). All 512 and 232 water drawers seen at the modern well site (GDG2) and the water fountain site (GDG3), respectively, were from Guièdougou. At GDG2, 97.27% of drawers were from Dougoutiguikin, 1.17% from Al-Hamdililaye, 0.98% from Bèrèkan and 0.59% from Ouahigouyakin. Those observed at GDG3 were from three quarters: Yinyinkin with 68.53%, Ouahigouyakin 27.16% and Bèrèkan with 4.31%. Out of a total of 229 water drawers seen at the hand pump site (GDG4), 99.56% came from Guièdougou. Only one drawer was from Lanfièra (0.44%). In Guièdougou, 96.07% of water drawers dwelled in Ouahigouyakin; Yinyinkin represented 1.75%, Al-Hamdililaye 0.87% while Bèrèkan and Dougoutiguikin accounted each for 0.44%. On the day of survey, irrigation canal water was available only at GDG1 located 1.54, 2.11 and 3.40 km from Guièdougou, Gouran and Lanfièra centroids, respectively (Figure 155). GDG2 is located in Dougoutiguikin quarter, while GDG3 and GDG4 are located in Yinyinkin and Ouahigouyakin (Figure 155).

- Travel distances for reaching water drawing sites in Di

Figure 156 shows the situation observed in Di. As expected, the water fountain site (DII2) showed a short spatial scope. 87.10% and 10.48% of a total of 118 water drawers observed dwelled in Mandou and Pinikina and their compounds were the closest to the hydraulic work. The rest of water drawers (2.42%) seen at DII2 were from Missin. The spatial scope of the Sourou River site (DII1) was too wide. The large proportions of the river water drawers were from Mandou, Missin and Kolon with 25.42, 24.58 and 21.19% of a total of 124 drawers seen, respectively. Respectively, 13.56 and 7.63% came from Mossikina and Irakina. The remaining 4.24 and 3.39% were represented by Pinikina and Sobassô, respectively. The distance between DII1 and the mean center of the compounds was 1.48 km. This is more than twice the distance of DII2 (586 m) (Figure 157).

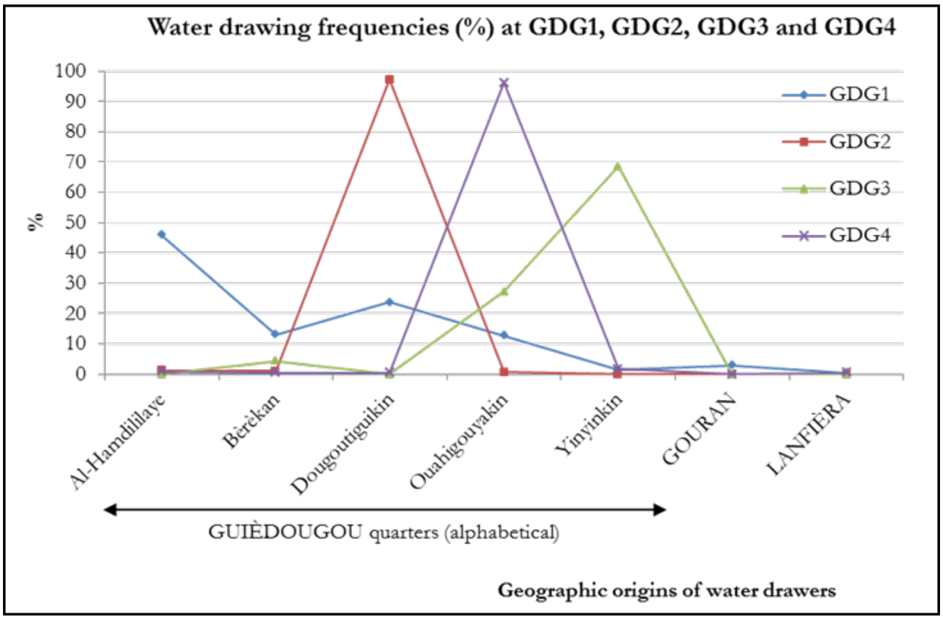


Figure 154: Water drawing frequencies per observed site in Guièdougou according to the origin of drawers

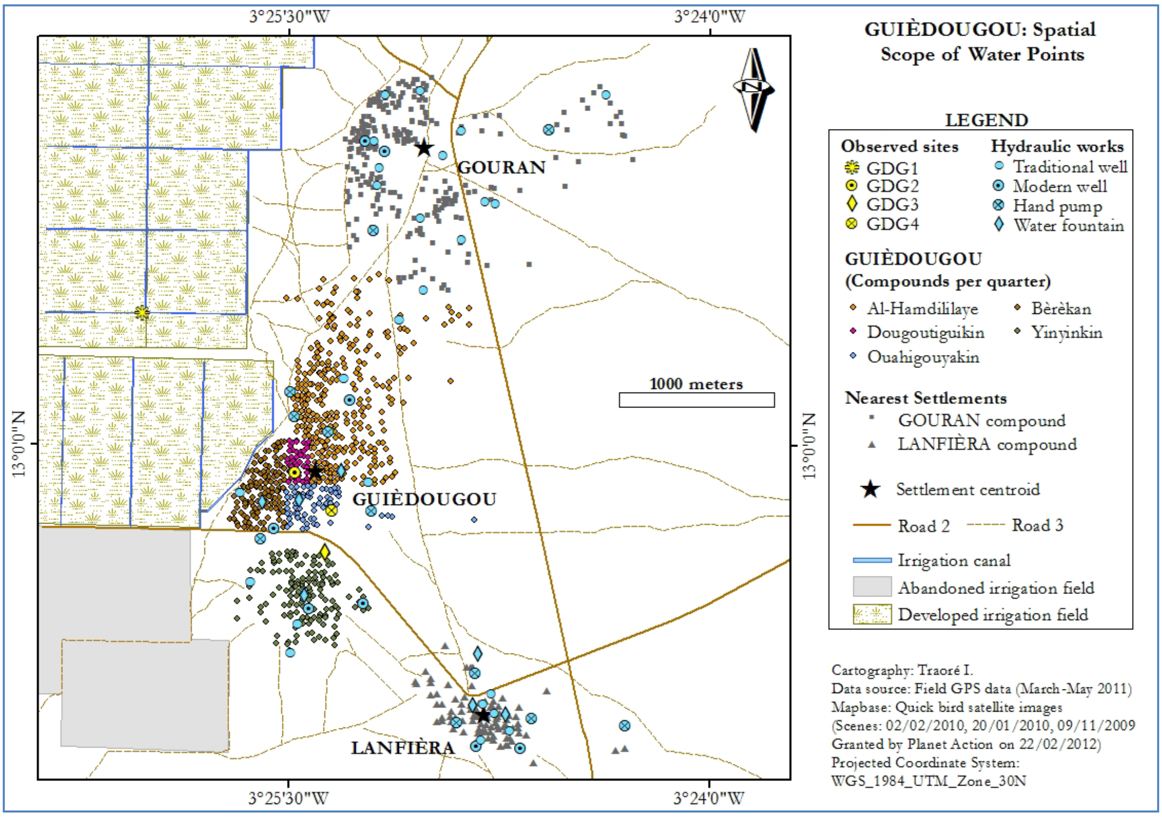


Figure 155: Spatial scope of observed water points used by nearest local communities

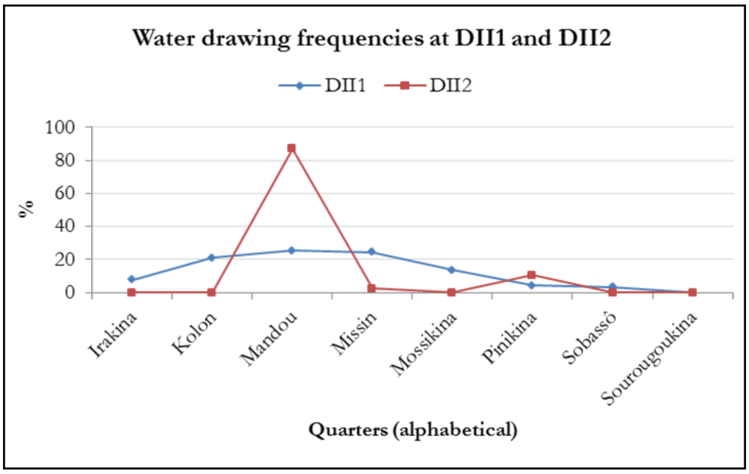


Figure 156: Water drawing frequencies per observed site in Di according to the origin of drawers

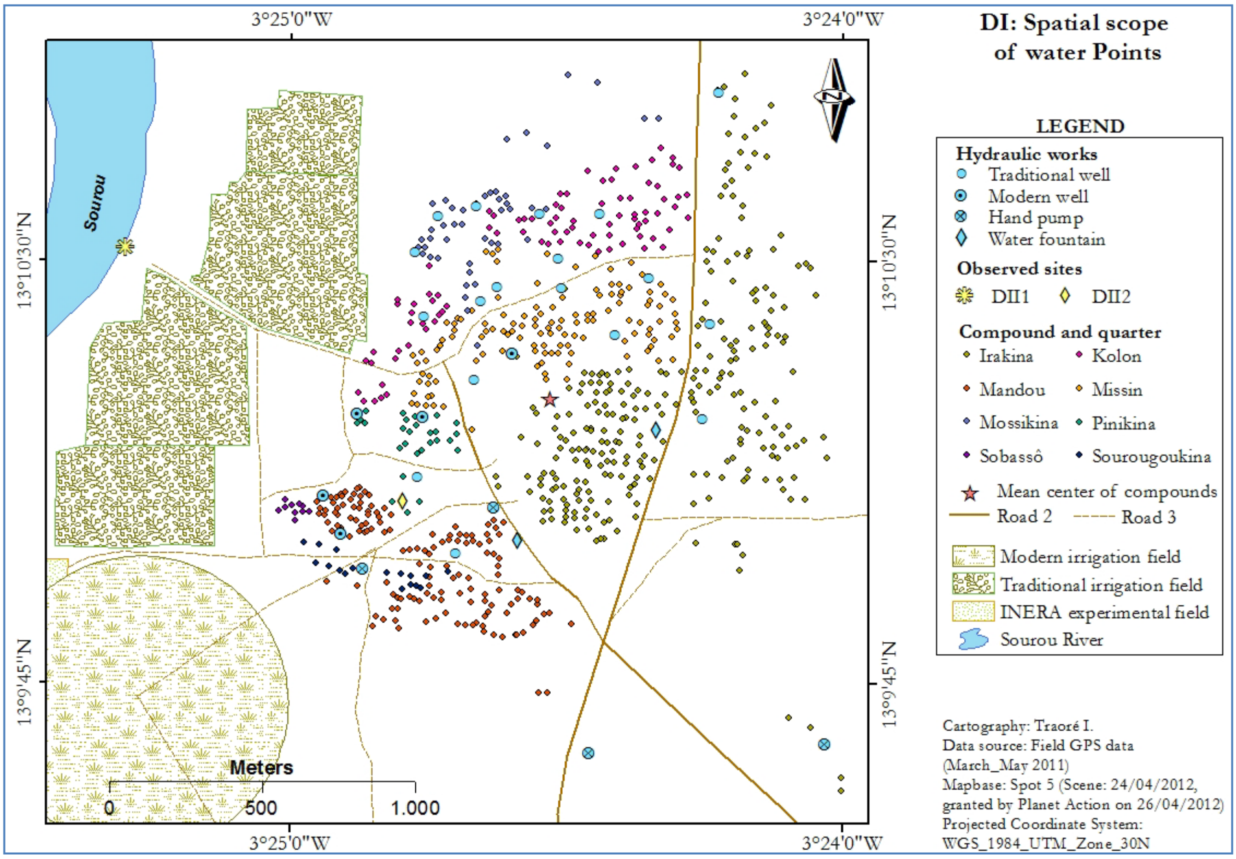


Figure 157: Spatial scope of observed water points used by the local community in Di

5.2.3.2. Travel distances for water drawing in Débé and Niassan

- Travel distances for reaching water drawing sites in Débé

Figure 158a compares the water drawing frequencies at two irrigation canals in Débé. A total of 404 water drawers were observed with 52.23% at the first irrigation canal site (DEB1) and 47.77% at second irrigation canal site (DEB2). Inhabitants of Zone 1, Zone 2 and Zone 3 were the most frequently seen at either observed sites with 31.28 and 17.10%, 31.75 and 20.21% and 24.17 and 27.98% each recorded at DEB1 and DEB2, respectively (Figure 158a). The proximity (0.95 km) of DEB2 from the quarter centroid of Bassinéré could explain the presence of all water drawers in this site as opposed to DEB1 (1.55 km from the centroid) (Figure 159). Centroids of Zone 4 and Zone 5 were located 1.24 km from DEB1, but Zone 4 was closer to DEB2 than Zone 5 (1.21 km vs. 1.41 km) (Figure 159).

- Travel distances to water drawing sites in Niassan

In Niassan, a total of 78 water drawers were recorded with 98.72% coming from Niassan and only 1.28% from Toma as seen in Figure 158b. With their centroids located 0.55 and 0.89 km from the irrigation canal (NSN1) (Figure 159), respectively, Kouroukan and Soukina represented 38.46 and 28.21% of water drawers. Gorakina and Gakina, located 0.67 and 0.83 km from NSN1, respectively, constituted 16.67 and 11.54% of drawers. The furthest origins were Silamèkin (1.14 km) and Niassan-Koura (1.76 km) with 1.28 and 2.56% of recordings, respectively. The travel distance from Toma to NSN1 was 2.38 km. No drawer originated from Lô which is 3.44 km from NSN1 (Figure 159). In Bossola, a lakeside settlement, people draw water directly from the stream.

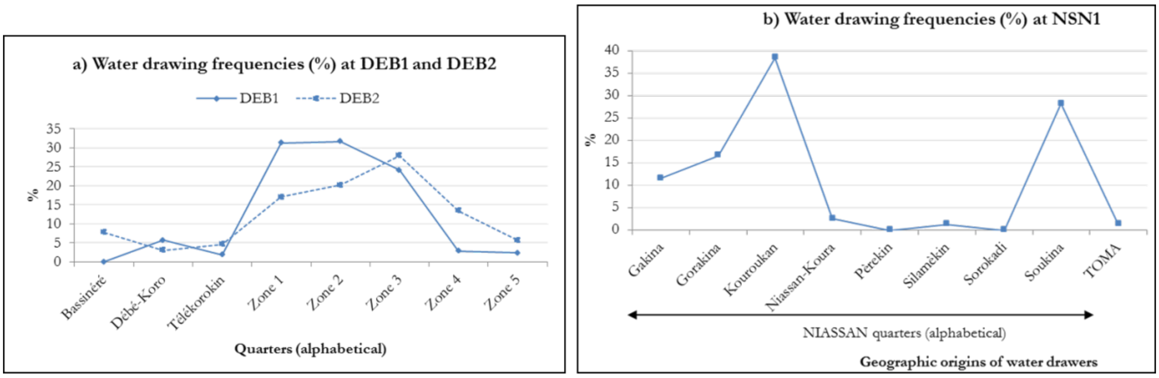


Figure 158: Water drawing frequencies according to the origin of water drawers and observed sites:

a) In Débé and b) In Niassan

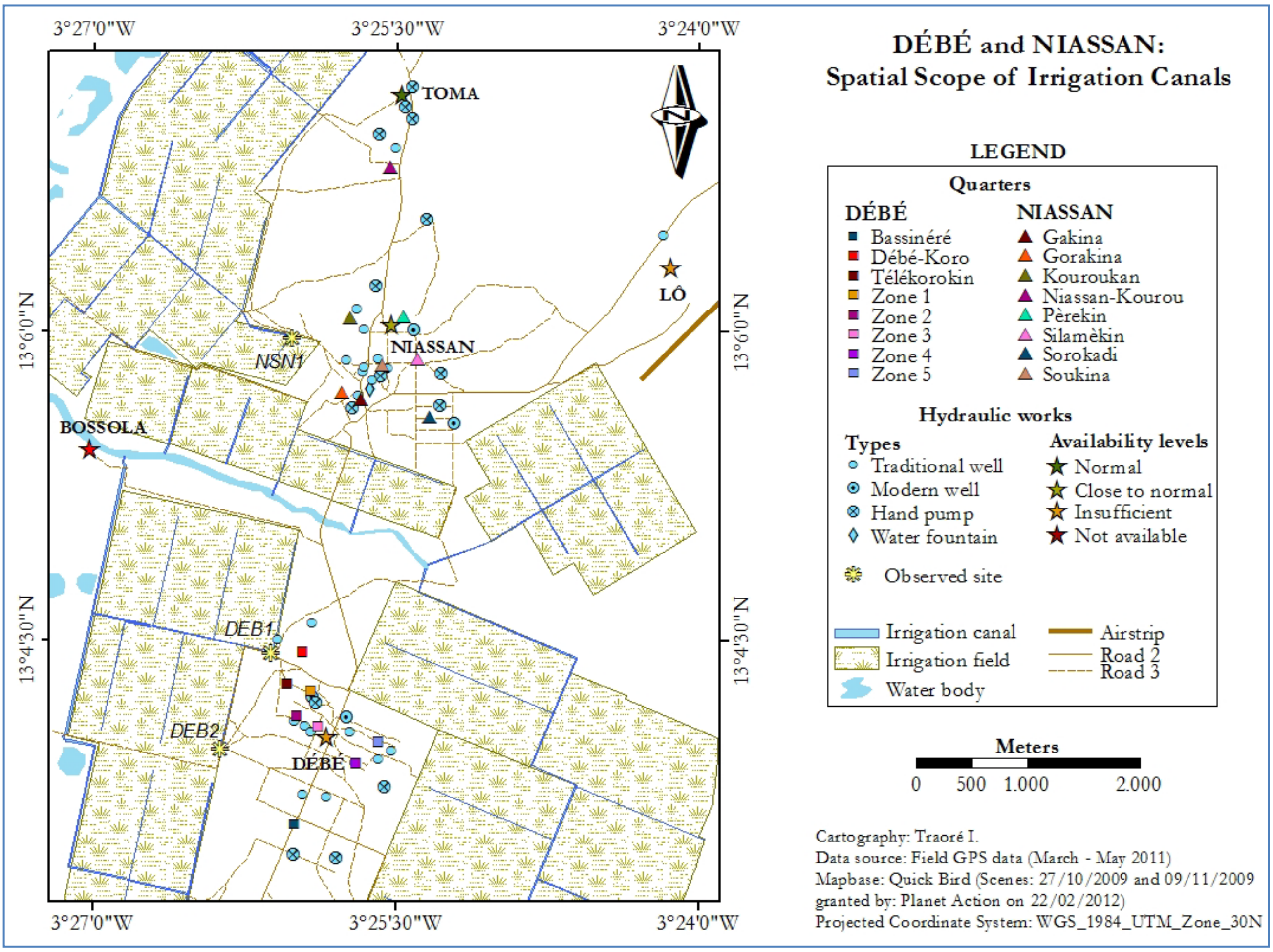


Figure 159: Plot of hydraulic works and freshwater bodies used by nearest communities in Débé and Niassan

5.2.4. Other determinants of the selection of water sources

Results show a relationship between the availability of transportation means, the water container to be transported, the water drawer gender and the selection of the water source.

5.2.4.1. Transportation means and gender determine observed sites' spatial scopes

- Availability of transportation means for carrying water containers

Figure 160a indicates that 70.61, 74.75, 46.85, 85.57 and 44.44% of water drawers observed at DEB1, DEB2, DII1, GDG1 and NSN1, respectively, used carts as transportation means to reach water bodies. Conversely, for hydraulic works, Figure 160b showed that 54.54, 71.20 and 50.87% of water drawers seen at DII2, GDG2 and GDG4 carried water on their head. The bicycle was employed by 41.16% of drawers observed at GDG3. Figure 160c indicates that the bicycle was the commonest transportation means used in the observed settlements while the cart was specific to water bodies (76.17%) and the head specific to hydraulic works (55.01%).

Figure 161a showed that plastic cans (20 L) and barrels (200 L) used to carry water from water bodies while Figure 161b shows that basins and plastic cans were mostly used to carry water drawn from hydraulic works. In terms of use of barrels, Figure 161c indicates 24.78% for water bodies vs. 9.64% for hydraulic works. Conversely, basins were 2.97% vs. 36.89%, respectively, for water bodies and hydraulic works. Statistics for plastic cans were 53.37% for water bodies vs. 47.17% for hydraulic works. Therefore, the availability or unavailability of a transportation means (cart and bicycle, mainly) and big containers (barrels) at the compound level could be a limiting factor for the selection of water bodies (see Annex 3 for transportation means distribution per settlement).

- Gender related-dependence

Figure 162a shows that, except at DII1, freshwater drawing was left to males. On the contrary, Figure 162b showed that drawing water from hydraulic works was left to females. Therefore, the water drawing frequency decreased for males and increased for females from water bodies to hydraulic works as shown in Figure 162c. However, the overall proportion of females was higher than that of males (55.79% vs. 44.21% of the total water drawers). This means that, in general, water drawing remains a female activity in the observed settlements.

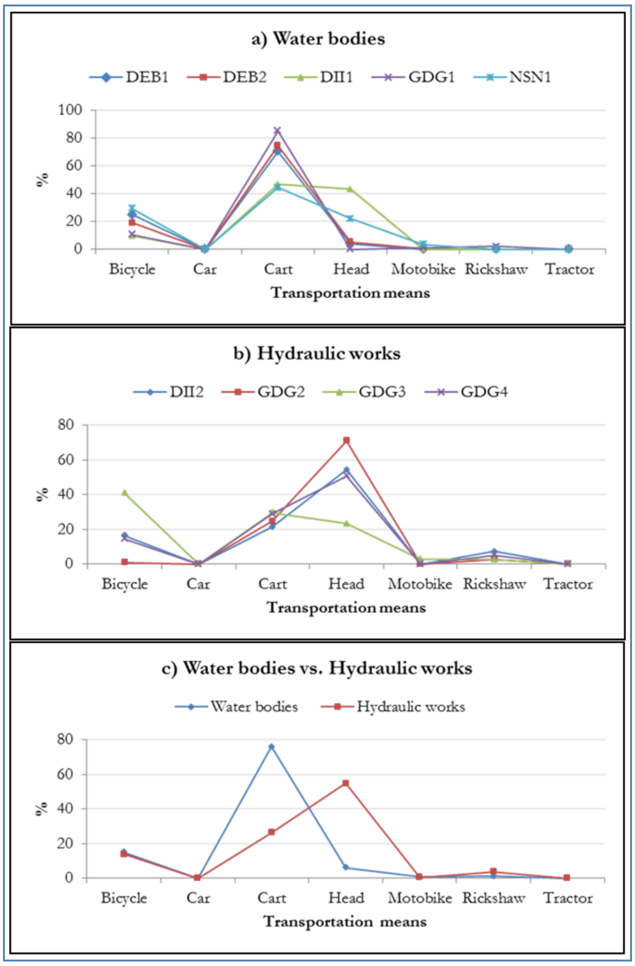


Figure 160: Pre-dominance of transportation means used for carrying water per observed site

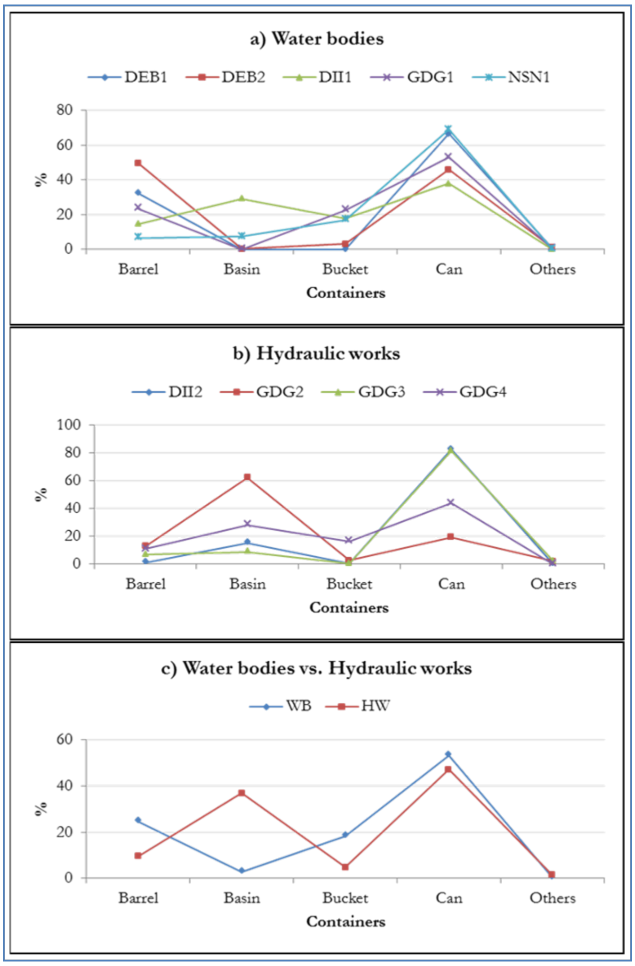


Figure 161: Pre-dominance of water containers used for carrying water per observed site

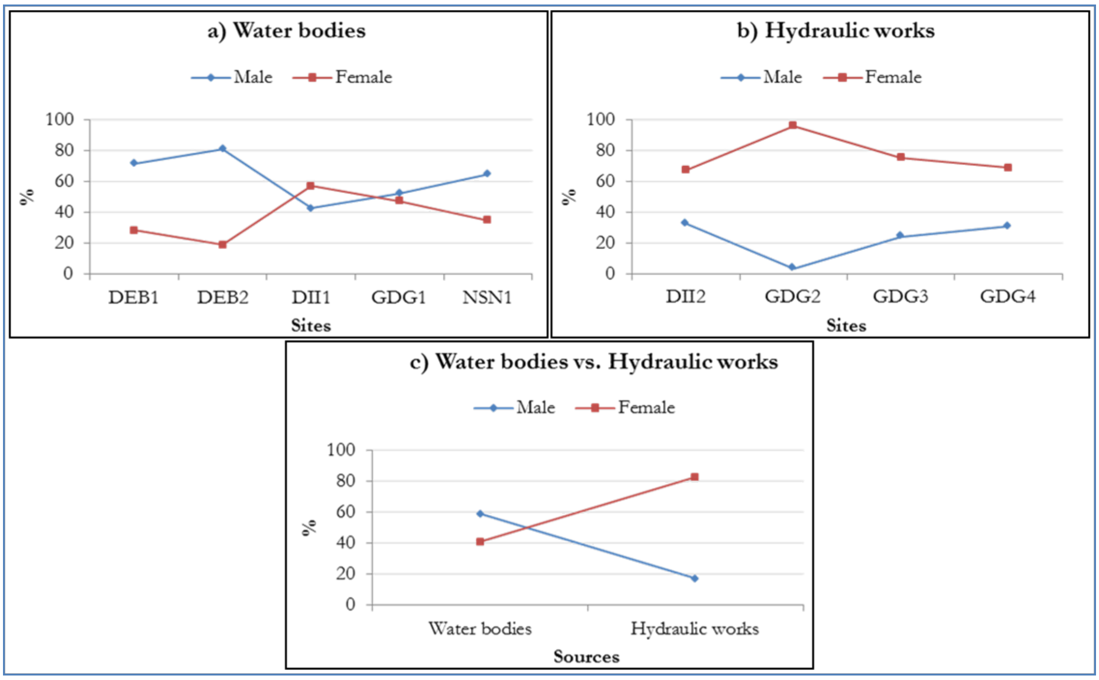


Figure 162: Pre-dominance of water drawers' gender per observed site

5.2.4.2. Hydraulic works access modalities determine their relative lower utilization

- Water access modalities

The modality of access to water determines the drawing site selection. The free-of-charge status of water bodies explained its frequent use (8.43%) by interviewees compared to hydraulic works (3.34%, which was reported only at GDG2) (R1 in Figure 152c).

Figure 163 shows that only modern and traditional wells were totally free-of-charge in the study area. The moderate contribution involved 65.63% of hand pumps. Here, a monthly amount (US Dollar 0.4) is fixed for all compounds irrespective of the quantity of water to be drawn.

The payment for water means that water is sold per unit of container and water fees are proportional to the quantity drawn in 95 and 17.19% of water fountains and hand pumps, respectively. However, water from fountains was more expensive when compare to water from hand pumps (water from fountains for US Dollar 0.01/20 L vs. water from hand pumps for US Dollar 0.01/40 L). The hand pump water selling concerned only three settlements: Koumbara, Guièdougou and Débé. Only one water fountain located at the medical center of Lanfièra was free-of-charge but only for admitted patients and those who care for them. Similarly, 17.19% of the rest of hand pumps belonged to primary and secondary schools. Therefore, they were free for teachers and limited for neighboring compounds. Figure 163 demonstrated that the cost of clean water can promote community exposure to free but contaminated freshwater bodies.

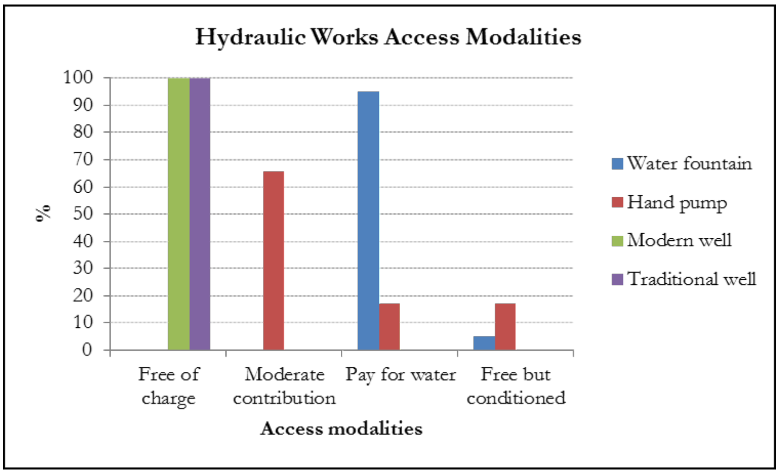


Figure 163: Water access conditions per type of hydraulic works in our AOI

- Influence of water access modalities on the seasonal demand

Figure 164 displays the evidence of the influence of water cost on the choice of water source. The water fountain was implemented at the end of 2006. First of all, we noticed decreased volumes of water use between 2007 and 2010: 895, 686, 265 and 291m^3. Figure 164 also demonstrates that each year the peak of water purchase appeared at the end of the dry season in May and drop three months later when the rainfall comes in August. It demonstrates that there is a seasonal shift in water source selection. During the dry warm season, wells dry out completely. People are obliged to buy water at the water fountain. With the onset of the wet season, the water table is reloaded by rainfall and wells are filled up at their maximum toward August. Since traditional wells are supplied, people concentrate on them and also collect rain water through roofs of houses. The amount of water consumed in October 2008 was only documented for a single day in which water was made available free-of-charge. This particular consumption volume (24 m^3) surpassed the entire consumption (21 m^3) for the month of April 2009 (Figure 164). In addition to rainfall, the curve representing monthly mean air temperatures shows an overlapping of peaks to those of water consumption (Figure 164).

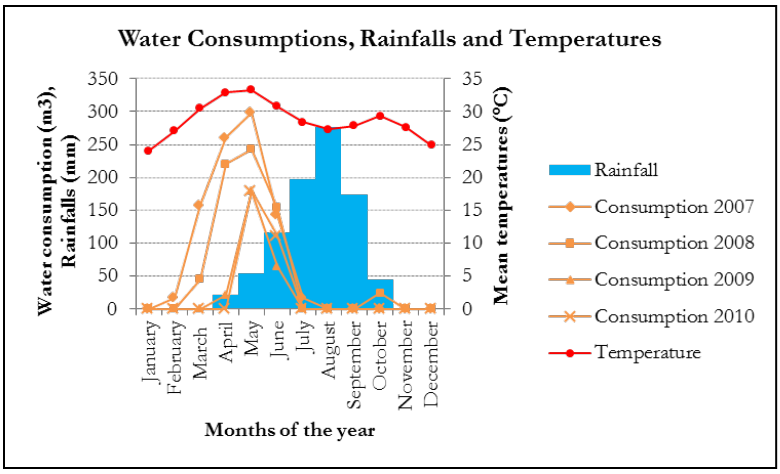


Figure 164: Plot of monthly water consumptions and potential climatic determinants

5.2.4.3. Water drawing from wells: a physical duty fatigue for women

Despite the free water of wells, results show that people were unable to get rope for water drawing. The reason led people (12.59%) drawing water from open water sources due to lack of rope (R3 in Figure 152c). Figure 165 shows the number of wells (modern + traditional) made an inventory and on which the calculation of mean lengths of ropes was based per settlement. On the 27 settlements, 29.63% had more than 25 m as length of rope to be drawn; 51.85% and 18.52% had 10-25 m and less than 10 m. The mean length of rope at the study area level was 18.99 m. Therefore we are right to accept the 20.77% of reported reasons pointed out the easiness of water drawing from water bodies (R7 in Figure 152c).

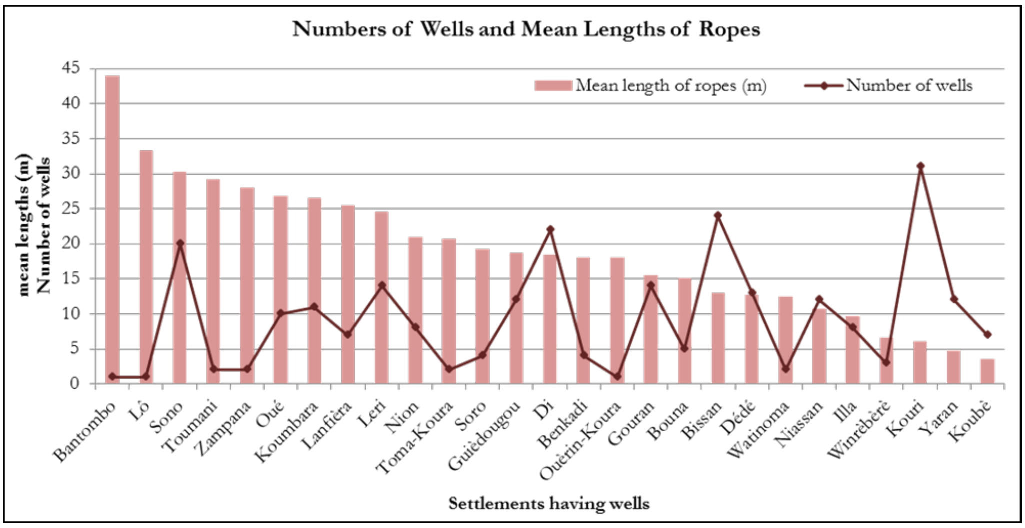


Figure 165: Spatial distribution of lengths of ropes and numbers of wells per settlement in 2011

5.2.4.4. *Organoleptic properties of water*

- Global situation

Soap saving was reported to be 10.20% at water bodies vs. 0.35% at hydraulic works (R6 in Figure 152c). The water utilization domain using soap is of great concern. Laundry and dish washing represented 31.15% for water bodies vs. 14.15% for hydraulic works (U3 in Figure 153c). In the AOI, ground water from Niassan is popularly qualified as poor thirst quencher due to its hardness. Through focus groups, women reported whitish residual color by drying out clothes after laundry with water from hydraulic works. On the other hand, they feel comfortable when doing laundry with irrigation canal water because it lathers well and clothes dry without whitish precipitate.

- Case from Bantombo

The most alarming picture of the whole community exposure to contaminated water bodies due to the organoleptic characteristics of water from hydraulic works was recorded in Bantombo. Despite the normal availability of hydraulic works, Figure 166 shows that the community traverses longer distance to reach ponds located 2207m from the centroid of compounds. To express the hardness of the ground water, the community employs a particular expression: *"Our water cannot boil the beans"*. Diarrhea resulting from the drinking water was also reported. Therefore, hydraulic works were abandoned in favour of water bodies for which the community has to move 10 times further (Figure 166). In addition to the main stream (Sourou River) and irrigation canals, semi-permanent ponds are also sites of water drawing in the study area.

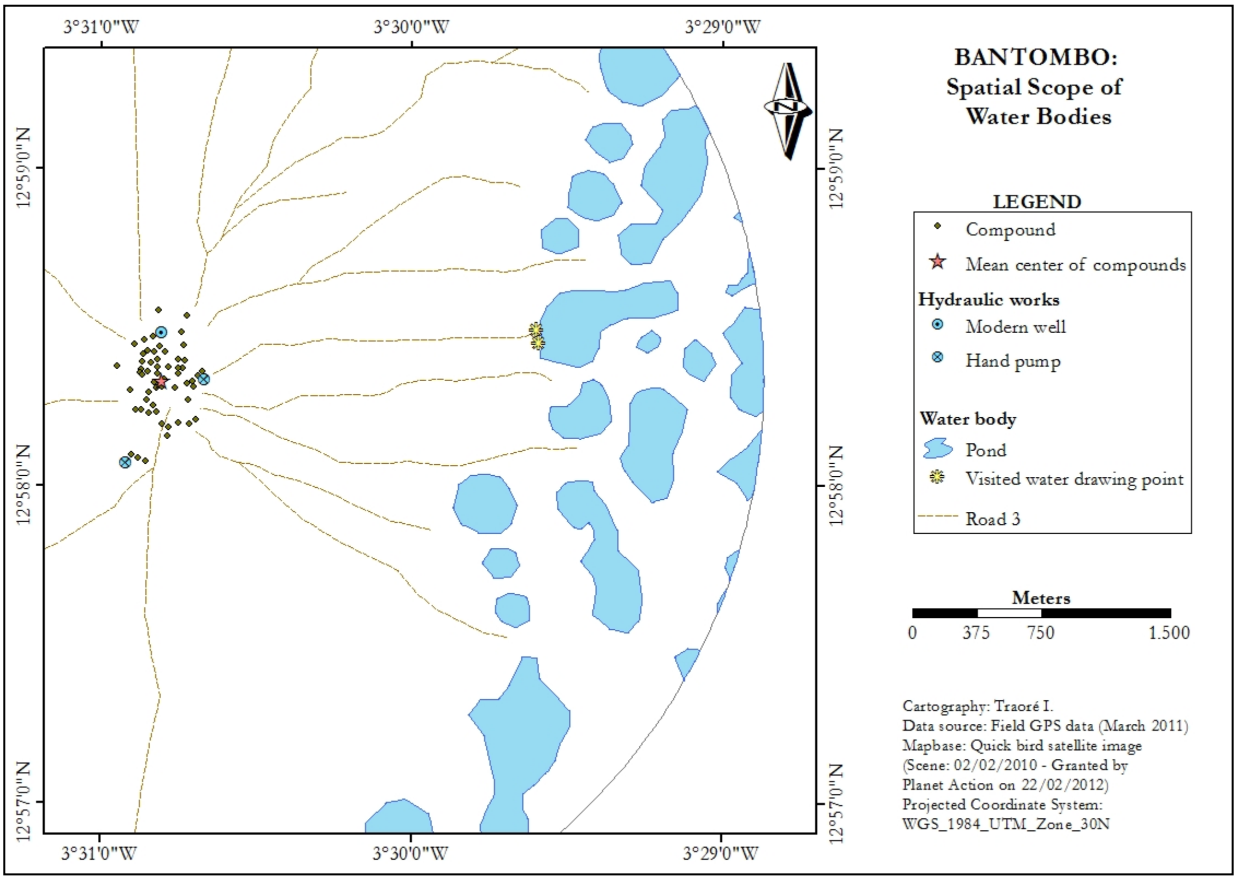


Figure 166: Plot of hydraulic works and semi-permanent ponds which are being used by the local community in Bantombo

5.2.4.5. Source of quarrels at water fountains and hand pumps

- Time related issue

Women are usually in a race against time because they have to accomplish diverse tasks mostly depending on the sunshine. Time saving played a capital role in the preference of water bodies to hydraulic works: 14.54% vs. 0.86% (R4 in Figure 152c).

To measure the waste of time, we focused on water drawing sites observed in Guièdougou because it gives us a spectrum of different sites but interestingly within the same community. For that only water utilization domains related to drinking, cooking and traditional beer making (U1, U2 and U4 in Figure 153) were analyzed in Guièdougou. These four domains totaled 1233 observations with 24.17, 40.71, 18.57 and 16.55% at the irrigation canal (GDG1), the modern well (GDG2), the water fountain (GDG3) and the hand pump (GDG4), respectively. In each the water drawing, elapsed time was obtained as the difference between time of departure and arrival time.

Figure 167 indicates that only GDG3 and GDG4 were highly represented for elapsed time more than one hour. Reasons for time saving (R4) were 21.05% at GDG1 (Figure 152a), 1.45, 0 and 0.82% at GDG2, GDG3 and GDG4, respectively (R4 in Figure 152b). These results indicate that the elapsed time is influenced by the number of individuals accomplishing the task together, the number of containers and their volume and the drawer-capacity of the water point. In this thesis we defined the drawer-capacity of the water point as the number of drawers the water point allows to draw water together and at the same time. Many drawers (at least four) were drawing water from water bodies (GDG1) and wells (GDG2) together and at the same time.

In the study area, the drawer-capacity of WF never exceeded two individuals at a time, because there are only two taps available. In most of cases, only one tap was in use. Therefore, the number of drawers served at the same time was maximum two. The lowest drawer-capacity was attributed to hand pumps with only one output. In most of cases hundreds of running was needed to fill up a single 20 L plastic can due to lower pressure of water output in hand pumps. In addition, the automatic system of water fountains and manual system of hand pumps revealed the fact that the elapsed time in the latter was higher than the former in the last three classes.

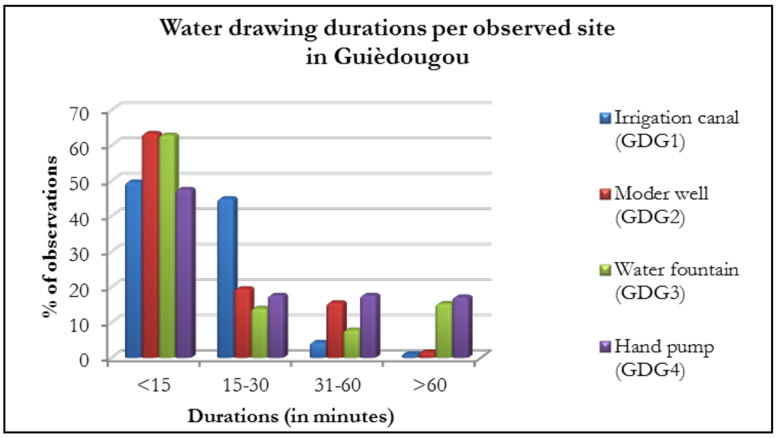


Figure 167: Water drawing duration per observed site in Guièdougou

- Seasonal interruption of water supply

During this field observation, we noticed a break of water supply for water fountains observed in Guièdougou (GDG3) and in Di (DII2). These water fountains as well as those in Bouna, Koumbara and Lanfièra were connected to water towers that were filled up using Volta solar panels. It means that in 78.95% (n = 15) of the study area, water fountains were using solar energy and only 21.05% (3 in Sono and 1 in Niassan) were using fuel engine generators. Cut off of water supply were recorded during cloudy days with less than four hours daily sunshine. Figure 168 shows the monthly distribution of proportions of days with less than four hours sunshine duration for a period of 31 years (1980-2010) with a $\chi^2 = 364.09$, (p-value < 0.001). It then demonstrates that water fountains do not work every day in the study area. Consequently, water drawing at the hand pumps and water fountains led to longer waiting periods. Higher water supply interruptions coincide with the raining season. This period is very busy due to a peak in wet agricultural activities.

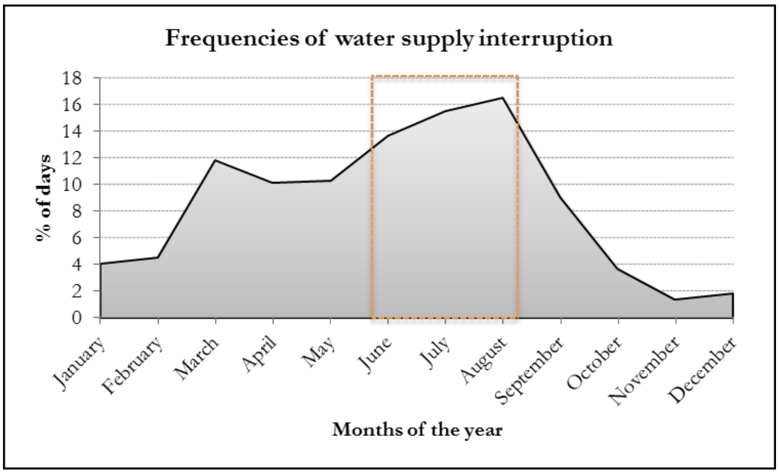


Figure 168: Frequencies of water supply interruption for water fountains powered by solar energy

5.2.4.6. Sustainable maintenance of water equipment

- Water management committees

In terms of clean water supply, hand pumps and water fountains come first. However, their durability depends on an appropriate management, continuity in maintenance of the equipment and consistent contribution of maintenance fee by users. Hand pumps are managed by water point management committees and water fountains by solar equipment management committees. At the village level, these committees form an association of water users. The money collected by the water point management committees is used to procure spare parts of equipment or fuel (in case of engine generator) and to support fees for maintenance. Despite these management measures, Table 41 points out difficulties in the sustainable maintenance of water equipment. An inventory of hydraulic works out of condition was made in 29.73% (n = 11) of the settlements in the study area with a global breakdown rate of 23.85%.

- Case from Gouran and Nion

Gouran showed a high rate of water points out of condition. After three years of functioning, the management committee was unable to afford the maintenance of the water tower and the drilling system broke down in mid-2009. In Nion, the hand pump, newly installed in December 2010, was found out of condition in March 2011. In this case, the responsibility could be attributed to the general contractor responsible for water drilling. Before mid-2009, Gouran had normal availability of hydraulic works but due six hydraulic works going out-of-condition, there is a reversal in availability to an insufficient level. Table 41 raises the question of capacity building transfer in terms of knowledge and mastery of equipment maintenance. It can be deduced that the expected returns from water sale is usually overemphasized during the planning stage when in reality we are faced by a community looking for free instead of “quality” water.

Table 41: Hydraulic works found out of condition in 2011 per settlement

Theoretical rates of hydraulic works out of condition						
	Numbers			Theoretical rates (%)		
Settlements	*Water fountain*	*Hand pump*	*Total*	*Water fountain*	*Hand pump*	*Total*
Benkadi	0	1	1	-	33.33	33.33
Débé	0	3	3	-	42.86	42.86
Gouran	4	2	6	100	50.00	75.00
Guièdougou	1	3	4	16.67	33.33	26.67
Leri	0	1	1	-	25.00	25.00
Lô	0	1	1	-	100	100
Niassan	2	3	5	66.67	25.00	33.33
Nion	0	1	1	-	100	100
Ouèrin-Koura	0	1	1	-	50.00	50.00
Sono	0	2	2	0.00	33.33	22.22
Toma-Koura	0	1	1	-	100	100
Total	**7**	**19**	**26**	**26.92**	**22.89**	**23.85**

5.3. Water contacts through recreational activities: Case study from Toma-Île

5.3.1. Short term pattern of children recreational swimming

From a total of contacts with 2693 children, 10.69% of swimming activities occurred during Period_1 and 89.31% was recorded during Period_2. Statistics in Table 42 showed that during Period_1 daily maxima and mean air temperatures (MAT) showed strong influences on swimming daily frequencies than did minima. Conversely, against all odds, air temperature variables during Period_2 almost failed to explain the fluctuation in swimming volumes. Plotting all 62 days data together, outputs indicated higher coefficients for daily MAT than minima and maxima which had the same power.

Table 42: Linear regression relationship between air temperature and occurrence of children recreational activities in Toma-Île

Influence of Daily Air Temperatures on Children Recreational Activities Occurrence									
Temperature (°C)	Period_1			Period_2			Period_1&2		
	r	*r²(%)*	*p-value*	*r*	*r²(%)*	*p-value*	*r*	*r²(%)*	*p-value*
Minima	0.68	46	0.000	0.13	2	0.239	0.72	52	0.000
Maxima	0.85	72	0.000	0.15	2	0.211	0.73	54	0.000
Means	0.88	78	0.000	0.02	0	0.469	0.78	61	0.000

Figure 169a shows that the first case of swimming during Period_1 was recorded from the 21st day of observation, that is, on 23rd of January 2011. Daily volumes of swimming varied from 20 to 40 children till the end of the first period of observation. Two months later, results of Period_2 demonstrated a big change in the daily volume of swimming which varied between 40 and 140 contact per day.

Figure 169b demonstrates that swimming started only when the daily MAT reached 25 °C. It also showed that before 23rd of January 2011, daily MAT was below 25 °C. Orange dots represent records of Period_1 and red dots those of Period_2. Only one day (3rd of April) was below 30 °C during Period_2. Figure 169c shows the time shifting and peak hours of swimming between Period_1 and Period_2. In the first, children started to play in the river from 10H while it occurred earlier in the second from 08H (# 2 hours).

The same length of time lag remained between highest peaks in the day during both periods of observation: 16H vs. 14H, respectively. Therefore, the curve for Period_1&2 displays two real peak hours of swimming in the daytime. The first and small one occurred in the morning at 11H or one hour before the mid-day break. The second and highest was reached at 14H or two hours after the mid-day break and coincides with the hottest hour of the daytime. Figure 169d shows that swimming was observed in 83% vs. 67% of the 12 hours of observation. Figure 169 thus demonstrates a clear influence of daily MAT on the behavior of children in terms of recreational activities.

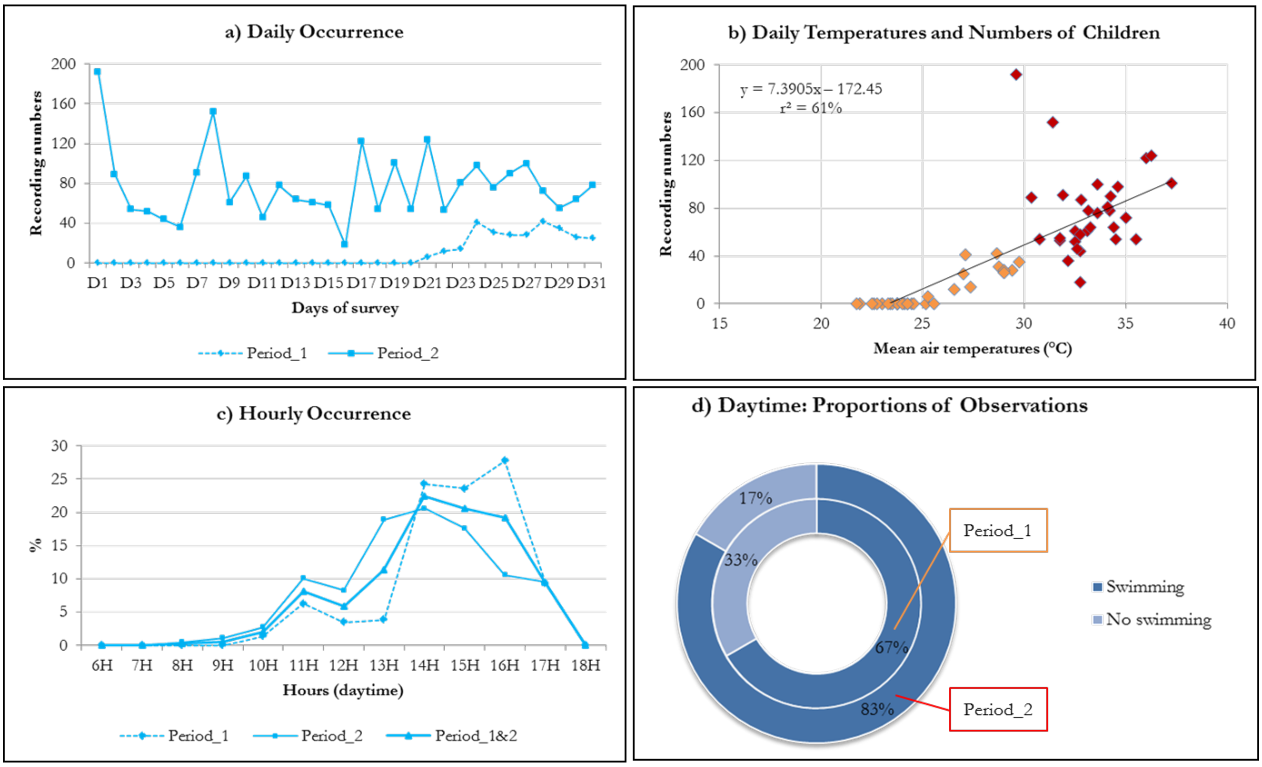


Figure 169: Occurrence pattern of children recreational swimming in Toma-Île:

5.3.2. Mean term pattern of children recreational swimming

We used the daily mean air temperature of 25 °C as cut-off point to demarcate cool days (<25 °C) from hot days (≥25 °C). For a convenience, we used hot days as proxy of temporal vulnerability index. Put simply, cold days meant no swimming and conversely, hot day implied occurrence of swimming. Next, the mean term influence was measured retrospectively. It included the distribution of proportions of cold and hot days for each month using 25 °C as cut-off point and extrapolated for a period of 31 years (1980 to 2010).

Figure 170a compares proportions of cold and hot days to monthly mean air temperatures. Days were distributed per month with a $\chi^2 = 4147.09$ (df = 11 and p-value < 0.001). On the other hand, Figure 170b shows proportions of days falling into each class of mean air temperature within the month. Days were distributed monthly and according to the five classes with a $\chi^2 = 10093.12$ (df = 44 and p-value < 0.001).

Figure 170a shows that with a slight difference between MAT (# 0.33 °C), April and May recorded the same proportions of hot days, 100% each. Figure 170b shows that 96% vs. 93% of days were located between 30 °C and 39 °C, respectively. The rest of days fell into the class 25-29 °C with 4 and 7 %, respectively.

Conversely, with a slight difference in MAT (# 0.21 °C) (Figure 170a), August and February showed a big difference in proportions of hot days (93% vs. 78%). Figure 170a points out the fact that daily MAT varied extremely in February than in August. Days in February fell into five classes while those in August were spread into only three classes. Furthermore, February recorded 22% of cold days against 7% for August.

December and January followed the same tendency with # 0.83 °C and 49% vs. 37% of hot days as displayed in Figure 170a. Figure 170b shows that days in both months fell into the same temperature classes. However, proportions in December increased toward hot days while those in January increased toward cold days.

Figure 170a also shows that, although March recorded higher MAT than October (# 1.15 °C), March had less proportions of hot days (98.82% vs. 99.58%). Figure 170b shows that days in March were spread into four temperature classes while those in October fitted into three. It implies that temperatures were more constant in October and varied extremely in March. In addition, March recorded more cold days than did October (1.18% vs. 0.42% corresponding to the class 20-24 °C).

5.3.3. Long term pattern of children recreational swimming

First of all, cold and hot days were distributed per year with a $\chi^2 = 296.16$ (df =30and p-value < 0.001). Figure 171a compares the behavior of the curve representing the annual numbers of hot days to that showing fluctuation in annual MAT. This means that the higher the annual MAT, the larger the number of hot days. Since annual MATs are rising according to Figure 171a, hot days will follow. The hottest year was 2010 which lasted for 76 hot days while the coolest year was 1982 and the annual MAT for the two periods differed by 2.32 °C. Figure 171a, therefore, demonstrated that the curve for annual number of days is nothing else than the outline of the annual MAT.

Consequently, projection of annual number of hot days is in the range of 12, 19 and 48 days for 2015, 2025 and 2050, respectively. This shows an increase trend when compared to 2010. We can, therefore, predict that the pressure on water bodies due to recreational swimming will increase considerably in the coming years due to climate change. Highlighted by Figure 170a, Figure 171b divides the year into three levels expressing the pressure of swimming on freshwater bodies. There was a higher pressure on water bodies due to swimming during the months of March, April, May, June and October with over 95% of hot days in each of these months within the year. Consequently, there was participation of children in recreational swimming in 42% of the whole year. There was moderate pressure on water bodies as a result of swimming in the months of July, August, September and November which constituted 33% of the whole year. These months had days with <10% occurrence of cold temperatures below 25 ºC. Lower pressure on water bodies due to swimming was recorded in the remaining three months (January, February and December), constituting 25% of the year with > 10% cold days observed.

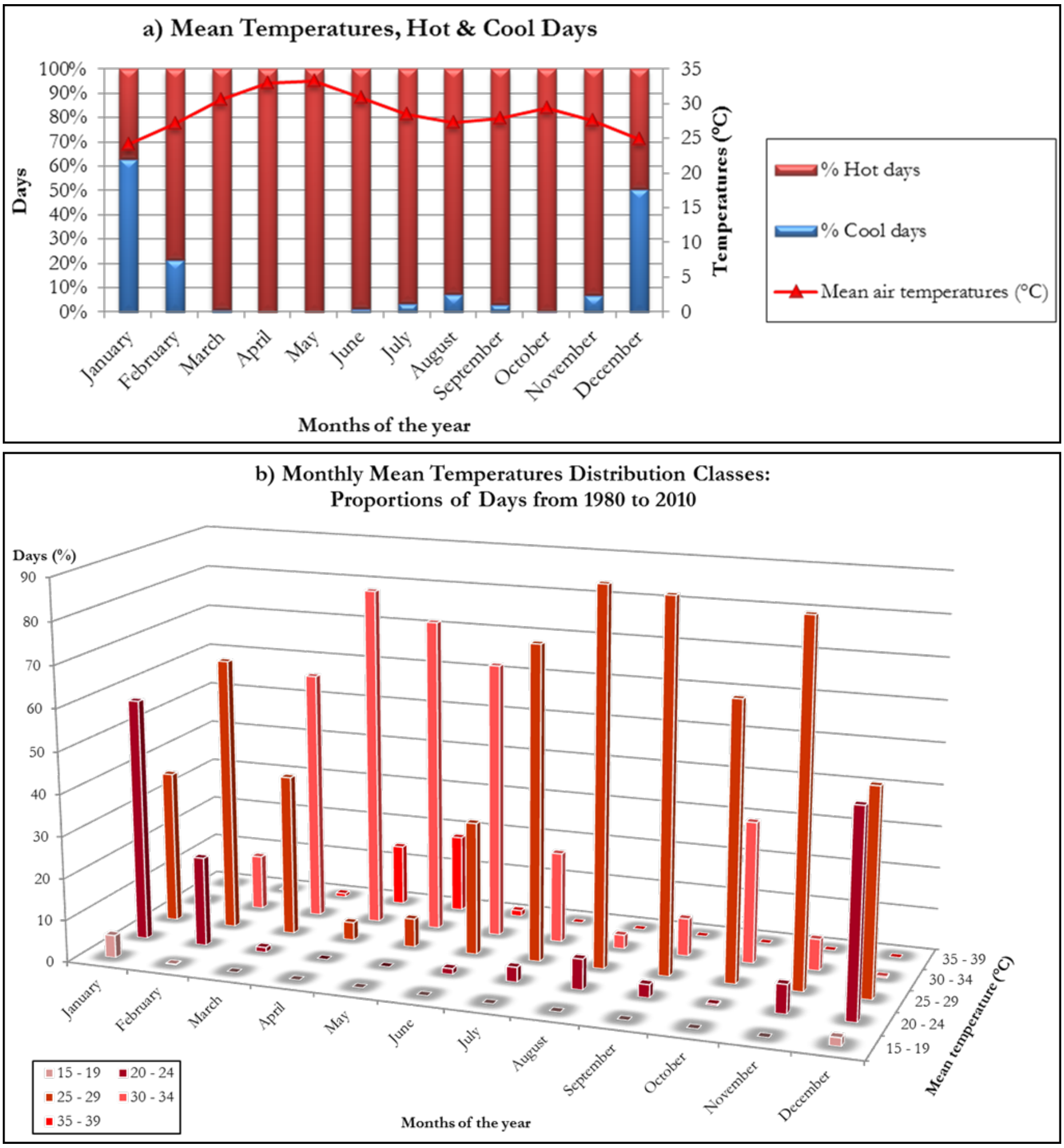


Figure 170: Mean air temperatures for 31 years (1980-2010)

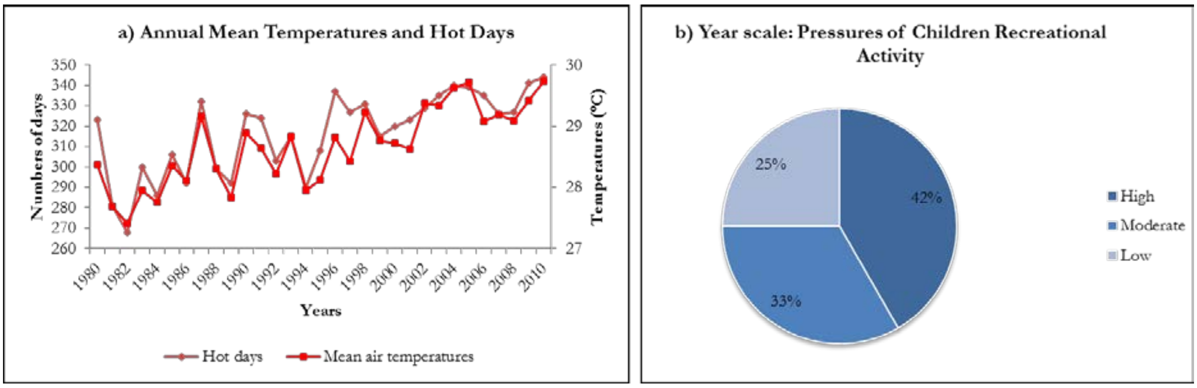


Figure 171: Long term influence of air temperature on children recreational swimming

5.3.4. School calendar and school attendants business with respect to swimming

Figure 172 displays the annual school calendar from October to May for secondary schools (eight months) and to June for primary schools (nine months). Figure 172 also shows that the school year is organized and divided into three discontinued quarters fragmented by breaks. Each cell is scaled to five days. In 67 and 58% of the year, primary school pupils and secondary school students, respectively, are kept away from exposure activities except for break periods which constitute 33 and 42% of the year for the afore-mentioned categories, respectively. The 1st and 2nd breaks last two weeks each and represent together 8% of the year while holidays represent 25% and 33% of the year per level, respectively. Holidays coincide with the wet season and the medium pressure of CRS due to rising MAT. The 1st break overlaps the dry and cold season and lower pressure of CRS. The 2nd break occurs exactly during the dry and hot season; and coincides with the highest peak of the pressure of CRS. Table 43 demonstrates the weakness of the daily scale of the school calendar. School -goers take advantage of each break time to do recreational activities even during school periods. Therefore school children do not totally escape from schistosomiasis risk during school terms. The classroom period occupied 71% of the week for both educational levels. Classroom attendance took 75% of the daytime. Educational weekly time table shows two break days: Thursday and Sunday for primary schools and Saturday and Sunday for secondary institutions.

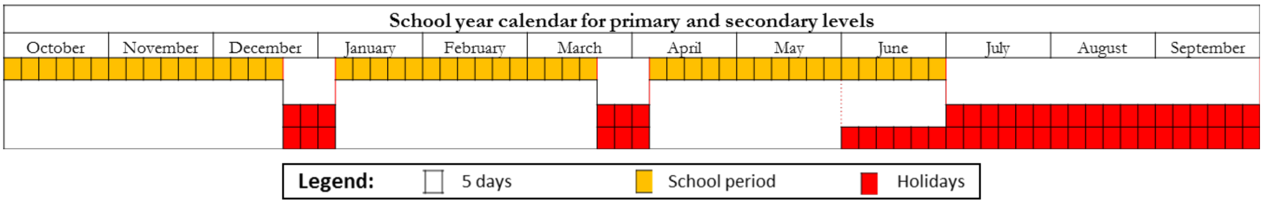


Figure 172: Classic calendar for Primary and Secondary Schools

Table 43 shows the distribution of three days observation of recreational swimming in Di. Table 43a shows that proportions of swimming children increase on break days. On Wednesday, 62 subjects were recorded from 12H to 14H. About 82% of them were not enrolled in school. They were secondary school students and only one was a primary school pupil. A total of 103 individuals were recorded on Thursday with equal proportions for those not attending school and primary school children. On Sunday, a common break day for school-goers, 111 subjects were recorded with 62% for school-goers (48.65% and 13.51% for primary and secondary schools, respectively). For these last two days, the survey was done between 13H and 17H because they are both school break days. Table 43a also shows that proportions decreased from non-enrolled subjects to secondary school students. Then, Table 43b shows the age-related occurrence of recreational swimming. Children between 10 and 14 years old represented the majority of non-enrolled and primary school pupils while the majority for secondary school students were in the 15-19 years age-group.

Table 43: School attendance status and frequencies of recreational swimming in Di

a) Daily distribution (N=276)				
	School attendance status			
Date of survey	*Non-enrolled*	*Primary school*	*Secondary school*	Sum
Wednesday 09-MAY-2012	18.48	0.36	3.62	**22.46**
Thursday 10-MAY-2012	14.13	14.13	9.06	**37.32**
Sunday 13-MAY-2012	15.22	19.57	5.43	**40.22**
Sum	**47.83**	**34.06**	**18.12**	**100**

b) Age group distribution (N=276)				
	School attendance status			
Age group	*Non-enrolled*	*Primary school*	*Secondary school*	Sum
5 - 9	7.97	7.25	0.00	**15.22**
10 - 14	22.10	24.64	1.81	**48.55**
15 - 19	14.86	2.17	15.94	**32.97**
20 - 24	2.17	0.00	0.36	**2.54**
25 - 29	0.72	0.00	0.00	**0.72**
Sum	**47.83**	**34.06**	**18.12**	**100**

5.4. Water contacts through socioeconomic and professional occupations: Case from irrigation, traditional fishing and water lily bulbs gathering

5.4.1. Reasons underlying people involvement in irrigation (IRR), traditional fishing in ponds (TFP) and water lily bulbs gathering (WBG)

A total of 501 compounds was additionally surveyed to understand the reasons leading members to participate in TFP (55%) and in WBG (45%). Table 44 shows that 54% of interviewed TFP was involved in the activity, while, 51% of WBG was not enrolled in the activity. It also shows that the WBG was done in 54% (n = 20) of AOI settlements, while the TFP covered 65% (n = 24) of settlements.

Table 44: Spatial distribution of compounds additionally interviewed about FTP and WBG

Compounds additionally interviewed for collecting reasons of the participation in traditional activities						
	TFP			WBG		
Settlement	*Yes (N=149)*	*No (N=125)*	*Total (N=274)*	*Yes (N=111)*	*No (N=116)*	*Total (N=227)*
Bantombo	1.82	0.36	2.19	3.96	3.96	7.93
Benkadi	0.73	0.73	1.46	0.44	0.44	0.88
Bissan	1.82	1.82	3.65	3.96	2.20	6.17
Bouna	1.09	1.09	2.19	0.88	0.88	1.76
Débé	1.46	0.00	1.46	2.20	0.00	2.20
Di	2.19	2.19	4.38	2.20	2.20	4.41
Gouran	4.74	4.74	9.49	2.64	2.64	5.29
Guièdougou	0.73	0.73	1.46	0.00	0.00	0.00
Illa	3.65	0.00	3.65	4.41	4.41	8.81
Koubè	3.65	0.73	4.38	2.20	2.20	4.41
Koumbara	3.65	3.65	7.30	0.00	0.00	0.00
Leri	1.82	1.82	3.65	0.00	1.76	1.76
Niassan	1.46	1.46	2.92	2.20	2.20	4.41
Nion	1.82	1.82	3.65	0.00	1.76	1.76
Oué	1.82	1.82	3.65	2.20	2.20	4.41
Ouèrin	1.82	1.82	3.65	3.08	3.08	6.17
Sono	4.01	3.65	7.66	7.05	7.05	14.10
Toma-Île	5.11	6.20	11.31	0.00	0.00	0.00
Toma-Koura	0.73	0.73	1.46	0.00	0.44	0.44
Toumani	1.82	1.82	3.65	0.00	0.00	0.00
Touroukoro	1.46	1.46	2.92	2.64	2.20	4.85
Winrèbèrè	1.82	1.82	3.65	0.44	0.44	0.88
Yaran	3.65	3.65	7.30	6.17	8.81	14.98
Yayo	1.46	1.46	2.92	2.20	2.20	4.41
AOI	**54.38**	**45.62**	**100**	**48.90**	**51.10**	**100**

TFP: Traditional Fishing in Ponds; **WBG:** Water lily Bulbs Gathering

5.4.1.1. Participation reasons and estimated incomes from WBG and TFP

- Reported reasons for WBG and TFP

Figure 173 shows spectrum of reasons reported by compounds involved in TFP and WBG. The source of food and money explained the participation of more than 80% of interviewees. About 2 and 1% of TFP was participated for purely cultural and purely income reasons, respectively. The cultural dimension is all the more important in the occurrence of TFP that it is regulated by customs. Each year, before the commencement of TFP, sacrifices are done by the *Kôtigui* or traditional priest in in local language. Days as well as ponds to be fished are communicated only by the *Kôtigui*.

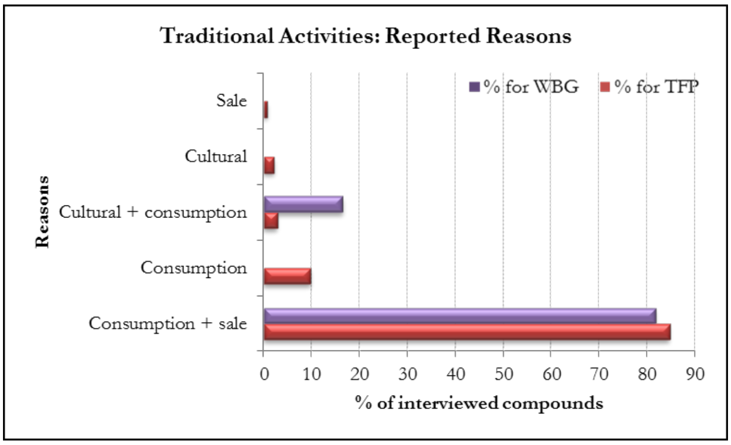


Figure 173: Proportions of interviewed compounds per reason for participating in WBG and TFP

TFP: Traditional Fishing in Ponds; **WBG:** Water lily Bulbs Gathering

- Estimated incomes from WBG and TFP

About 62% of TFP and 50% of WBG were able to estimate incomes resulting from the sale of fishes and bulbs. Figure 174 shows that incomes from TFP were higher than that of WBG. About 45% of TFP was above 60 US Dollar while 54% of WBG was below 40 US Dollar. Therefore, traditional activities are embedded in socio-cultural practices.

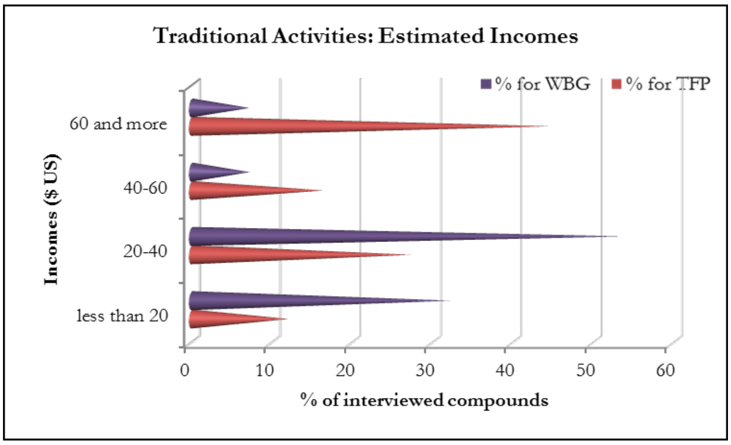


Figure 174: Proportions of compounds per amount of income for WBG and TFP

5.4.1.2. Non-participation reasons in traditional fishing in ponds (TFP) and water lily bulbs gathering (WBG)

On the other hand, Table 45 summarizes reasons for non-involvement in TFP (Table 45a) and in WBG (Table 45b). For both WBG and TFP, the remoteness of ponds came third place among 24 and 14 reported reasons, respectively.

Table 45: Proportions of compounds per reported reasons for non-participation in WBG and TFP

a) Reasons of the non-involvement in traditional fishing in ponds (TFP)

N°	Reason	Number	%
1	We are professional fishermen	29	23.20
2	It is not our job	17	13.60
3	Ponds too remote	11	8.80
4	Risk of diseases	10	8.00
5	We are not used	8	6.40
6	There is nobody to participate	7	5.60
7	More tiring than benefic	6	4.80
8	Not enough fishes	5	4.00
9	Nothing	5	4.00
10	There is much water this year (2011)	5	4.00
11	I am market gardener	3	2.40
12	No time to participate	3	2.40
13	I am new here	2	1.60
14	I am too old	2	1.60
15	Risk of drowning	2	1.60
16	I don't like this job	2	1.60
17	Because of our religion	1	0.80
18	I am not a Dafing	1	0.80
19	I won't my children to do that	1	0.80
20	I don't know fishing	1	0.80
21	I am a trader	1	0.80
22	The fishing in ponds makes too dirty	1	0.80
23	We are blacksmiths	1	0.80
24	We are marabouts	1	0.80
Total	24	125	100

b) Reasons of non-involvement in water lily bulbs gathering (WBG)

N°	Reasons	Number	%
1	It is not our job	30	25.86
2	There are no more old women for gathering	20	17.24
3	Ponds too remote	19	16.38
4	Risk of diseases	16	13.79
5	There is no water lily in the closest ponds	13	11.21
6	Our wives are not used gathering bulbs	4	3.45
7	Nothing	3	2.59
8	There is lot of water	3	2.59
9	We are not used gathering bulbs	2	1.72
10	Our wives have other occupational activities	2	1.72
11	Old-activity	1	0.86
12	There are other persons for that in the village	1	0.86
13	We simply buy it	1	0.86
14	We have enough to eat	1	0.86
Total	14	116	100

5.4.1.3. Reasons for irrigation (IRR)

The main dream of all farmers is to get rich within a short time. The financial management record of CANI, a co-operative with 500 ha of irrigated land, gave us access to information on direct incomes from paddy farming produced by its members. In 2010, the highest incomes were from rice irrigation worth 2373 US Dollar in the dry season and 2061 US Dollar in the wet season (a difference of 312 US Dollar). The 500 ha perimeter is subdivided into 10 blocks. Table 46 shows the income status for the two agricultural seasons per co-operators of the same blocks. It demonstrates that the number of co-operators farming the rice as well as the income status varied according to seasons and blocks. For both seasons block 4, 8 and 10 recorded debit co-operators (Table 46). Areas varied between dry and wet seasons from 308.59 ha to 282.47 ha (# 26.12 ha) with a decrease in number of co-operators in the range of 20 persons (Table 46). The influence of the area on the yield was r = 0.87, r^2 = 76% (p-value = 0.000) and between the irrigated surface and direct income was r = 0.72, r^2 = 52% (p-value = 0.000).Greater than 95% of members of the *Cooperative Agricole de Niassan* made profit from selling paddy in both dry and wet seasons after deduction of operating costs.

Table 46: Net income from irrigated paddy production

Co-operative Agricole de Niassan: Incomes status co-operators in 2010						
	Dry season			Wet season		
Blocks	*Farmers*	*% in excess*	*% in debit*	*Farmers*	*% in excess*	*% in debit*
Block 1	31	80.65	19.35	31	100	0
Block 2	29	100	0	28	100	0
Block 3	33	100	0	29	100	0
Block 4	44	95.45	4.55	35	91.43	8.57
Block 5	24	100	0	24	100	0
Block 6	32	100	0	32	100	0
Block 7	29	100	0	28	100	0
Block 8	32	96.88	3.13	33	93.94	6.06
Block 9	37	100	0	36	94.44	5.56
Block 10	42	97.62	2.38	37	83.78	16.22
Total	**333**	**97.00**	**3.00**	**313**	**95.85**	**4.15**

5.4.2. Age and gender involvement in irrigation (IRR), traditional fishing in ponds (TFP) and water lily bulbs gathering (WBG)

5.4.2.1. Traditional activities

Traditional activities are common in the community and involve all classes of people in the community. Figure 175 demonstrates that there are age and gender clusters for WBG and TFP. Women were more involved in WGB while TFP was mostly done by men. In addition, TFP concerned all age groups and WBG was more clustered around adult women. More interesting was the involvement of youths in both TFP and WBG in the AOI.

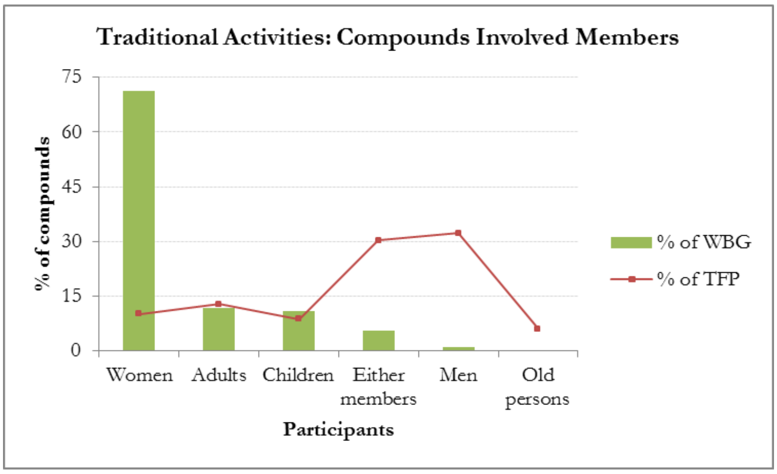


Figure 175: Compound members involved in traditional activities

TFP: Traditional Fishing in Ponds; **WBG:** Water Lily Bulbs Gathering

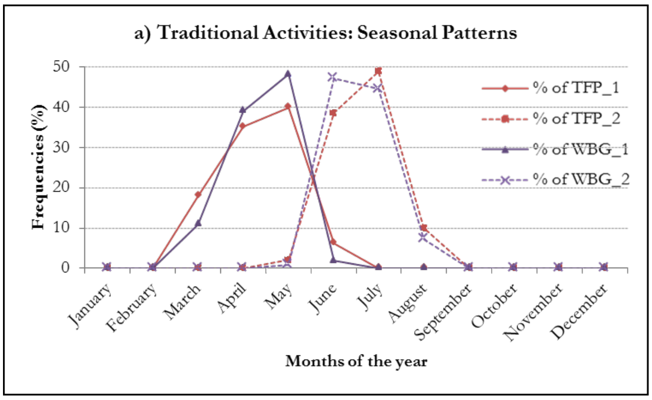
5.4.2.2. Modern activities

Conversely, modern irrigated agricultural activities are carried out at the familial scale and involved all members of the family. The importance of involvement per age and gender follows the demographic structure of the compound. To justify the higher level of involvement of youths in irrigation tasks, heads of compounds usually stated that "*The backs of children do not dry*" in local adage. The real meaning of this statement is that youths are tireless workers.

5.4.3. Seasonal occurrence of activities

5.4.3.1. Traditional activities

Figure 176a displays the distribution, on one hand, of the reported months in which compound members usually begin the TFP (% of TFP_1) and WBG (% of WBG_1), and on the other hand, months in which members end the TFP (% of TPF_2) and WBG % of WBG_2). It then demonstrates that the bulk of community exposure to schistosomiasis due to traditional activities in ponds occurs in the dry warm season from March to May. Curves of TFP and WBG have the same pattern because they occur only in lower-water period, when ponds are not flooded. It also demonstrates that the majority of participants abandon the practice with the setting of the wet season in June and July. The months for commencing and ending TFP and WBG activities varied extremely depending on the compounds. Figure 176b shows the distribution of length of community exposure to contaminated water. The participation for most of the compounds does not exceed two months. However, certain members can continue the TFP for a period of 4 to 5 months.



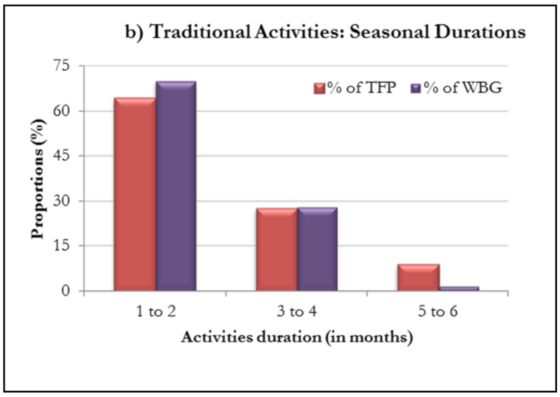


Figure 176: Traditional activities, seasonal patterns and duration

TFP: Traditional Fishing in Ponds; **WBG:** Water Lily Bulbs Gathering

5.4.3.2. Modern activities

Compared to traditional activities which take place only during the dry season, modern irrigated activities occur twice in a year. Agricultural calendar as well as the crop itinerary is theoretically fixed. The dry season goes from December to May and the wet season from June to November, that is to say, a length of six months each season. Weeding occurs two months later in February and August and can last about two months or more.

5.4.3.3. Influence of annual rainfall on seasonal occurrence of traditional and modern activities

Traditional activities do not take place systematically each year and remain strongly determined by amounts of rainfall. Comparison of the annual total rainfall with responses from the *Kôtigui* or traditional priest revealed that TFP does not take place when the wet season recorded less than 600 mm or more than 850 mm(Figure 177a). Therefore, both deficit and excess of rainfall lead to the same result of nonoccurrence of TFP. Total annual rainfall between 600 and 850mm are optimal for the implementation of traditional activities in ponds (52% of the 31). The *Kôtigui* or traditional priest organizing the TFP also stated the failure of the activity by a raining day. Figure 177b shows that the TFP does not occur every day in the dry season. There are at least five days in May and nine days in June without the TFP. From July it rains every two days on average. These higher proportions of raining days contribute to stopping the TFP. Water shortage for modern irrigation has been reported during the dry season following the less than 600 mm of rainfall in the preceding wet season. The low-water creates a gap between the intake canal and the principal one. Therefore, the theoretical crop itinerary is affected.

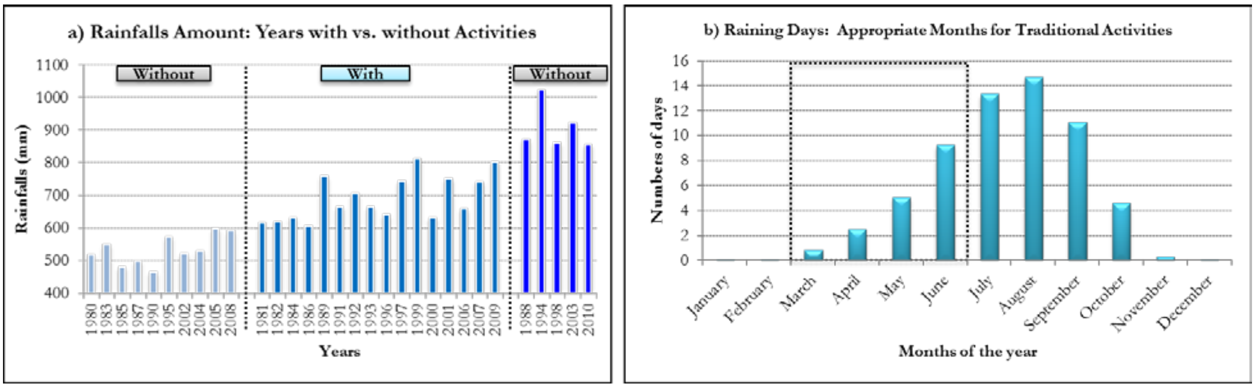


Figure 177: Influence of rainfall on traditional activities, seasonal occurrence patterns and daily frequencies

5.4.3.4. Spatial scopes of IRR and TFP

Traditional settlements on the western bank of the Sourou River and those on the eastern bank, particularly in the south of Koumbara, depend on traditional dry season irrigation. This is portrayed in Figure 178 with Illa as an example. Irrigated parcels and infrastructures such as irrigation canal are manually and traditionally made (see Picture in Figure 178) imitating the modern system. Incomes from the sale of garden products (tomatoes, onions) help to improve the economic status of the compounds. The scope of TFP could be linked to the high mobility of people using transportation means such as bicycles or motorbikes (Figure 179) (see Annex 3 for transportation means distribution per settlement). We interviewed a total of 77 participants in the TFP in May 2012 and Table 47 shows the distribution of the geographic origin per age group. About 5, 91 and 4% of participants were children (< 15 years), adults (15-64 years) and elderly (65 and more), respectively. Data also showed that 78% of participants were coming from inside the AOI while 22% were coming from outside of the boundary of the AOI. Table 47 also demonstrates that the spatial scope of TFP goes beyond the radius of 7 km with use of transportation means.

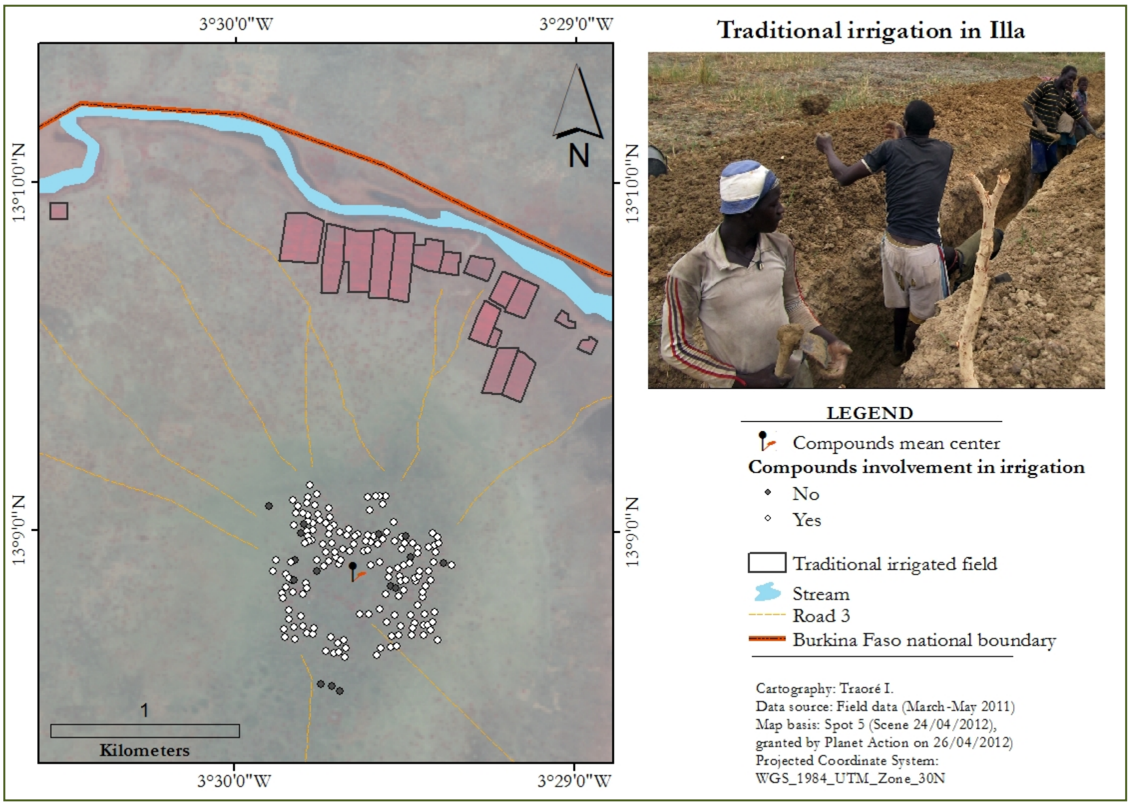


Figure 178: Traditional irrigation in Illa

Table 47: TFP: Participants per origin and age group

Geographic provenances of participants in the TFP in May 2012 (N = 77)				
Age group	Di	Niassan	Outside AOI	Total
10 - 14	3.90	1.30	0.00	5.19
15 - 19	23.38	2.60	3.90	29.87
20 - 24	9.09	5.19	6.49	20.78
25 - 29	6.49	0.00	0.00	6.49
30 - 34	3.90	1.30	0.00	5.19
35 - 39	7.79	2.60	2.60	12.99
40 - 44	2.60	0.00	1.30	3.90
45 - 49	2.60	0.00	0.00	2.60
50 - 54	0.00	0.00	5.19	5.19
55 - 59	0.00	1.30	1.30	2.60
60 - 64	1.30	0.00	0.00	1.30
65 - 69	1.30	0.00	1.30	2.60
70 - 74	0.00	0.00	0.00	0.00
75 - 79	1.30	0.00	0.00	1.30
Total	**63.64**	**14.29**	**22.08**	**100**

Figure 179: Participants on the road for TFP

5.4.4. Understanding exposure patterns by sensed human water contact activities

5.4.4.1. Main characteristic of sensed water contact activities

- Location of sensed water contact activities

able 48 shows that the five activities were sensed into two types of environment (natural and man-made). Environment types were divided into four groups as indicated in able 48. Aquatic vegetation coverage varied from zero to 100%. Figure 180 displays the various natural and man-made environments in which activities were sensed. Figure 181 illustrates sensed activities showing more details on the variation in vegetation cover per nature of water body.

able 48: Vegetation cover of location of water contact activities

Sensed Activities Places			
Activities	Occurrence places		
	Type	*Nature*	*Vegetation cover*
Children recreational swimming	Natural	Sourou River	<1%
	Man-made	Main canal	0%
Irrigated paddy parcel weeding	Man-made	Rice parcel	100%
Traditonal fishing in ponds	Natural	Ponds	1-100%
Laundry	Natural	Sourou River	<2%
Water lily bulbs gathering	Natural	Ponds	100%

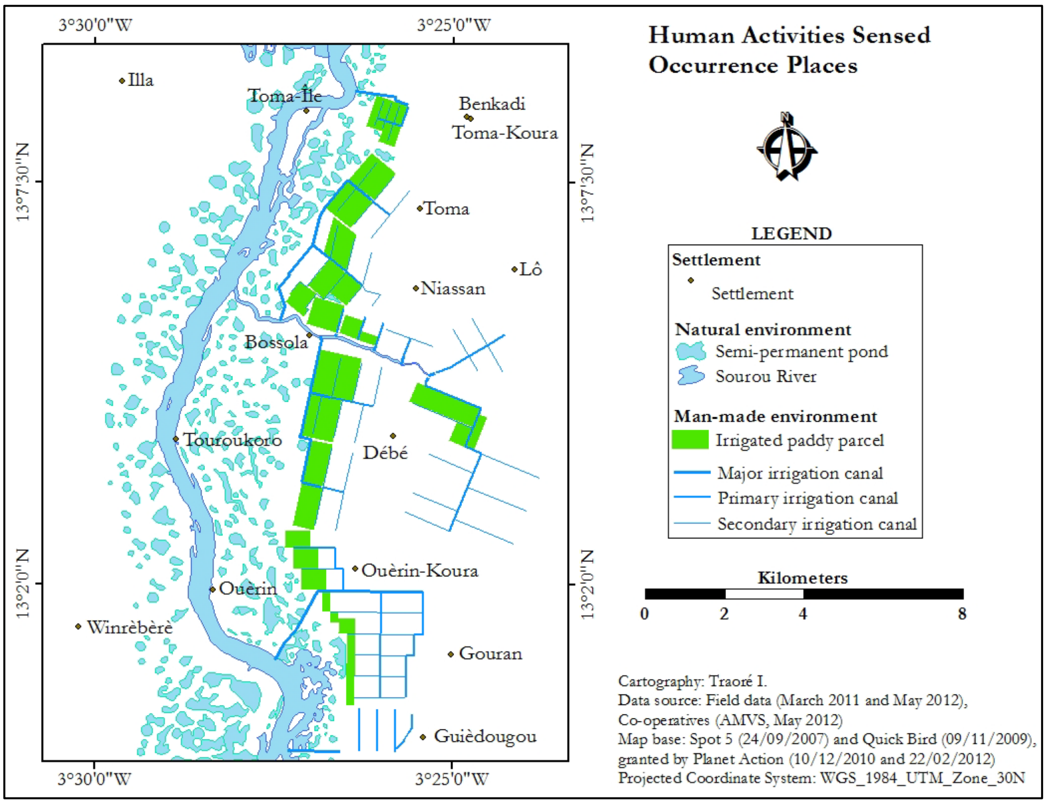


Figure 180: Geo-visualization of sensed human water activities occurrence environments

Figure 181: Illustrations of sensed human activities

CRS: Children Recreational Swimming; **CLW:** Laundry; **IRR:** Irrigated paddy parcel weeding;

TFP: Traditonal Fishing in Ponds; **WBG:** Water lily Bulbs Gathering

- Altitudes

Figure 182 shows, on one hand, numbers of track points per activity which varied from 289 (CLW) to 410 (CRS). On the other hand, Figure 182 shows average altitudes measures varying from 167 m (CRS) to 266 (IRR). The total immersion of the GPS under deep water could result in weak reception of signals, thus lower and even negative values of altitudes, 6.15% for CRS. (See Annex 4 for details per actitivy).

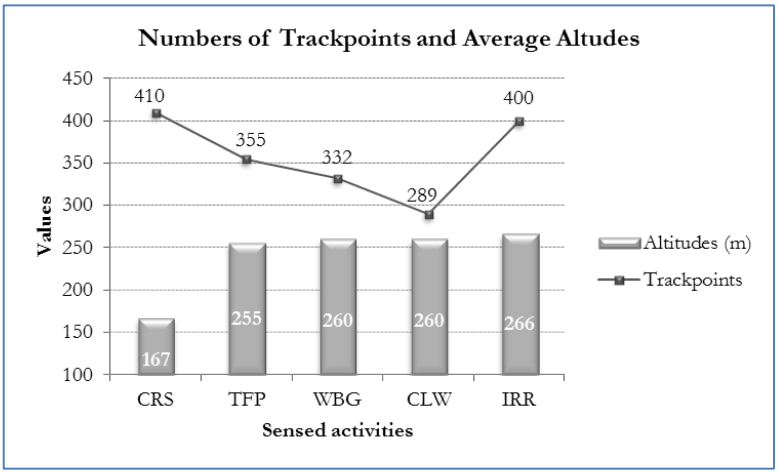


Figure 182: Average altitudes of sensed activities occurrence places

- Ground signatures

The dynamics of occurrence of activities was characterized using the average track lengths and speed of movement as indicated in Figure 183. Average speed varied from 0.28 mph (meter per hour) for CLW to 1469.01 mph for CRS. Path average measures varied between 519 m (IRR) to 2306 m (TFP). The geo-visualization of paths of occurrence of activities on ground is shown in Figure 184.

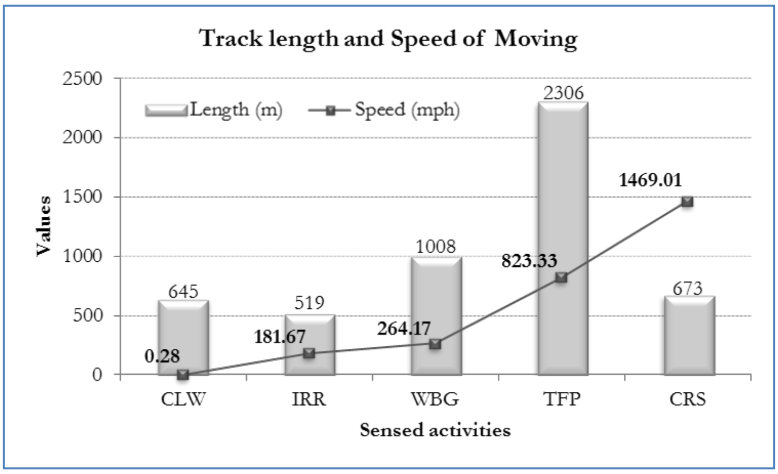


Figure 183: Path lengths and average speed of individuals moving within the water body

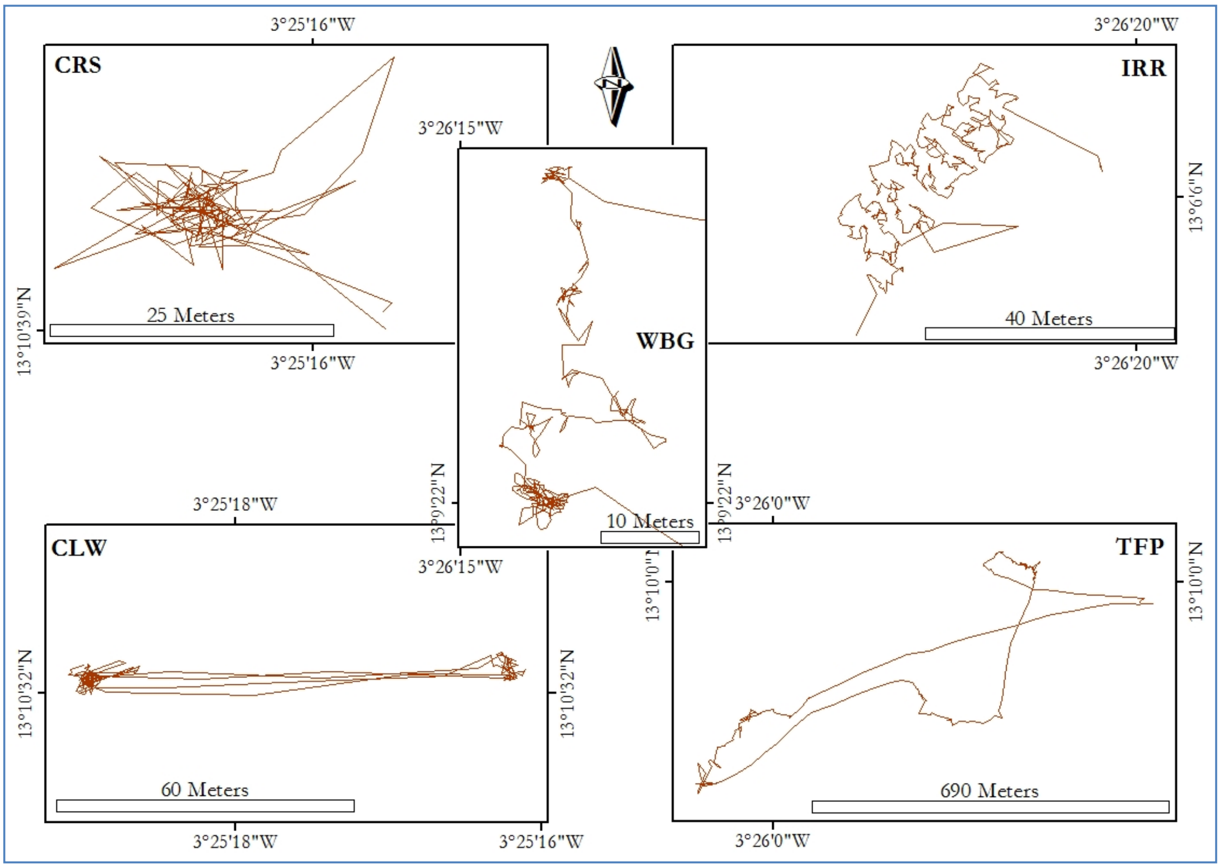


Figure 184: Geo-visualization of ground signatures characterizing each type of sensed activities

- Distribution of individual position within the water body

A break point was defined when two conditions were met: speed = 0 and length = 0. Otherwise the point was defined as moving point. Figure 185 shows that proportions of break points were characteristic of the type of activity. The half of CLW recorded points were break positions while TFP recorded only 17%. Figure 186 geo-visualizes break (red dots) and moving points. The human position distribution shows that individuals visited several micro-environments within the same water body. This could increase the chance of coming in contact with free swimming cercariae.

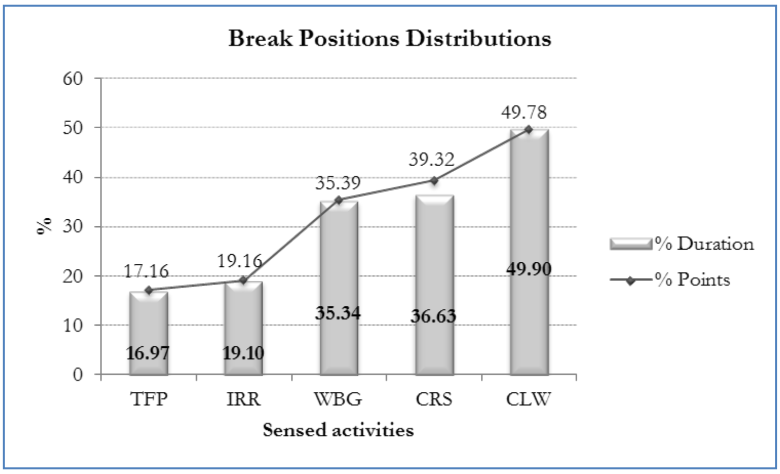


Figure 185: Proportion and duration of break-points

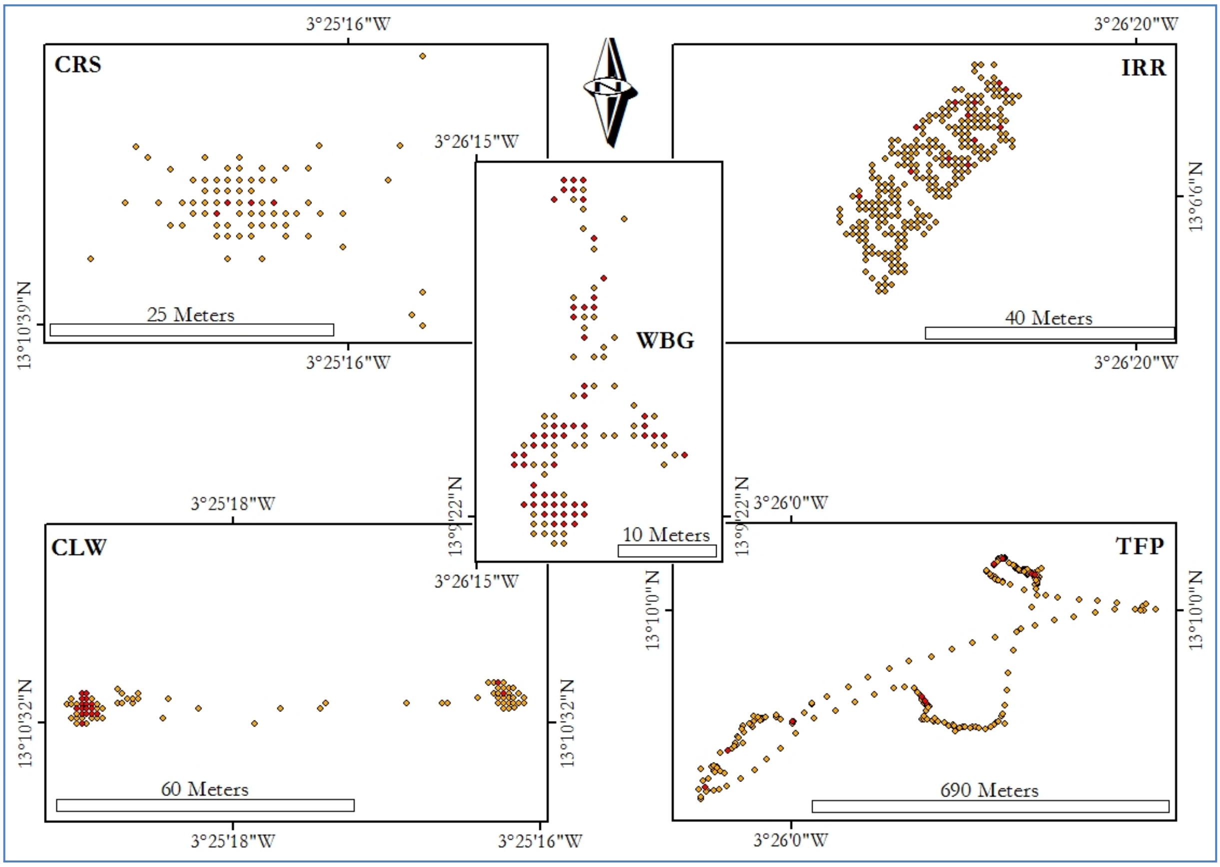


Figure 186: Geo-visualization of break-points distribution compared to moving-points per type of sensed activity

- Combining high spatial resolution satellite images with Thiessen polygon to predict the occurrence of water contact

The overlapping of track points on a high spatial resolution Pléiade image confirms that the tightening Thiessen polygons coincide exactly with water bodies as indicated in Figure 187. Therefore, the combination Pléiades – Thiessen polygon could help to solve respondent recall problems about the history of contact with contaminated water.

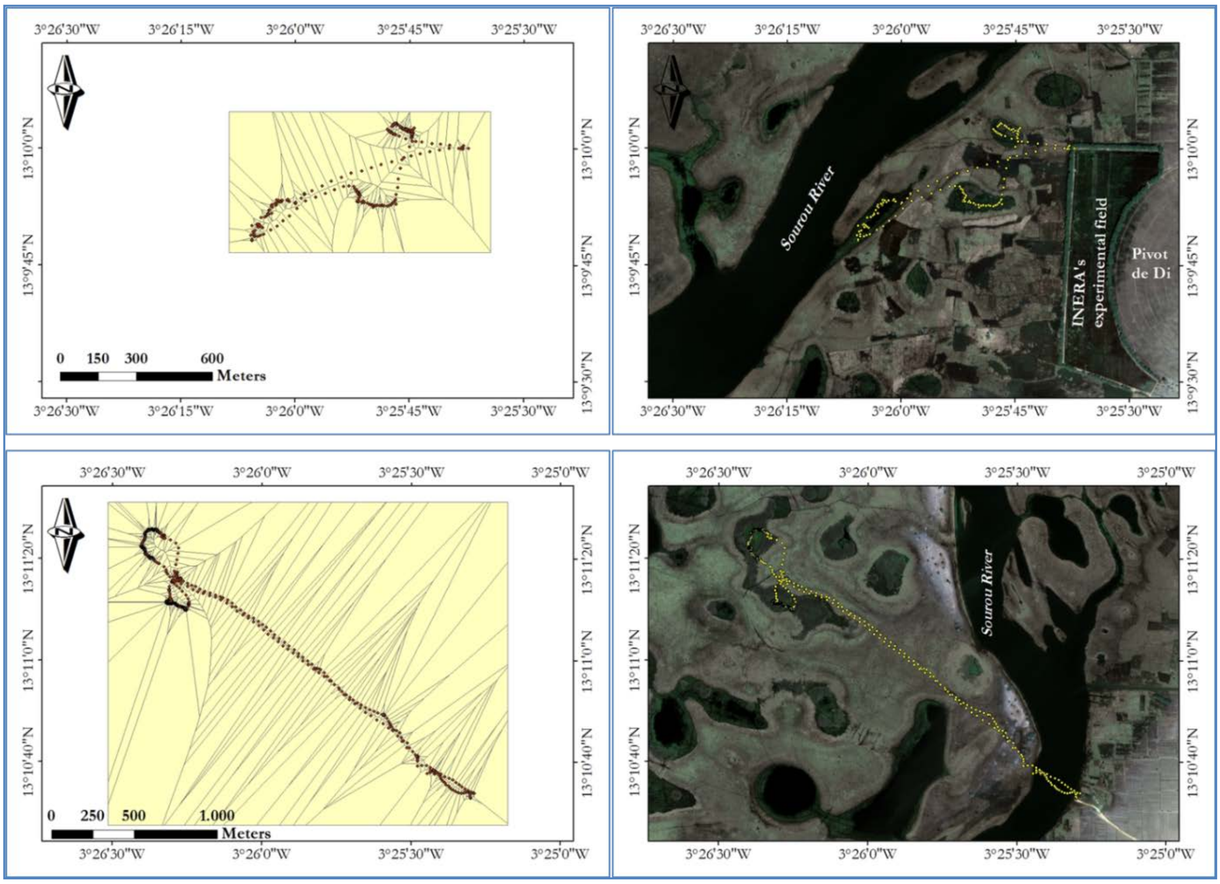


Figure 187: Overlapping of track points on Thiessen polygons and a Pléiades image for TFP

- Exact count of exposure duration by activities

Figure 188 shows that WBG took place from 15:25:33 to 19:12:10. The ground signature shows several clusters. The first occurred between 15:37:33 and 17:03:38. The second occurred between 17:34:38 and 17:48:38. The third occurred between 17:48:38 and 17:54:38. The last two occurred around 18:27:10 and 18:57:10. The GPS holder started to leave the pond at 19:12:10. Agglomeration of track points implies that women spend more time in search of bulbs due to the density of the vegetation and abundance of bulbs at observed ponds.

Figure 188 shows that the GPS was turned on at 16:00:13 for TFP and the holder visited three different ponds before 18:29:06 at which the GPS was given back. The upper right shows that he started fishing at 16:05:13 and left the first pond at 17:08:14. He reached the second pond at 17:11:14 and left at 17:40:44 to reach the third one at 17:46:14 where he stayed till 18:13:06. The density of track points on the upper right demonstrates that the individual lasted longer in this pond about one hour and compared to the two other ponds in which the elapsed time did not exceed 30mn. Probably there was more catching to do in the first pond than in the last two. The visit of several ponds in one session of TFP explains the length of the path.

For IRR, Figure 188 informs that the GPS holder did the IRR during two time periods: first, from 09:36:58 to 12:23:06 and second, from 12:43:37 to 13:46:40. He went out from 12:23:06 to 12:43:37 and the GPS was given back at 13:47:22.

Figure 188 shows that CLW occurred with two major clusters of track points distinguishable by the concentration of break points. The first cluster with higher density of red dots indicates the washing position. The second cluster with few break points and located at 83 m apart from the washing place indicates clothes in the process of drying. These two clusters are connected by four paths. It means that the GPS holder went two times (at 12:37:21 and at 13:59:23) to the drying out point and came back to continue washing. The relative closeness of these positions explains the relative short mean length of the track (644.67 m). The minor cluster of track points next to the washing position represented where dirty clothes were stored.

In general, TFP and WBG took place in the afternoon, starting between 13H and 14H and ending about 17H. Conversely, the IRR usually occurs in the morning, beginning between 8H and 10H and finishing between 12H and 13H because the 5-10 cm of irrigated water comes in contact with the sole of farmer's feet resulting in a burning sensation. This sensation was as a result of heating of the water by the sun.

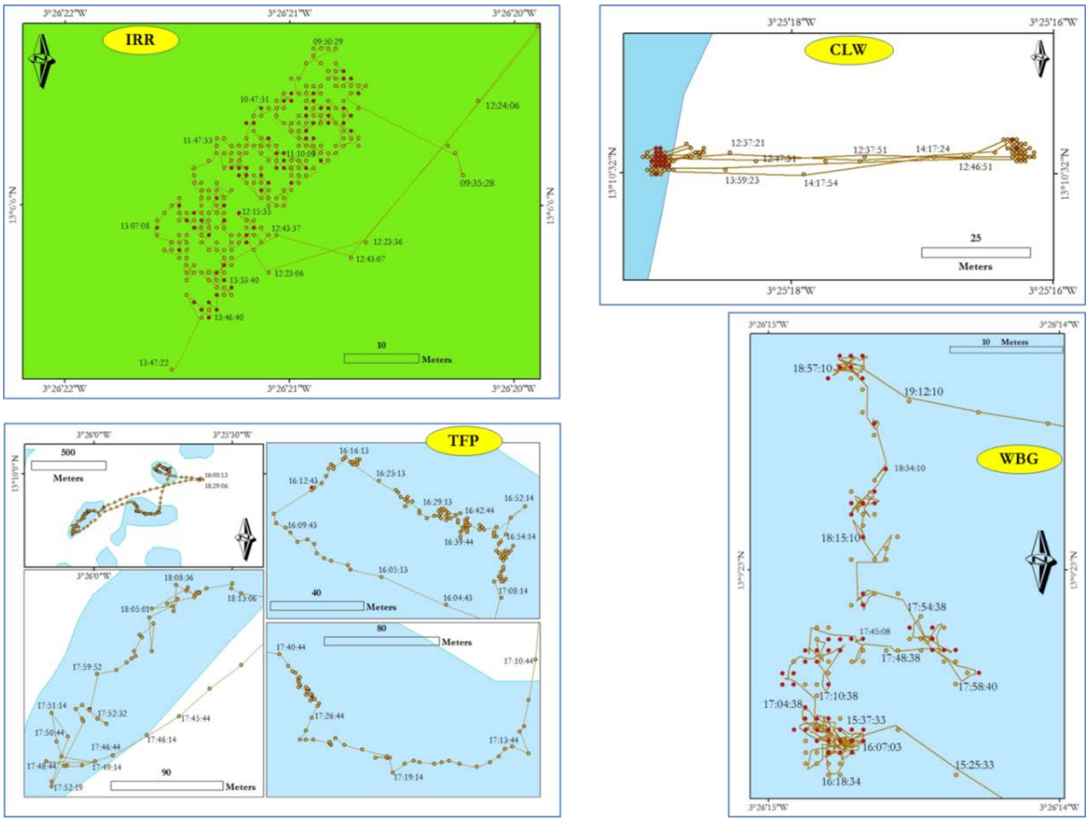


Figure 188: Plot of ground signatures, environment data and time

- Average duration of sensed activities

Figure 189 shows that the average duration of water contact ranged from 37mn (CRS) to 205mn (WBG). This means that water contact duration is between 3.7 and 20.5 times longer than the time needed for the infesting cercariae to complete its penetration of the human skin. Within the same type of environment, the difference in terms of infestation probability will depend on the contact duration. (See Annex 4 for details per actitivy).

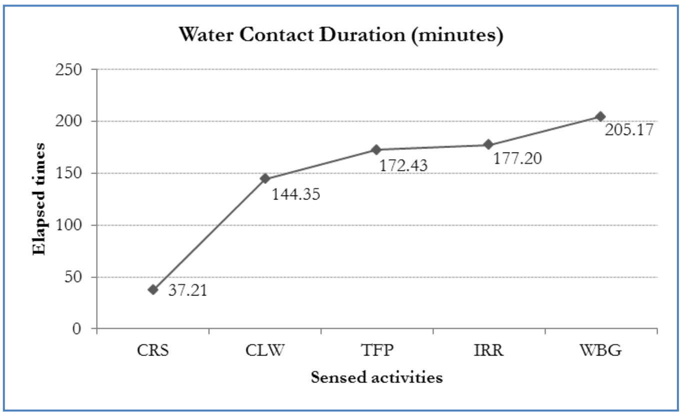


Figure 189: average duration of water contact per sensed activity

- Diverse relationships highlighting difference between sensed activities

Table 49 shows a higher and positive correlation between track lengths and the duration of activities for WBG and TFP while IRR and CLW recorded lower and negative coefficients. Compared to the length-duration relationship, the speed-total trackpoints showed strong correlation for CLW and CRS. Table 49 also shows that all correlations were positive for TFP and negative for IRR. WBG and CRS observed the same pattern with a negative coefficient in the speed-break duration relationship. This statistics indicate that CRS leads to extreme dynamic movement in the water body while CLW induces extremely slow movement. TFP led to regular movement in the water body. On the other hand, IRR occurs with an irregular speed in movement. (See Annex 4 for details per actitivy).

Table 49: Additional relationships characterizing sensed activities

Linear Regression Statistics															
	WBG			TFP			IRR			CLW			CRS		
Relationship	*r*	*r^2 (%)*	*p-value*	*r*	*r^2 (%)*	*p-value*	*r*	*r^2 (%)*	*p-value*	*r*	*r^2 (%)*	*p-value*	*r*	*r^2 (%)*	*p-value*
Track length --> Activity duration	0.72	52	0.004	0.86	75	0.013	-0.19	04	0.278	-0.04	0	0.487	0.01	0	0.483
Average speed --> Total trackpoints	0.57	32	0.027	0.48	22	0.166	-0.36	13	0.127	-0.84	71	0.182	0.70	49	0.003
Average speed --> % of break duration	-0.78	60	0.001	0.41	17	0.21	-0.88	77	0.000	0.47	22	0.345	-0.43	19	0.061

CLW: Laundry; **CRS:** Children Recreational Swimming; **IRR:** Irrigated parcel weeding; **TFP:** Traditional Fishing in Ponds; **WBG:** Water Lily Bulbs Gathering

5.5. Individual knowledge about schistosomiasis transmission route

5.5.1. Spatial distribution of individuals interviewed

205 individuals were interviewed in 70% (n = 26) of the AOI settlements. Table 50 shows proportions of individual interviewed per settlement and gender in order to measure the perception of local people about human schistosomiasis. Proportions ranged from 0.98% to 15% and males represented 86%.

Table 50: Spatial distribution of individuals per gender

Individuals interviewed			
Settlement	**Female**	**Male**	**Total**
Lanfièra	0.00	0.98	0.98
Lô	0.00	0.98	0.98
Toma-Koura	0.00	0.98	0.98
Benkadi	0.00	1.46	1.46
Bouna	0.00	1.46	1.46
Yayo	0.00	1.95	1.95
Bissan	0.49	1.95	2.44
Lanfièra-Koura	0.49	1.95	2.44
Leri	0.98	1.46	2.44
Nion	0.49	1.95	2.44
Niassan	0.00	2.44	2.44
Touroukoro	0.00	2.44	2.44
Toumani	0.49	1.95	2.44
Toma-Île	0.00	2.44	2.44
Ouèrin	0.00	2.44	2.44
Winrèbèrè	0.00	2.44	2.44
Gouran	0.00	3.41	3.41
Débé	0.00	3.90	3.90
Di	1.46	2.93	4.39
Bantombo	0.00	4.88	4.88
Koubè	1.95	2.93	4.88
Koumbara	0.98	4.39	5.37
Guièdougou	0.00	6.34	6.34
Yaran	0.49	9.27	9.76
Illa	2.93	7.32	10.24
Sono	3.41	11.22	14.63
Total (n = 205)	**14.15**	**85.85**	**100**

5.5.2. Awareness of types of Schistosomiasis and stigma status

5.5.2.1. Types of Schistosomiasis known in the study area

Table 51a shows answers of individuals in the AOI about how many forms of schistosomiasis they were aware of. Results revealed that no-one of them was aware of the intestinal form of schistosomiasis. The knowledge of 99% of individuals was limited only to the urogenital form locally named Gnèguèni-ouilé, recalling the blood passing in urine. Among them, 35% misclassified the loss of whitish pus from genital apparatus as an advanced and complication of the urinary schistosomiasis, thus the spelling of whit urine by reference to the whitish pus (instead of blood) coming from the genital area. About 44% of interviewed persons reported having experienced the illness. Table 51b shows the spectrum of symptoms and manifestations they cited to answer to the question: how did you recognize that you was or are suffering from schistosomiasis? BPU and urination pains were the most frequently reported: 62% and 29%. Therefore, the perception of local people of the illness can be equated as follows:

$$Schistosomiasis = Urine * Blood$$

Table 51: Individual illness status definition

a) Reported numbers of forms

Number	Local word	Meaning	Number	%
One	*-Gnèguèni-ouilé*	Red urine	130	63.42
Two	*-Gnèguèni-ouilé* *-Gnèguèni-Guè*	Red urine White urine	72	35.12
Didn't know	-	-	3	1.46
Total	**-**	**-**	**205**	**100**

b) Reported symptoms and manifestations

Symptom and manifestation	Number	%
Blood	56	61.54
Blood + urination pains	26	28.57
Blood + urination pains + fever	5	5.49
Urination pains	2	2.20
Blood + urination pains + stomachache	1	1.10
Blood + fever	1	1.10
Total	**91**	**100**

5.5.2.2. Stigma status attributed to urinary Schistosomiasis in the study area

The urogenital form of the disease associating genital apparatus, matter of taboo, and the BPU, is seen for 66% of individual as shameful illness according to Table 52. Among this group 44% did not contract the illness and represented 52% of the 56% without experience of the illness. Conversely, 32% agreed that there is no shame to be a bilharzian. Among this later 22% was bilharzian and represented 15% of the 44% with experience of the illness.

Table 52: Individual representation of urinary schistosomiasis as an ashameful illness

Individual statements about the status of shame (N = 205)			
Shame status	Already experienced the illness		Total
	Yes	***No***	
Yes	37.07	28.78	**65.85**
No	6.83	24.88	**31.71**
No answer	0.49	1.95	**2.44**
Total	**44.39**	**55.61**	**100**

5.5.3. Individual and collective knowledge about schistosomiasis transmission

5.5.3.1. The role of freshwater in schistosomiasis transmission

Asking individual to cite water associated diseases, Figure 190a shows that only 26% mentioned schistosomiasis. However, 93% of those who did not cite schistosomiasis were aware of it as indicated in Figure 190b. thus, according to Figure 190, about 95% of individual interviewed were aware of schistosomiasis. Note that the awareness does not imply experience on the disease.

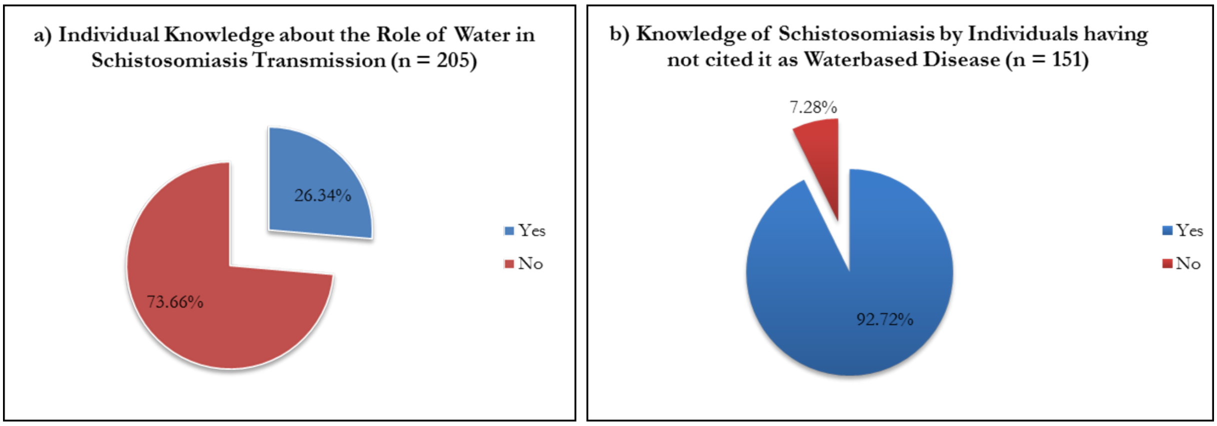


Figure 190: Individuals awareness of schistosomiasis

5.5.3.2. Schistosomiasis transmission routes

Results of an advanced interview of the 26% of individual having recognized schistosomiasis as water associated disease are indicated in Table 53. The combination pond-rice parcel was the mostly cited (31%) among 10 different combinations.

Table 54 shows 23 different combinations of cited transmission route by the 95% of individual that were aware of schistosomiasis. 54% of individual were illiterate. The most mentioned transmission route was the sun (18%). This route was reported at 88.58% by illiterate individuals. The contaminated water drinking came at the second place (14%). More than 66% of individual with a university background mentioned the water contact. We must recall that answers were pre-codified and fieldworker could cross several answers. All cited route different from those reported in Table 54 (single route) were codified as others (11.34%). Therefore the three mostly cited routes accounted for 43% of interviewed. This means that about half the individuals had a limited knowledge about schistosomiasis transmission through the skin immersion in contaminated water.

Table 53: Schistososmiasis transmission sources cited by individual

Schistosomiasis transmission sources cited by individual having cited it as waterbased disease		
Sources	**Numbers**	**%**
River	2	3.70
Pond + Irrigation canal	2	3.70
River + Pond + Rice parcel + Irrigation canal	2	3.70
River + Pond + Rice parcel	3	5.56
Rice parcel	4	7.41
River + Rice parcel	4	7.41
River + Pond	5	9.26
Pond	15	27.78
Pond + Rice parcel	17	31.48
Total	54	100

Table 54: Schistosomiasis transmission route per individuals' educational level

Transmission routes cited by individuals knowing schistosomiasis (n = 194)							
	Educational status						
Transmission routes	*Not any*	*Primary school*	*Secondary school*	*University*	*Teaching of literacy*	*Primary + Teaching of literacy*	Total
Seat	0.00	0.52	0.00	0.00	0.00	0.00	**0.52**
Water contact + Sexual intercourse	0.52	0.00	0.00	0.00	0.00	0.00	**0.52**
Sexual intercourse + Food	0.52	0.00	0.00	0.00	0.00	0.00	**0.52**
Food + Seat	0.00	0.00	0.52	0.00	0.00	0.00	**0.52**
Water contact + Water drinking + Food	0.00	0.00	0.52	0.00	0.00	0.00	**0.52**
Water contact + Sexual intercourse + Sun	0.52	0.00	0.00	0.00	0.00	0.00	**0.52**
Water drinking + Sexual intercourse + Sun	0.52	0.00	0.00	0.00	0.00	0.00	**0.52**
Sexual intercourse + Sun	0.00	0.52	0.00	0.00	0.00	0.00	**0.52**
Water contact + Sexual intercourse + Food + Seat + Sun	0.52	0.00	0.00	0.00	0.00	0.00	**0.52**
Water contact + Water drinking + Sun	1.03	0.00	0.00	0.00	0.00	0.00	**1.03**
Sexual intercourse + Sun	1.03	0.52	0.00	0.00	0.00	0.00	**1.55**
Food + Sun	2.06	0.00	0.00	0.00	0.52	0.00	**2.58**
Water contact + Sun	1.03	1.03	0.00	0.00	0.52	0.52	**3.09**
Water drinking + Food	1.03	0.00	0.52	0.00	2.06	0.00	**3.61**
Water contact + Food	0.52	0.52	1.55	0.52	1.55	0.00	**4.64**
Water drinking + Sun	4.12	0.52	0.00	0.00	0.00	0.00	**4.64**
Didn't know	4.64	0.00	0.52	0.00	1.03	0.00	**6.19**
Water contact + Water drinking	0.52	1.55	2.06	0.00	2.58	0.00	**6.70**
Food	2.58	0.00	1.55	0.00	3.09	0.00	**7.22**
Water contact	2.58	3.09	2.06	1.03	2.06	0.00	**10.82**
Others	5.67	1.55	0.00	0.00	4.12	0.00	**11.34**
Water drinking	8.76	2.06	1.03	0.00	2.06	0.00	**13.92**
Sun	15.98	0.00	0.00	0.00	2.06	0.00	**18.04**
Total	**54.12**	**11.86**	**10.31**	**1.55**	**21.65**	**0.52**	**100**

5.5.3.3. Individual and collective knowledge about human re-infestation with schistosomiasis

Against all odds, Figure 191 shows that the majority (52%) of individual agreed with the re-infestation possibility after having had a treatment. However, the proportion of interviewed who think that one contracts the disease once is still worrying (41%).

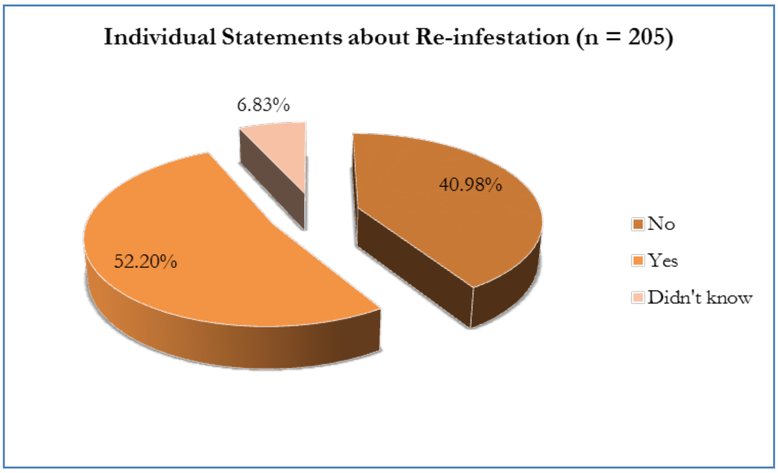


Figure 191: Individuals' knowledge about subjects re-infestation by schistosomiasis

Chapter 6. Complex geographic determinants of environment contamination in the Sourou Valley

In this chapter we deal with the role of local natural and social geographic determinants of the environment contamination. We analyzed ways through which local people stand as vectors of parasites (eggs) which they transmit to snail intermediate hosts through inadequate excreta management and seeking care against the disease.

6.1. Access to familial latrines

6.1.1. Defecation space utilization by peasants

According to peasant philosophy, the rural settlement is viewed as a set that is subdivided into three subsets based on demographic age structure of the main users (Figure 192). The pattern of space utilization by peasants for the purpose of defecation takes two forms, i.e., indoor and open air types. In the first type, people use latrines located within compounds (*loukônô*) while in the second, excreta are dropped in the open air. Open air defecation was divided into two categories, namely, *kènèma* and *banankô*, based on proximity to the compound and the need for privacy by the main users. The vernacular words, *kènèma* and *banankô*, represent defecation outdoors close to the compound and defecation outdoors further from the compound, respectively. The dotted double arrows are used to relate indoor defecation to open air defecation (Figure 192).

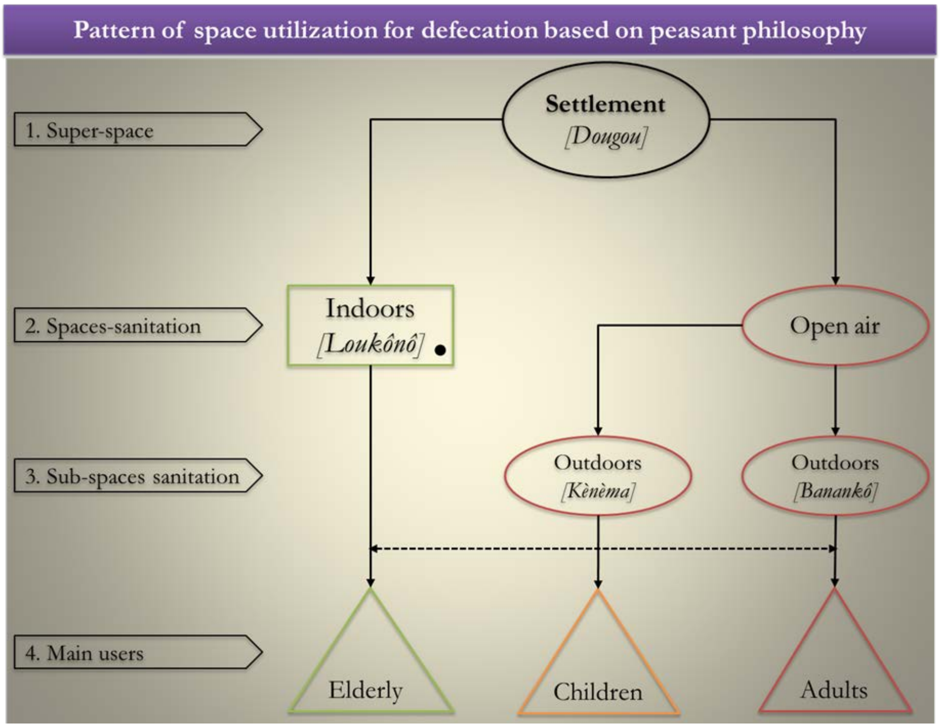


Figure 192: Pattern of space utilization for defecation based on peasant philosophy

6.1.2. Influence of the defecation-sanitation philosopy on the demand for familial latrines

6.1.2.1. Building of familial latrines: Indoor defecation

Table 55 shows the spatial distribution of 359 compounds additionally survey for gathering reasons about the demand for latrines in 93% of settlements. At the settlement level proportions of survey compounds varied between 1.37 and 100%. About 19% of AOI compounds with latrines was survey. About, 25% of the total surveyed compounds having latrines was concentrated in Guièdougou (Table 55).

In the local language, *lou* refers to the compound and *loukônô* means within the compound or indoors. Located indoors and fenced (Figure 193a), the latrine becomes convenient for the elderly who cannot move long distances and need privacy. In light of data presented in Figure 193b, the bulk (99.72%) of the surveyed compounds reported having built their familial latrines on self-initiative. Only 0.28% was subsidized by a project.

Table 55: Compounds found with familial latrines and additional interviewed per settlements

Compounds with latrines interviewed			
Settlement	Number	% within the settlement	% at the AOI level
Badala	1	14.29	0.28
Lanfièra	1	1.37	0.28
Lô	1	6.67	0.28
Ouèrin-Koura	1	100	0.28
Soro	1	100	0.28
Koubè	3	60.00	0.84
Kouri	3	14.29	0.84
Benkadi	5	41.67	1.39
Bissan	5	26.32	1.39
Nion	5	45.45	1.39
Toma-Koura	5	35.71	1.39
Toumani	5	18.52	1.39
Bantombo	6	66.67	1.67
Oué	8	10.81	2.23
Bouna	10	41.67	2.79
Koumbara	10	30.30	2.79
Leri	10	20.00	2.79
Illa	15	30.00	4.18
Gouran	19	18.10	5.29
Sono	20	19.42	5.57
Débé	25	25.25	6.96
Yaran	25	44.64	6.96
Niassan	36	15.25	10.03
Di	51	12.29	14.21
Guièdougou	88	19.78	24.51
AOI	**359**	**18.76**	**100**

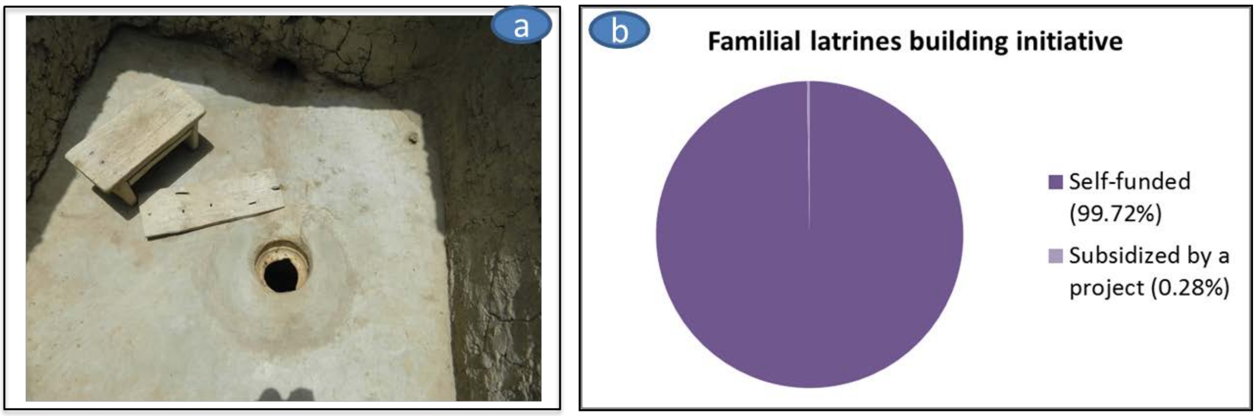


Figure 193: Familial latrine

- Reasons for demand of familial latrines

Figure 194 shows the nine main reasons for the increased demand for familial latrines as reported by heads of compounds. The highest ranked main reason (119 out of 359 respondents) was the prestige it gives latrine owners in the community.

Table 56 shows the nine main and 38 secondary reasons for increased demand of familial latrines. The distance to the bush area used for defecation was reported as the highest secondary reason for latrine demand (67 out of 359 respondents).

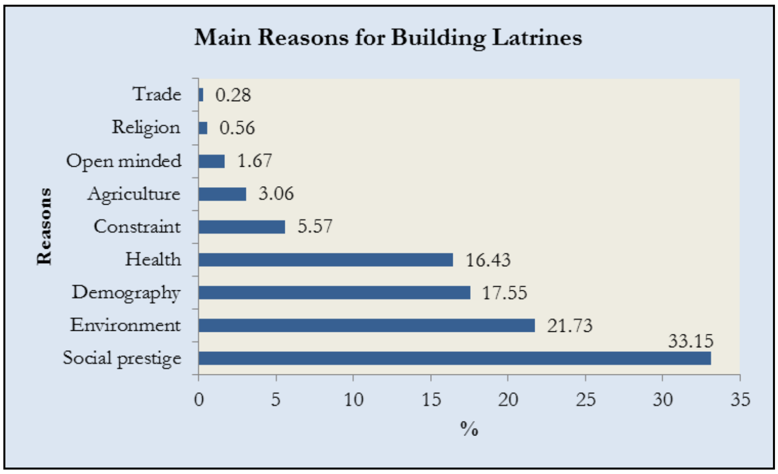


Figure 194: Main reasons of demand for familail latrines

Table 56: Distribution of main and secondary reasons for building latrines

Main and Secondary Reasons for building Familial Latrines			
Main reason	**Secondary reason**	**Frequency**	**%**
1. Social Prestige	It is not good to go in the nature	28	7.80
	To have my privacy	21	5.85
	It is good to have a latrine	19	5.29
	To earn respect from of strangers	13	3.62
	To be comfortable	10	2.79
	A compound without latrine is not a compound	6	1.67
	To avoid the shame	5	1.39
	Each family must have a latrine	4	1.11
	Tiredness from frequent visit to the bush	3	0.84
	To avoid the distance (walking)	3	0.84
	The popularity of the compound	3	0.84
	It is not comfortable to go in the nature when raining	1	0.28
	To have a latrine means to be a very important person	1	0.28
	To be respected you must have a latrine	1	0.28
	A real man must have a latrine	1	0.28
2. Environment (Land cover/use)	The bush is too faraway	67	18.66
	The bush is empty	10	2.79
	Because irrigated fields use up grater proportion of the bush	1	0.28
3. Demography	Because of older people	38	10.58
	Because of the growing of the village	14	3.90
	Because of the large family	11	3.06
4. Health/ Hygiene/ Security	To protect one' self against diseases	38	10.58
	For hygiene and sanitation	10	2.79
	In case of sickness (diarrhea)	4	1.11
	Thanks to the sensitization	4	1.11
	To avoid snakes in the night	2	0.56
	To avoid problems from the use of the bush	1	0.28
5. Constraint/ Challenge	We don't have anywhere to defecate	8	2.23
	We won't use latrines of neighbors	8	2.23
	We are at the center of the village	2	0.56
	Our father forced us to do it	1	0.28
	My neighbor drove me to build a latrine	1	0.28
6. Agriculture	To get compost for the field	11	3.06
7. Open minded	The decision was taken by our children living in Côte d'Ivoire	5	1.39
	I lived in a big city	1	0.28
8. Religion	Because of the Islamic faith	1	0.28
	A good Christian must not disturb others	1	0.28
9. Trade	Because of the restaurant	1	0.28
TOTAL	**38**	**359**	**100**

6.1.3. Influence of the space-sanitation logic on the non demand for familial latrines

6.1.3.1. Non building of latrines: Open air defecation

- Kènèma

It refers to the space surrounding the compound and left between compounds including paths, and landfills located within the settlement. About 95% of latrines' owners reported that their children were not using latrines while the remaining 5% represent a situation where all members utilize latrines (Figure 195a). Figure 195b shows the distribution of the answers to the question: where do non-users of familial latrines defecate? Results show that outdoor defecation was commonly (93%) admitted by children (Figure 195c). Under-age children, who cannot utilize latrines, defecate in chamber pots and the excreta were thereafter disposed into familial latrine. Nudity is a taboo in these communities and due to the closeness to compounds and the lack of privacy in the *kènèma,* adults and the elderly cannot use this facility during the daytime. However, during the night the *kènèma* can be used by all classes of people.

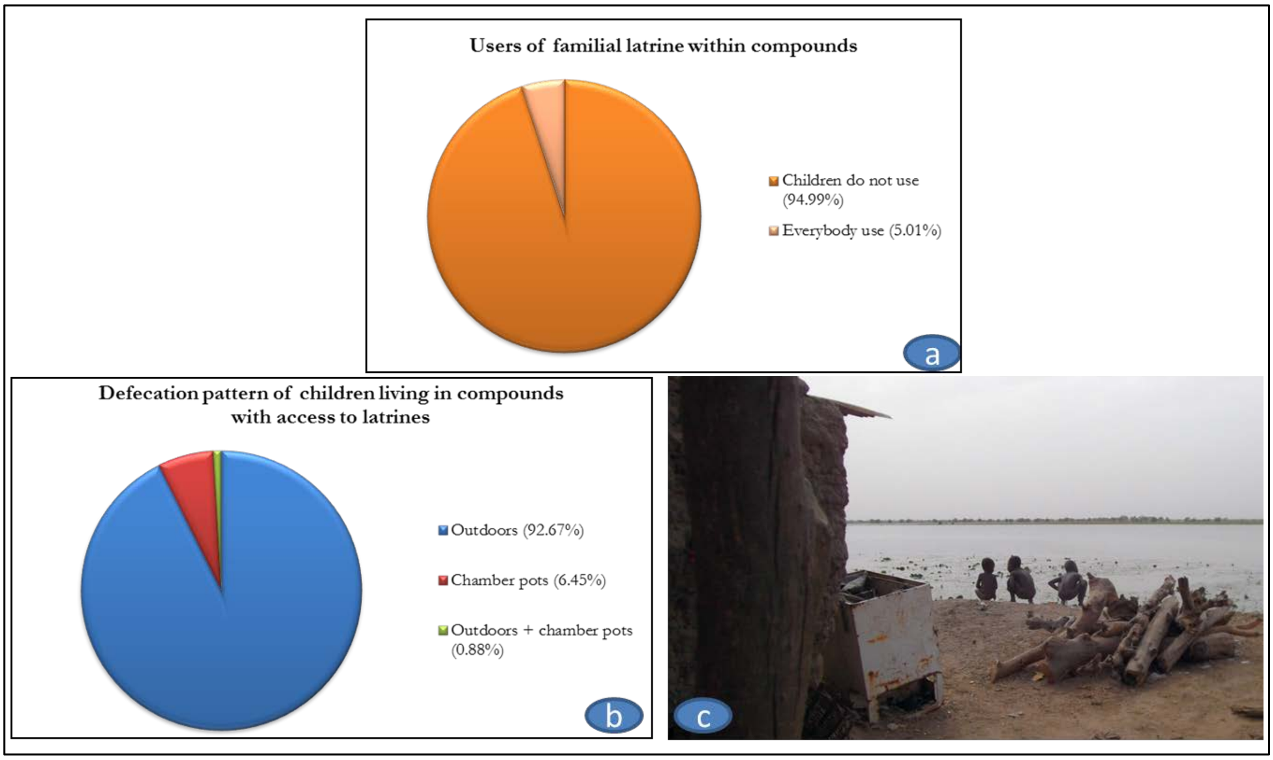


Figure 195: Defecation pattern of children living in compounds with access to latrines

- Banankô

Spatially, *banankô* refers to a buffer area, not surrounding the compounds, but rather the settlement itself. It is the peripheral area of the settlement (Figure 196). The *banankô* is the area dedicated for the excreta disposal: hence the word *banankô-ta* attributed to it. The suffix *ta* means "what belongs to" in the local language and thus, *banankô-ta*, in its direct translation, means "what belongs to the *banankô*" means human feces.

Figure 196: ***Banankô*** **area**

- Reasons for non-demand of familial latrines

Table 57 shows the spatial distribution of a total of 375 compounds without latrines whom heads were interviewed in 81% of the AOI settlements in order to better understand reasons of the non-demand of familial latrines. These compounds represented about 13% of all compounds non-owner of latrines in the AOI. However, about 16% of respondents was concentrated in Di.

Figure 197 shows the six main reasons for non- demand of familial latrines as reported by heads of compounds. The highest ranked main reason (220 out of 375 respondents) was the poverty. Table 57 shows the six main reasons and 23 secondary reasons. 38 out of 375 respondents reported proximity to the bush as a secondary reason for non-availability of latrines.

Table 57: Compounds found without any familial latrine and additionally interviewed per settlement

Compounds without latrines interviewed			
Settlement	Number	% within the settlement	% at the AOI level
Lanfièra	1	5.26	0.27
Lô	1	6.67	0.27
Ouèrin	1	1.92	0.27
Soro	1	3.45	0.27
Bossola	3	60.00	0.80
Dabokitila	3	27.27	0.80
Kouri	3	4.00	0.80
Lanfièra-Koura	3	42.86	0.80
Watinoma	3	21.43	0.80
Bantombo	4	8.33	1.07
Benkadi	5	7.14	1.33
Nino	5	5.95	1.33
Toma-Koura	5	55.56	1.33
Wèrimbèrè	5	25.00	1.33
Koubè	6	24.00	1.60
Toma-Île	6	15.00	1.60
Oué	8	5.26	2.13
Bissan	10	20.83	2.67
Bouna	10	35.71	2.67
Koumbara	10	9.80	2.67
Leri	10	10.53	2.67
Toumani	10	45.45	2.67
Illa	14	11.67	3.73
Gouran	19	12.84	5.07
Sono	20	9.22	5.33
Yaran	25	17.99	6.67
Guièdougou	34	13.77	9.07
Débé	41	16.80	10.93
Niassan	50	12.66	13.33
Di	59	18.73	15.73
AOI	**375**	**12.69**	**100**

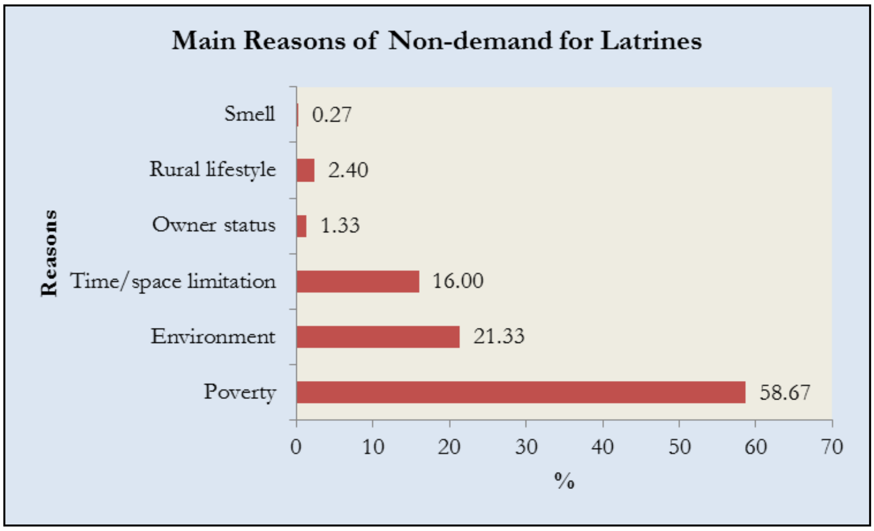


Figure 197: Main reasons of non-demand for latrines

Table 58: Main and secondary reasons justifying the absence of familial latrines in surveyed compounds

Main and Secondary Reasons of Non-demand for Latrines			
Main reason	**Secondary reason**	**Frequency**	**%**
1. Poverty	We are poor	210	56.00
	Problem to get paving	9	2.40
	There are rich people who build latrine to show themselves	1	0.27
2. Environment (Land cover/use)	We are close to the nature	38	10.13
	I fill comfortable outside	35	9.33
	The place is rocky and hard to dig	5	1.33
	Because of the water table	2	0.53
3. Time and space limitation	No time to dig the septic tank	17	4.53
	Not in my program	15	4.00
	No space to build a latrine	10	2.67
	There is no one to dig the septic tank	9	2.40
	We are digging	6	1.60
	The one I had is out of use	3	0.80
4. Rural lifestyle	We share the latrine in the big family	3	0.80
	Our neighbors have latrine and it for all of us	2	0.53
	We are living in a rural area	2	0.53
	Because my compound is not fenced	1	0.27
	Because all the village will use it	1	0.27
5. Ownership status	We are newly arrived	3	0.80
	We are nomads	1	0.27
	We are not owners of the house	1	0.27
6. Smell	To avoid bad smell in the compound	1	0.27
TOTAL	**23**	**375**	**100**

6.1.4. Mapping open air defecation areas

6.1.4.1. Open air defecation boundaries

For simplification and standardization, we used values of nearest neighbor compounds distances ($NNCD$) to limit the extension of each compound within the same settlement. The area obtained from $NNCD$ buffers was considered as the minor *kènèma* (S_{mk}). The area of the minor *kènèma* was mainly influenced by the number of compounds within the settlement. Drawing the minimum enclosed boundary from the minor kènèma, we defined the major *kènèma* (S_{MK}) as the space left between $NNCD$ buffers within the settlement. The area of the major outdoors was mainly influenced by the spatial organization pattern and the geographic extension shape of compounds within settlements. Finally, we used the minimum enclosed boundary as the limit of the *kènèma*, defecation space close to compounds and use by children. Then, the area of the *kènèma* (S_K) can be equated for each settlement i as follows:

$$S_{K_i} = S_{mk_i} + S_{MK_i}$$

For the same reasons of simplification and standardization, we used the nearest neighbor settlements distance ($NNSD$) as imaginary boundary to limit the area of the *banankô* for all settlements. The area of the *banankô* (S_B) for a settlement was calculated as follows:

$$S_B = (2\pi \times 2.63) - S_K$$

Results in Figure 198 show a dynamic variation of the open air defecation areas from one settlement to another. The inequal number of compounds, compounds spatial organization pattern and geographic extension shape proper to each settlement explain this dynamic pattern.

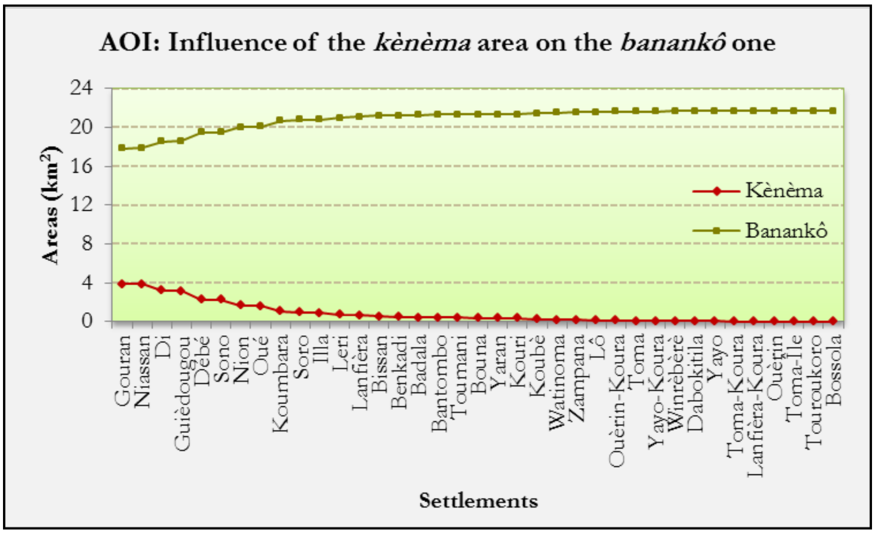


Figure 198: Plot of *banankô* and *kènèma* areas per settlements

Compounds geographic extension within the settlement and settlements closeness can result in the interconnection of *kènèma* spaces between nearest settlements (Figure 199). It was the case for four couples of settlements: Benkadi – Toma-Koura, Guièdougou – Gouran, Niassan – Toma, and Sono – Zampana (Figure 199). Except for these four cases, *kènèma* areas between settlements were fragmented by the *banankô*, even though the nearest neighbor status was observed: Dabokitila – Watinoma, Bouna – Oué, Guièdougou – Lanfièra, Niassan – Lô, Toma – Toma-Koura and, Toma – Benkadi (Figure 199).

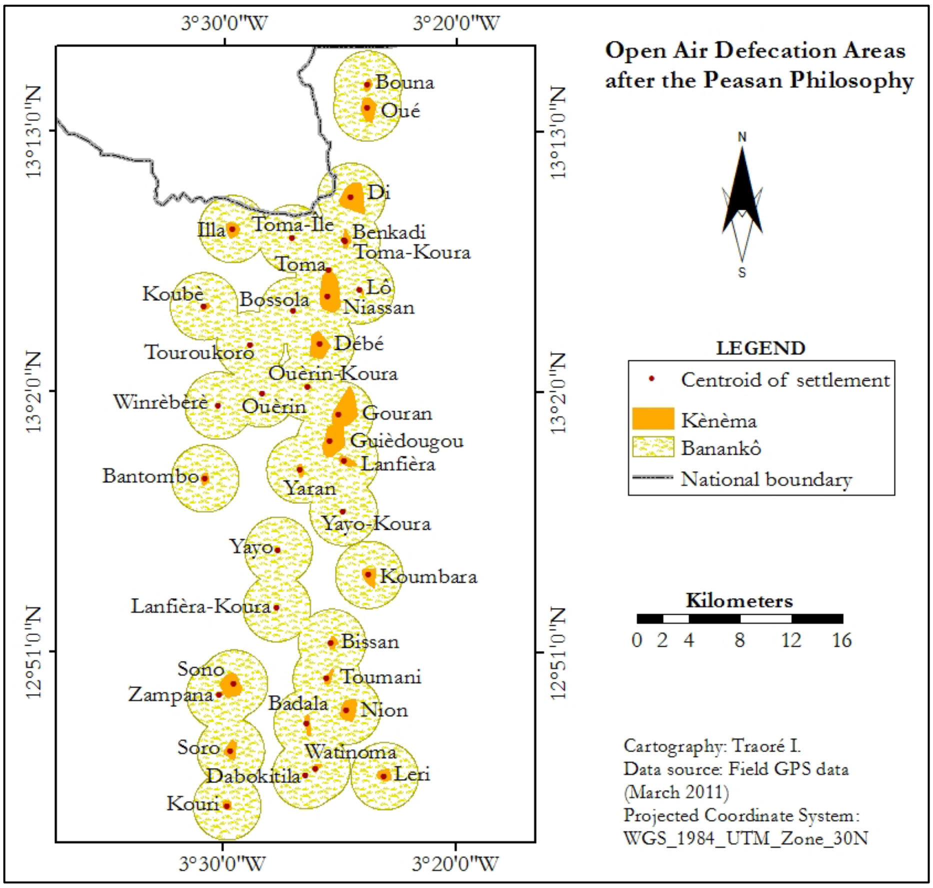


Figure 199: Open air defecation-spaces per settlement

6.1.4.2. Collective open air defecation sites: Example in Gouran

In Gouran, proportions of compounds with latrines were 91.67, 38.50 and 34.29% for the cluster north, south-west and south-east, respectively (Figure 198). In peasant perception, both north and south-east clusters of compounds are considered as peripheral compounds as opposed to the cluster south-west which is seen as the "inner-city". Locally, peripheral compounds are called *banankô-da lou*. The suffix *da* meaning the door, therefore, the word *banankô-da* refers to the entry of the *banankô* and *banankô-da lou* to compounds located at the door of the *banankô*.

The woodland appearing within the boundary of the *kènèma* represents real sites of open air defecation. These woodlands are features of the *banankô* that are located in the *kènèma*. Offering appropriate hiding places for privacy, these sites are used in the daytime for defecation by the community (irrespective of sex and age); hence, the reference to them as collective open air defecation sites (Figure 196).

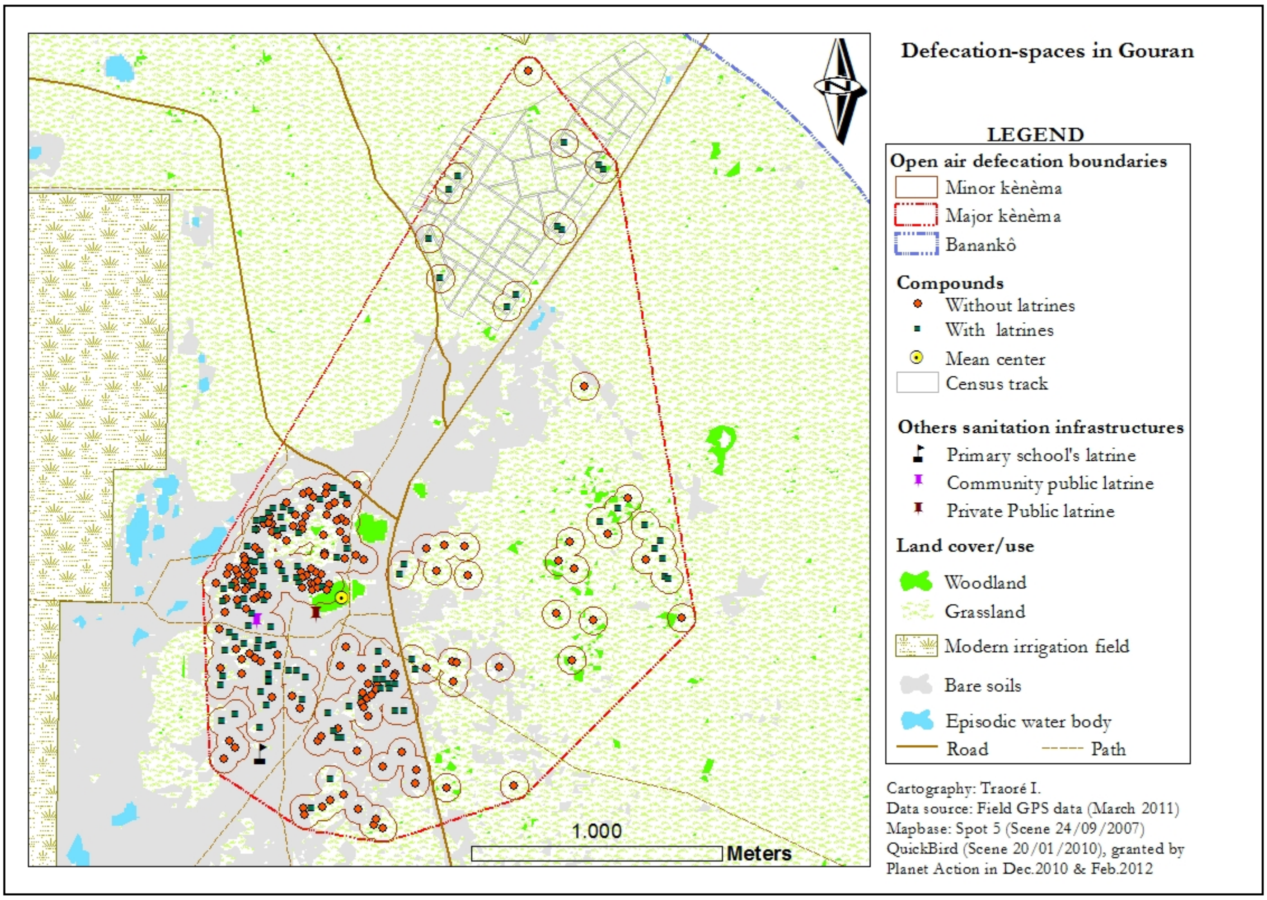


Figure 200: Geo-visualization of indoor and open air defecation areas in Gouran

6.1.5. Using SD and SDE measures to predict demand for familial latrines

First of all, all curves responded to the even decrease of values of SD and SDE with an extreme uneven speed. This means that we cannot predict the demand of familial latrines on the basis of measures of d and $\overline{SDE}_{x,y}$ in the AOI. Next, curves crossed more in Figure 201a than in Figure 202a: 8 times vs. 2 times while Figure 201b and Figure 202b showed the same number of crossing 9 times, each. This means that the demand for latrines increased around the centroid of these settlements. Evidence of the higher demand for familial latrines for compounds located within polygons (therefore, closer to the "inner-city") compared to the lesser need of latrine for compounds outside polygons (therefore, closer to the *banankô*) are shown in Figure 203. Proportions of compounds with latrines within SD (85%) and SDE (93%) polygons were higher while those outside SD and SDE polygons constituted only 15 and 7% of settlements, respectively.

The distribution of the total of 1914 latrines at the AOI level showed 69% within SD against 68% within SDE. Results also demonstrate that familial latrines were found irrespective of the location of compounds but latrines were more concentrated around the centroid of the settlement. The availability of latrines decreased peripherally toward the *banankô*.

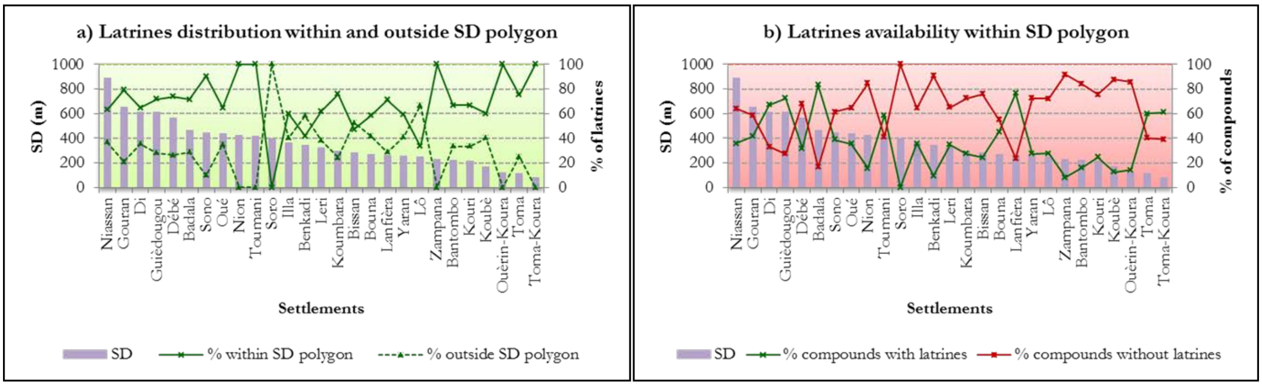


Figure 201: Concentration of latrines within the SD polygon

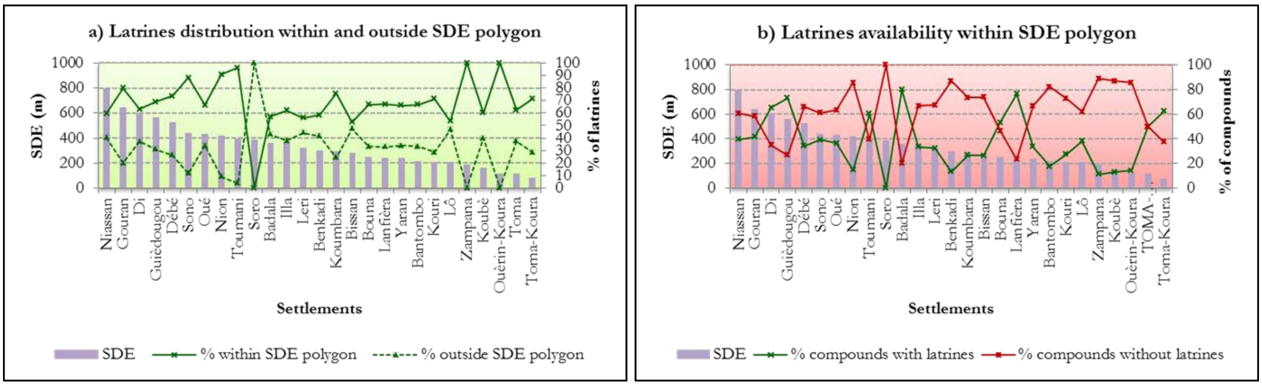


Figure 202: Concentration of latrines within the SDE polygon

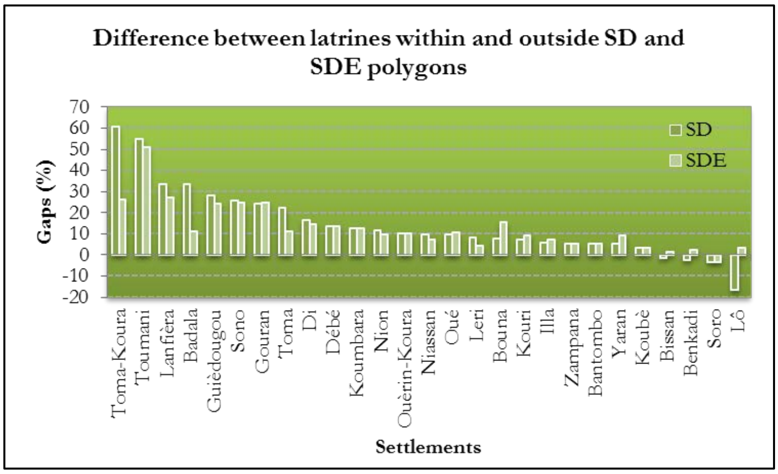


Figure 203: Comparison between SD and SDE polygons

6.1.6. Redifined access to familial latrine in the rural context

6.1.6.1. Excreta disposal behaviors for compounds found without any familial latrine

Figure 204 shows that the majority (76%) of compounds without latrines was defecating only in the open air. Flying toilets were essentially reported in the lakeside communities. It means that adults and the elderly defecate indoors in the daytime within plastic bags and throw them outdoors. Many plastic bags filled with fresh feces were observed in Toma-Île and Yayo.

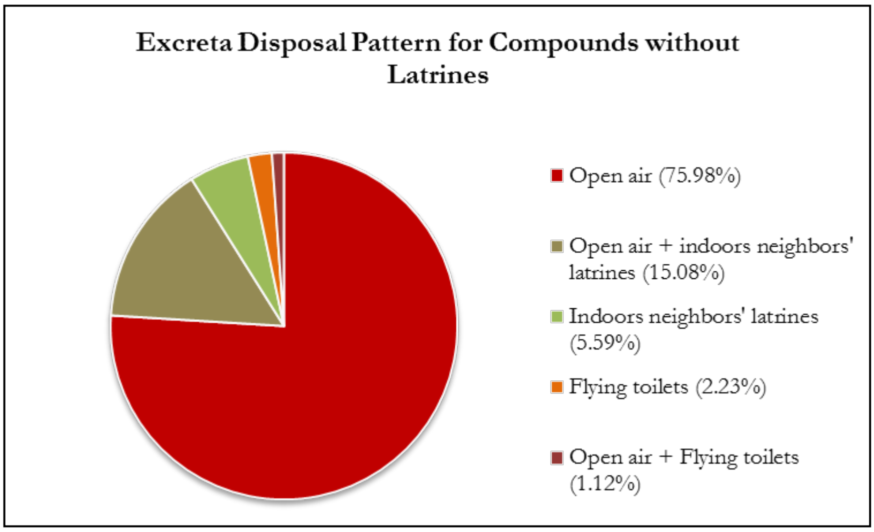


Figure 204: Excreta disposal patterns for compounds found without any latrine

6.1.6.2. Possibilities for familial latrine sharing in the community

A total of 10 settlements were found without any latrines (Table 24). Obviously, for compounds within this group, absence of latrine means no access to and no use of latrines which, therefore, means total open air defecation. However, for the 27 settlements having compounds with latrines, we can conclude that a total of 2684 compounds had no latrine, but it might be wrong to infer that the 23807 inhabitants living in these compounds do not have any access to latrines (Table 59). Data in show that about 73.26% of compounds reported their latrines being used by external people. Among the four identified main reasons leading to the sharing of familial latrines, social relationship came first place (254 out of 264 respondents). Out of 18 secondary reasons, good neighborhood (140 out of 264 respondents) was the most cited reason for allowing external members to use the latrine (Table 59).

Among reasons for non-sharing of familial latrines reported by the remaining respondents (95 out of 359) only 17 out of 95 respondents specified rejection by latrine owners. Three out of 95 respondents cited heal concerns as the main reason for non-sharing of latrines (Table 60).

Table 59: Reported reasons leading to the sharing of familial latrines

Main and Secondary Reasons Leading to Sharing Latrines			
Main reason	**Secondary reason**	**Frequency**	**%**
1. Social relationship	Good neighborhood	140	53.03
	Friends who visit us	35	13.26
	We form the same family	32	12.12
	It is nasty if you refuse	14	5.30
	Because of humanism	12	4.55
	Because they cannot move with their latrines	9	3.41
	I cannot forbid people	4	1.52
	They know I have a latrine	2	0.76
	We also passed through the same situation	2	0.76
	The latrine is outside the fence	1	0.38
	I am a stranger and it is not nice to refuse	1	0.38
	Because the well done is never lose	1	0.38
	I gain benediction from people	1	0.38
2. Work/Trade place	Our customers	5	1.89
	The water drawers	2	0.76
	It is a work place	1	0.38
3. Sensitization	It allows me to sensitize them	1	0.38
4. Religion	A good Christian is always nice	1	0.38
TOTAL	**18**	**264**	**100**

Table 60: Reported reasons for non-sharing of familial latrines

Main and Secondary Reasons of Non-sharing of Latrines			
Main reason	**Secondary reason**	**Frequency**	**%**
1. Availability	The neighbors have latrines	45	47.37
	They prefer the bush	2	2.11
2. Neutral	They don't come	11	11.58
	No reasons	7	7.37
	They are ashamed	4	4.21
	The compound is fenced	3	3.16
	They are afraid	2	2.11
	My compound is isolated and far from others	1	1.05
3. Restriction	Everybody can have a latrine	11	11.58
	It is only for my family	4	4.21
	The latrine is used only by the elderly	1	1.05
	Because nobody has done that for me	1	1.05
4. Health	Because of diseases	3	3.16
TOTAL	**13**	**95**	**100**

6.1.6.3. Using the NNCD to detect compounds with partial access to latrines

- Categorizing compounds into three groups of availability of latrines

In Figure 205 green squared dots represent compounds found with latrine in Leri and therefore difined as compounds with a total access to latrine. The grey circles represent buffer zone drawn based on the nearest neighbor compounds distance (NNCD = 36.95 m) in Leri. Compounds without latrine and located within buffer zones were detected as compounds with partial access to latrines (orange triangular dots). Compounds without latrines and located outside buffer zones were definitively classified as having no access to latrines (red circular dots).

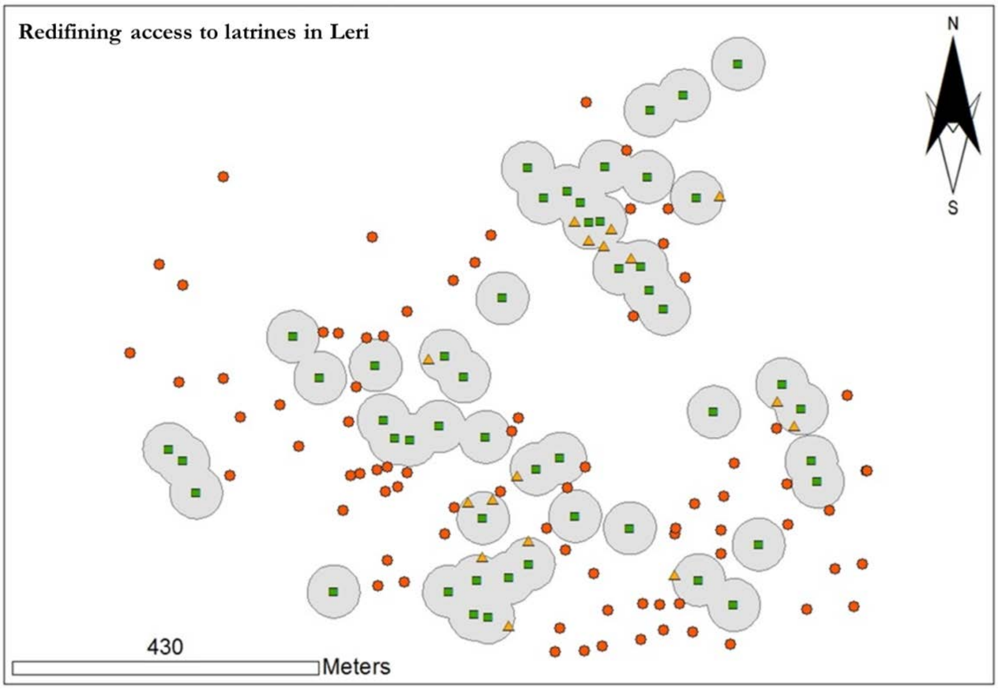


Figure 205: Compounds classification into three groups of access to latrines in Leri
(green squared dots: total acess; orange triangle dots: partial access; red circular dots: no acess)

- Access to familial latrines redifined

Table 61 shows the application of the described process to all 37 settlements of the AOI. The single compound found with latrine in Soro did not have any nearest neighbor. Then, 19.68 and 16.45% of AOI compounds and populations, respectively, were defined as having a partial acces to latrines based on the social relationship and their nearest neighbor status wit respect to compounds owners of latrines.

Table 61: Access to familial latrines redefined per settlement

Settlements	Accessibility to Familial Latrines					
	Total access		Partial access		No access	
	%Compounds	*%Populations*	*%Compounds*	*%Populations*	*%Compounds*	*%Populations*
Bossola	0.00	0.00	0.00	0.00	100	100
Yayo-Koura	0.00	0.00	0.00	0.00	100	100
Lanfièra-Koura	0.00	0.00	0.00	0.00	100	100
Dabokitila	0.00	0.00	0.00	0.00	100	100
Watinoma	0.00	0.00	0.00	0.00	100	100
Wèrimbèrè	0.00	0.00	0.00	0.00	100	100
Touroukoro	0.00	0.00	0.00	0.00	100	100
Toma-Île	0.00	0.00	0.00	0.00	100	100
Ouèrin	0.00	0.00	0.00	0.00	100	100
Yayo	0.00	0.00	0.00	0.00	100	100
Soro	3.33	5.54	0.00	0.00	96.67	94.46
Zampana	5.56	8.00	11.11	8.00	83.33	84.00
Bantombo	15.79	13.64	5.26	5.53	78.95	80.83
Ouèrin-Koura	10.00	20.00	10.00	4.00	80.00	76.00
Benkadi	14.63	12.93	13.41	14.00	71.95	73.07
Nion	11.58	15.10	18.95	12.50	69.47	72.40
Kouri	21.88	27.50	12.50	10.60	66.67	61.90
Koubè	16.67	19.10	23.33	27.39	60.00	53.52
Bissan	28.36	35.58	13.43	12.88	58.21	51.53
Lô	50.00	43.75	3.33	4.91	46.67	51.34
Leri	34.48	39.61	11.03	9.75	54.48	50.63
Illa	29.41	35.74	17.65	15.21	52.94	49.05
Yaran	28.72	39.77	14.87	11.66	56.41	48.58
Sono	32.19	37.30	24.69	23.00	43.13	39.70
Oué	32.74	44.92	21.24	15.88	46.02	39.20
Toma	44.44	56.22	11.11	5.99	44.44	37.79
Débé	28.86	36.33	29.15	28.44	41.98	35.23
Koumbara	24.44	37.22	33.33	28.82	42.22	33.97
Niassan	37.40	43.62	24.25	23.30	38.35	33.08
Bouna	46.15	59.69	17.31	12.09	36.54	28.22
Toma-Koura	60.87	71.43	13.04	8.96	26.09	19.61
Di	56.85	67.20	19.32	14.73	23.84	18.07
Gouran	41.50	52.20	36.36	31.27	22.13	16.52
Toumani	55.10	68.12	28.57	19.43	16.33	12.45
Guièdougou	64.31	76.70	16.76	11.54	18.93	11.76
Badala	77.78	86.96	11.11	4.35	11.11	8.70
Lanfièra	79.35	84.76	17.39	12.40	3.26	2.85
TOTAL	**39.32**	**48.32**	**19.68**	**16.45**	**41.02**	**35.23**

6.1.7. Using compounds illness status and latrine availability to assessment the environmental contamination potential in space

Table 62 shows numbers of compounds with respect to their urinary schistosomiasis-illness status and the presence/absence of familial latrines per settlement. Results indicated that 664 compounds have reported some of members suffering from urinary schistosomiasis-illnee and did not have any familaila latrine. This means that at least 664 infested subject were defecating in the open air. Most populated settlements occupied the last position.

Table 62: Spatial distribution of numbers of compounds per contamination degrees and scenarios

Settlement	Numbers of compounds according to the availability of latrines and the urinary schistosomiasis-illness status			
	Illness + without latrine	*Illness + with latrine*	*Healthy + without latrine*	*Healthy + with latrine*
Niassan	74	49	321	187
Guièdougou	60	139	187	306
Di	59	113	256	302
Débé	55	26	189	73
Illa	45	21	75	29
Ouèrin	35	0	17	0
Benkadi	35	1	35	11
Oué	35	32	117	42
Yaran	33	21	106	35
Yayo	32	0	56	0
Toma-Île	24	0	16	0
Bantombo	23	4	25	5
Sono	23	18	194	85
Koumbara	16	11	86	22
Nion	16	4	68	7
Leri	14	15	81	35
Kouri	12	3	63	18
Gouran	11	21	137	84
Touroukoro	8	0	19	0
Bissan	7	6	41	13
Lanfièra	5	11	14	62
Bossola	5	0	0	0
Dabokitila	5	0	6	0
Winrèbèrè	5	0	15	0
Toma	4	4	6	4
Koubè	4	3	21	2
Soro	4	0	25	1
Toma-Koura	2	3	7	11
Lanfièra-Koura	2	0	5	0
Ouèrin-Koura	2	1	7	0
Toumani	2	7	20	20
Lô	2	3	13	12
Bouna	2	12	26	12
Yayo-Koura	1	0	5	0
Watinoma	1	0	13	0
Zampana	1	0	16	1
Badala	0	0	2	7
TOTAL	**664**	**528**	**2290**	**1386**

6.1.8. Neglected aspects of resettlement of farmers with respect to provision of latrines

The principal determinant of increasing population density in some settlements is not spread but continued migration to the frontier from outside the area. Therefore, settlements playing the role of agricultural sites remain the ones where the two processes of new colonization and spread are observed simultaneously in the same place and at the same time.

From 1984, farmer migration and resettlement in the study area were coordinated by the AMVS located in Niassan (Figure 206). It is unbelievable that despite the involvement of AMVS in the said coordination, latrines were not taken into consideration in the plan for farmers' quarters in Niassan. Therefore, it could be assumed that the conception of the planners reflected absolutely dependence on the open air by peasant farmers as a site of for defecation. The picture shows the location of the accommodation provided for newly recruited farmers pending the time they are able to build their own. Built in 1992 using local materials, the accommodation was rebuilt with bricks in 1996 as shown in below. It contains 48 apartments, each designed to accommodate two families, that is to say a total of 96 households. In March 2011, we found a total of 35 families and 173 individuals living in this accommodation.

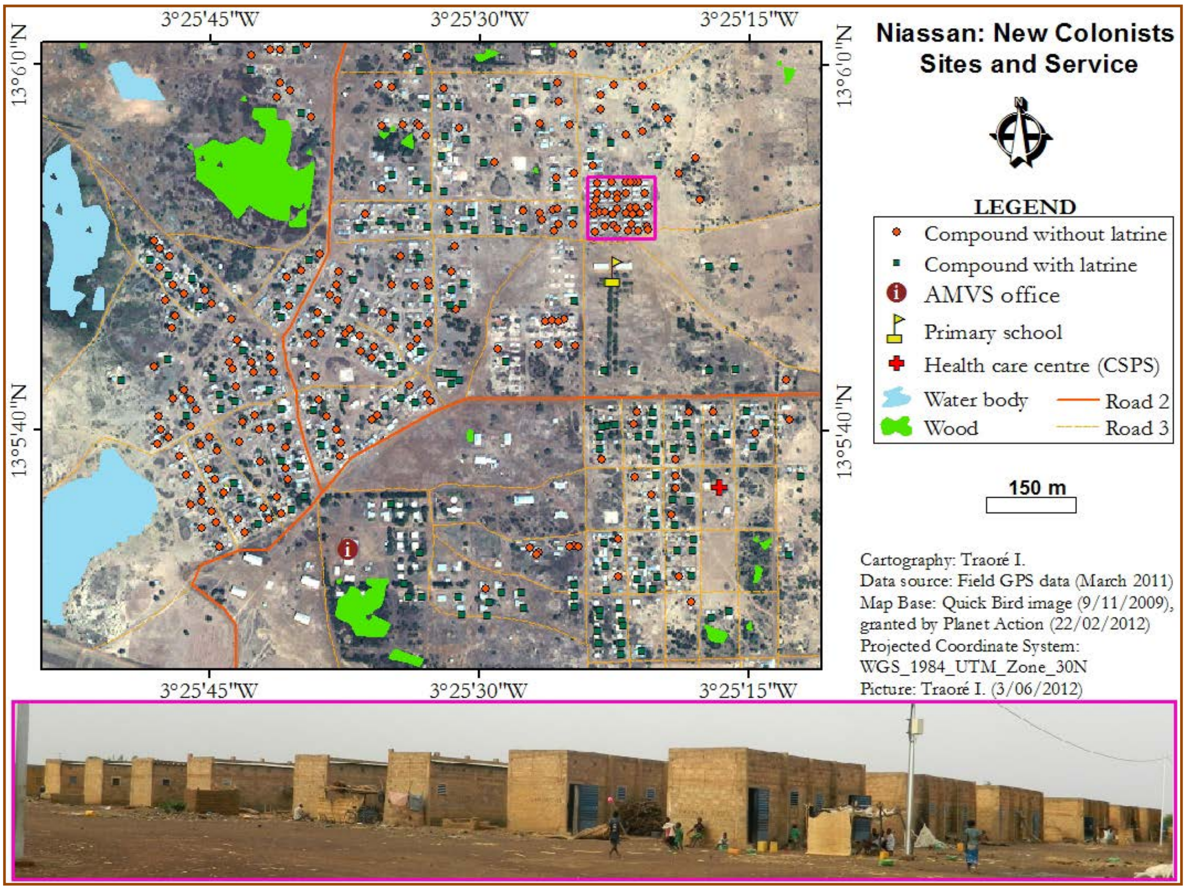


Figure 206: Farmer accommodation (Cité Trame d´Accueil) in Niassan

6.1.9. Patterns of environmental contamination due to defecation

6.1.9.1. Direct route of environmental contamination due to open air defecation

- Raining season

Lakeside settlements are of major interest. During the raining season the *banankô* of these settlements are flooded because of flooding of the Sourou River (Figure 207). Flying toilets are thrown outdoors and fall directly down in the flood water. Some adults use canoes to reach the level of the *banankô*, stand in the canoe and defecate directly in the water. This seasonal direct route of environmental contamination is the result of the lack of latrines and proximity to permanent water bodies

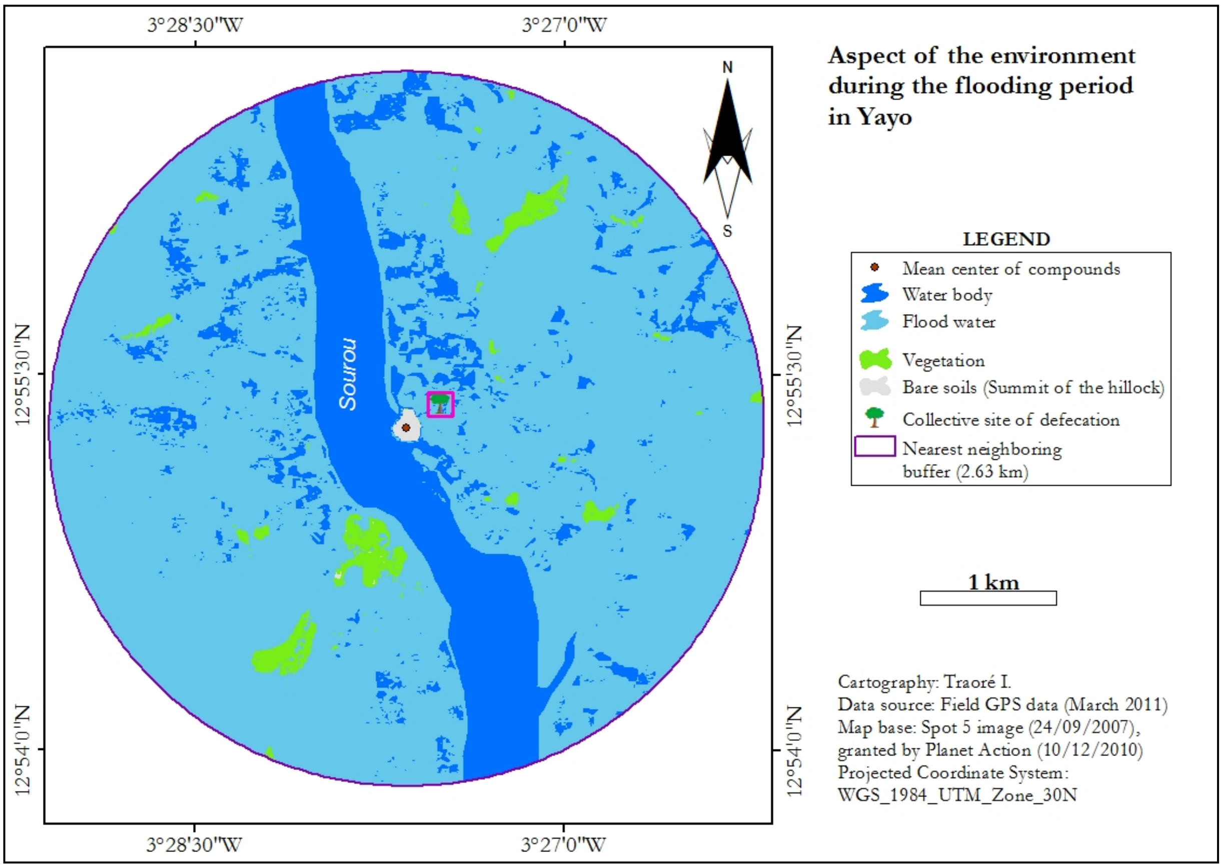


Figure 207: Intermittent flooding in Yayo and related environment data

- Dry season

Children recreational swimming activities are of concern. During field observation of children daily swimming behavior in Toma-Île, children were asked, on exiting the river, if they have urinated whilst playing in the water. Out of a total of 2405 recordings from 3rd of April to 3rd of May 2011 (31 days), 4.49% reported that they urinated whilst swimming. Figure 208 shows that among 10-14 year olds, only boys reported urination. Overall, boys were involved in more than 60% of urinations.

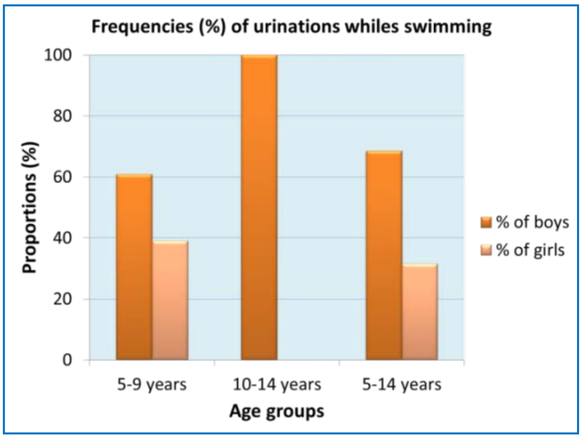


Figure 208: Frequencies of urination during swimming according to age group and gender

6.1.9.2. Indirect route of environment contamination due to the open air defecation

- Raining season

Contaminated excreta deposited outdoor are washed away and transported to freshwater bodies by rainfall. This occurs mainly between March and October according to, which shows the quantitative distribution of rainfall per month in the pentad scale. Rainfall amount is used here to determine the duration of this indirect transmission route in the AOI. Focusing on daily rainfall (DR), b shows that the potential washing effect might be restricted to five months: June to October. However, only three months show peaks of proportions of DR with at least 40 mm rainfall: July to September. The five classes of rainfall were distributed with a χ^2 = 2597.98 (df = 55), a CC = 0.43 and a p-value < 0.001. Figure 209 shows a break in the indirect environmental contamination route during four months: November to February. Conversely, the frequency and intensity of excreta washing and discharging into water bodies due to run-off from rainfall increase progressively up to the peak of rainfall in August and then decrease rapidly from August to October.

This indirect route combines lack of latrines at home and work places. In the rural context, work places refer here to irrigation and rain-fed agricultural fields where both familial latrine owners and non-owners spend the majority of time during the wet season due to farming activities. Modern agriculture fields as well as those of traditional agriculture lack latrines. Therefore, workers defecate in the open air. TFP and WBG complete the list of occupational activities bringing people far from their houses and leading to open air defecation as illustrated in Figure 210.

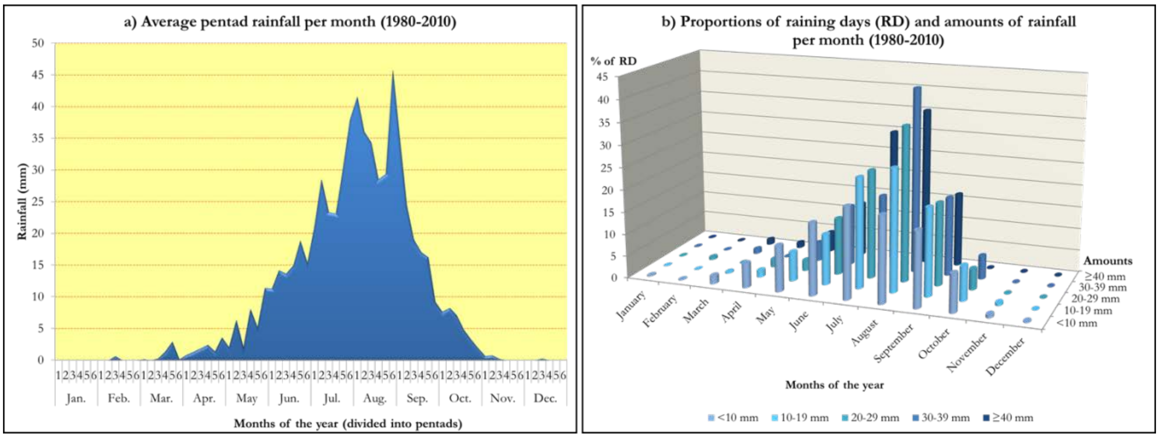


Figure 209: Seasonal pattern of rainfall in our AOI.

Figure 210: Defecation during a session of traditional fishing in pond

6.1.10. Individual knowledge about environment contamination

Individual who were aware of schistosomiasis were further interviewed to highlight their belief about the environment contamination. Results in Table 63 show that 48% of them think that an infested subject can contaminate de water body. Conversely, 45% disagreed with. 71% of individuals who did not know anything about schistosomiasis transmission from human to the snail intermediate host were illiterate. In general proportions of Yes dominated execpt for teaching of literacy status where No dominated other statements.

Table 63: Individual knowledge about the environment contamination route

Individuals Perception of Enviroment Contamiantion (n = 194)				
Educational status	Statements			Total
	No	*Yes*	*Didn't know*	
Not any	23.71	25.26	5.15	**54.12**
Primary school	5.67	6.19	0.00	**11.86**
Secondary school	3.61	6.70	0.00	**10.31**
University	0.00	1.55	0.00	**1.55**
Teaching of literacy	11.86	7.73	2.06	**21.65**
Primary school + Teaching of literacy	0.00	0.52	0.00	**0.52**
Total	**44.85**	**47.94**	**7.22**	**100**

6.2. Access to health care services with respect to schistosomiasis

6.2.1. Behaviors of the seeking care against schistosomiasis in the AOI

6.2.1.1. Individual and community therapeutic choice for schistosomiasis treatment

- Spatial distribution of compounds additionally interviewed

About 14% (n = 169) of compounds within which illness cases were reported were interviewed in 65% (n = 24) of the AOI settlements to better understand the scope of the seeking care (Table 64).

Proportions compounds interviewed at the settlement level varied between 2% and 100%. Sono alone concentrated 12% of AOI respondents.

Table 64: Spatial distribution of compounds additionally interviewed about seeking care

Compounds with illness cases additionally interviewed			
Settlement	Number	% within the settlement	% at the AOI level
Bouna	1	7.14	0.59
Kouri	1	6.67	0.59
Yayo	1	3.13	0.59
Benkadi	2	5.56	1.18
Lanfièra-Koura	2	100	1.18
Touroukoro	3	37.50	1.78
Guièdougou	4	2.01	2.37
Bissan	5	38.46	2.96
Koubè	5	71.43	2.96
Leri	5	17.24	2.96
Nion	5	25.00	2.96
Oué	5	7.46	2.96
Toumani	5	55.56	2.96
Winrèbèrè	5	100	2.96
Niassan	6	4.88	3.55
Ouèrin	8	22.86	4.73
Bantombo	10	37.04	5.92
Débé	10	12.35	5.92
Di	10	5.21	5.92
Gouran	10	31.25	5.92
Koumbara	10	37.04	5.92
Toma-Île	10	45.45	5.92
Yaran	11	20.37	6.51
Illa	15	22.73	8.88
Sono	20	48.78	11.83
AOI	**169**	**13.97**	**100**

- Individual awareness of health care providers

Table 65 shows that the modern health care center (CSPS) was more frequently cited than the traditional healer (TH) (39% vs. 14%). Figure 211 shows the spatial distribution of the three providers of medicine against schistosomiasis in our AOI.

Table 65: Individual awareness of where to get medicine against schistosomiasis

Schistosomiasis medicine providers reported by individual		
Source	Number	%
Health care center + Traditional healer	82	40.00
Health care center	80	39.02
Traditional healer	29	14.15
Didn't know	8	3.90
Health care center + Street medicine dealer	2	0.98
Traditional healer + Street medicine dealer	2	0.98
Health care center + Traditional healer + Street medicine dealer	1	0.49
Street medicine dealer	1	0.49
Total	**205**	**100**

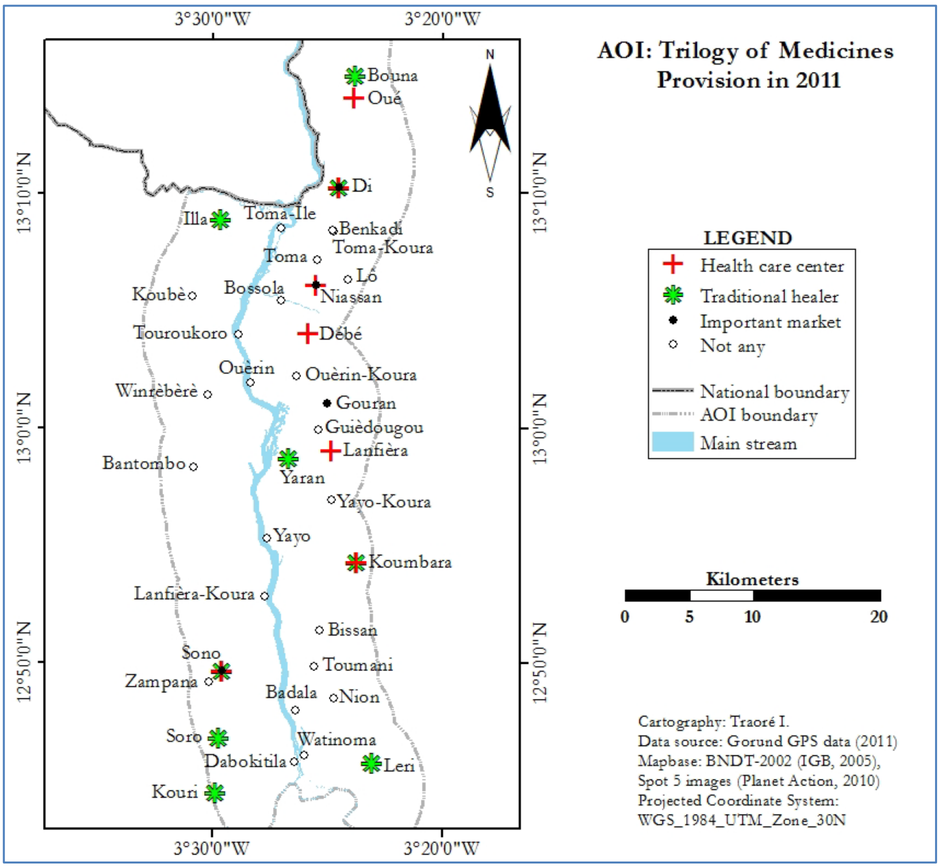


Figure 211: Spatial distribution of schistosomiasis medicine providers in our AOI

- Schistosomiasis therapeutic choice

- Therapeutic choice patterns

In fact, 87.5% of compound members interviewed provided medicine to ill members as indicated in Table 66a. Similarly, Table 66b shows that 89.01% of individuals interviewed who experienced the illness have received treatment.

Table 66 shows higher frequency of TH compared to CSPS at both community and individual levels. At the compound and individual levels, SM came last (1%) and not cited at all, respectively. Results also show that at both compound (Table 66a) and individual (Table 66b) levels the non-seeking of care in case of schistosomiasis-illness represented 13 and 11% of respondents, respectively.

Table 66: Frequencies of types of medicines used for schistosomiasis treatment in our AOI

a) Heads of compounds		
Therapeutic choice	**Number**	**%**
Traditional medicine	71	42.26
Modern medicine	47	27.98
Traditional + Modern medicines	26	15.48
No treatment	21	12.50
Street medicine	2	1.19
Traditional + Modern + Street medicines	1	0.60
Total	**168**	**100**

b) Individuals		
Therapeutic choice	**Number**	**%**
Traditional medicine	41	45.05
Modern medicine	25	27.47
Traditional + Modern medicines	15	16.48
No treatment	10	10.99
Total	**91**	**100**

- Reasons underlying community therapeutic choice

We focused on data at the compound level, where 86% (n = 145) of respondents completed the questionnaire. According to Table 67, the therapeutic choice mainly depends on efficiency (47%) and affordability (15%). The proximity (travel distance) came fourth (14%). From the experience of the community, the CSPS and TH were equal in efficiency (21% each). Table 7a also shows that modern treatment provided by the CSPS and the SM dealers had equal proportions (1% each in terms of affordability).

Table 67: Reasons underlying schistosomiasis treatment choice reported by heads of compounds

Compounds' therapeutic choice							
	Reported reasons						
Choice	***Efficiency***	***Affordability***	***Spontaneous choice***	***Proximity***	***Others***	***Acceptability***	***Total***
Traditional medicine	21.38	8.28	8.97	6.21	2.76	0.00	**47.59**
Modern medicine (CSPS)	21.38	1.38	5.52	2.07	1.38	0.00	**31.72**
Traditional + modern (CSPS)	4.14	4.14	0.00	4.83	1.38	2.76	**17.24**
Street medicine	0.00	1.38	0.00	0.00	0.00	0.00	**1.38**
Others	0.00	0.00	0.00	0.00	1.38	0.00	**1.38**
Traditional + modern + street	0.00	0.00	0.00	0.69	0.00	0.00	**0.69**
Total	**46.90**	**15.17**	**14.48**	**13.79**	**6.90**	**2.76**	**100**

- Degree of satisfaction after treatment

Table 68 shows degrees of satisfaction of patients after the treatment. In general, data show that 52% had total recovery (100% of satisfaction), 41% were more or less satisfied (50%) and 7% reported failure of treatment (0%).

Table 68: Satisfaction obtained after treatment per medicine provider

Degrees of satisfaction after treatment				
Medicine provider	**0%**	**50%**	**100%**	**Total**
Traditional medicine	3.45	15.86	28.28	47.59
Modern medicine (CSPS)	3.45	13.10	15.17	31.72
Traditional + modern (CSPS)	0.00	11.03	6.21	17.24
Street medicine	0.00	0.69	0.69	1.38
Others	0.00	0.00	1.38	1.38
Traditional + modern (CSPS) + street	0.00	0.00	0.69	0.69
Total	**6.90**	**40.69**	**52.41**	**100**

- Disturbing trend of usage of street medicine in our AOI

Table 69 shows the settlements visited by seven dealers who accepted to participate in this survey conducted in May 2011. Ages varied between 18 and 37 years while education levels showed 43% each for illiteracy (E0) and primary (E1) and 14% for secondary (E2) education. Table 69 also shows that the dealer D2 was the most mobile with seven visited settlements in the AOI, followed by D1 and D6 with six, each. On the other hand, 100, 71 and 57% of dealers visit Di, Gouran and Niassan, respectively, because these settlements house important local markets. Lakeside settlements such as Toma-Île, Ouèrin and Touroukoro are also targeted by ambulatory dealers.

Table 69: Mobility of street medicine dealers within our AOI

AOI settlements visited by street medicine dealers								
	Dealers (Age in years / Educational levels)							
Settlement	***Dealer1*** *(36/E2)*	***Dealer2*** *(37/E1)*	***Dealer3*** *(26/E0)*	***Dealer4*** *(33/E0)*	***Dealer5*** *(18/E0)*	***Dealer6*** *(27/E1)*	***Dealer7*** *(21/E1)*	**Total**
Di	1	1	1	1	1	1	1	**7**
Gouran	1	1	1	1	0	1	0	**5**
Niassan	1	1	1	0	0	1	0	**4**
Toma-Île	1	1	0	0	0	1	0	**3**
Illa	1	1	0	0	0	0	0	**2**
Sono	0	1	0	0	0	1	0	**2**
Koubè	1	0	0	0	0	0	0	**1**
Ouèrin	0	0	0	0	0	1	0	**1**
Touroukoro	0	1	0	0	0	0	0	**1**
Total	**6**	**7**	**3**	**2**	**1**	**6**	**1**	

Figure 212: Street medicine

6.2.1.2. Seasonal pattern of visiting CSPS by schitosomiasis patients

In accordance with Figure 213a, CSPS were visited by schistosomiasis patients every month throughout the year. However, highest peaks of visits of CSPS by schistosomiasis patients were observed in March (15%) following by August (11%) while, November and December recorded the lowest proportions. The seasonal distribution in Figure 213b indicates that 37% of visits occurred during the dry warm season (March – May and October) following by the wet season (June – September) whit 44% of found cases.

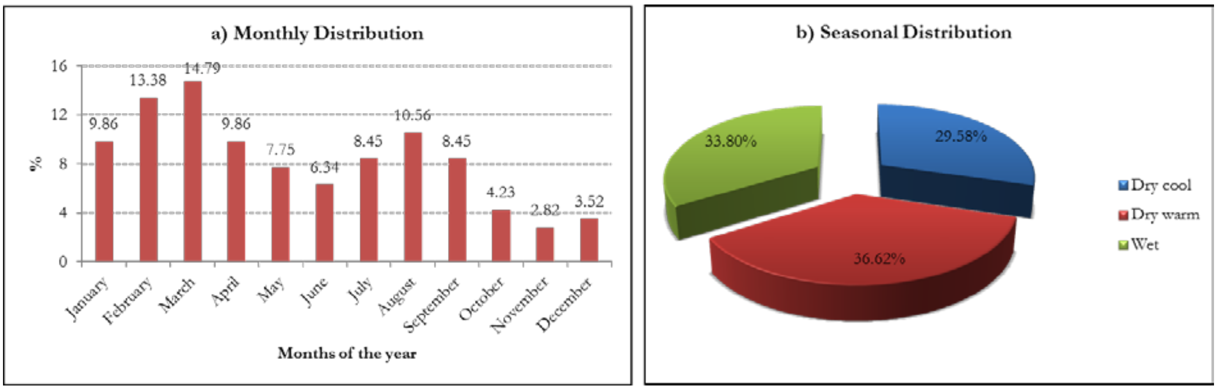


Figure 213: Temporal distribution of visit of CSPS for schistosomiasis

- Seasons influence on road links to CSPS

Figure 214a shows a strong usability of paths during the dry season. During the dry season, patients are able to visit CSPS irrespective of the transportation means. On the other hand, Figure 214b shows the non- to partial usability of road links during the wet season. During the wet season, many settlements found themselves cut from their CSPS of reference because of the flood of paths. Travel distances are at their maximum due to detours imposed by flood which is evident even for the closest CSPS. Only roads remain usable during the wet season. Therefore, Figure 214b also indicates that settlements on the western bank of the river experienced, typically, seasonal accessibility to modern heath care services. Finally, Figure 214c shows that some of the AOI settlements were served by public transportation. A bus connects, every day, the Sourou Valley to Ouagadougou via Tougan and Ouahigouya. Within our AOI the bus connects Niassan – Lô – Gouran – Guièdougou – Lanfièra. Patients having access to this transportation means can visit the HD in Tougan, the CHR in Ouahigouya and a CHU/N in Ouagadougou. Therefore, settlements on the eastern bank of the river and along the bus track were not subjected to seasonal limitation in seeking healthcare.

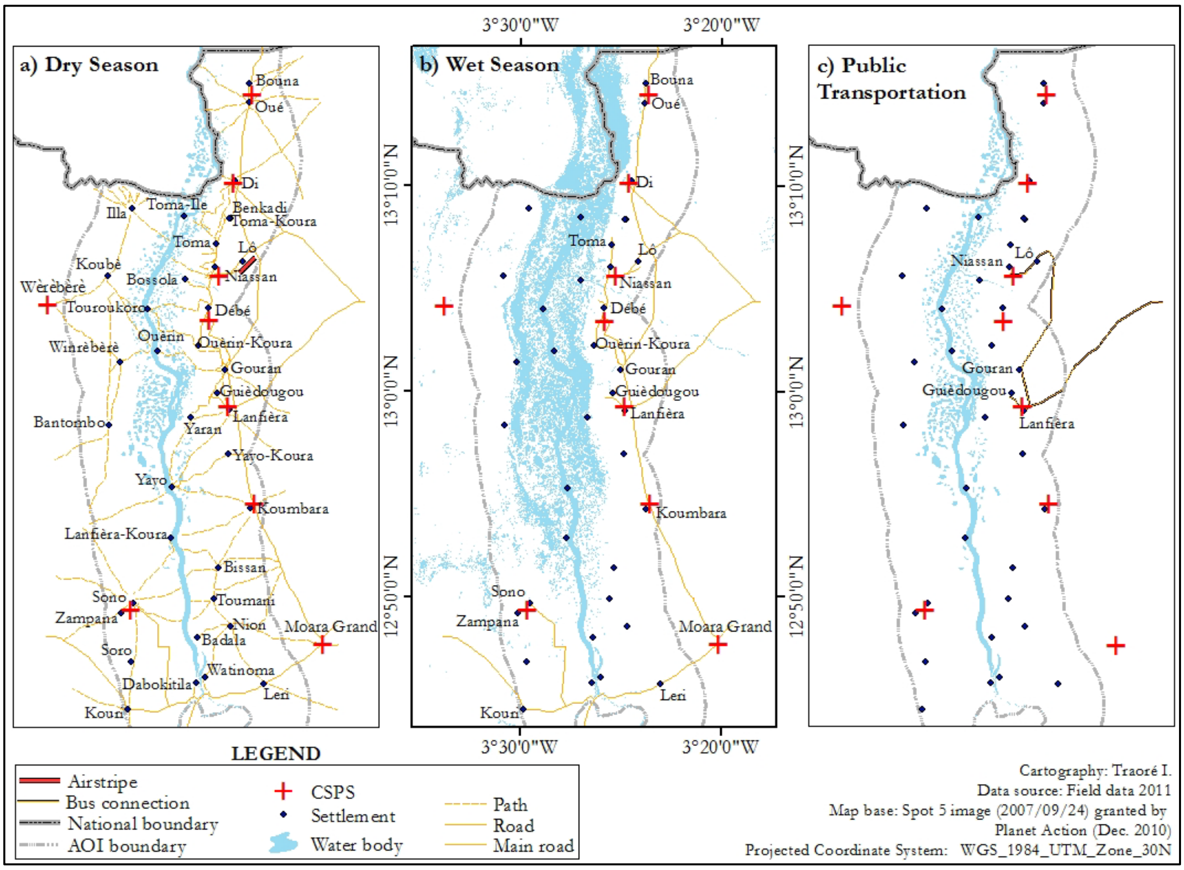


Figure 214: Seasonal accessibility to CSPS

Chapter 7. Integrating Identified Geographic Determinants for Mapping Schistosomiasis-susceptible Communities in the Sourou Valley

7.1. Outcomes of the calculation of nominative absolute scores

7.1.1. Nominative absolute scores per class of geographic element

Details on the output of geographic parameters' classes nominative scoring using urinaryschisotsomiasis-illness prevalence rate as indicator of magnitude with respect to human infestation risk status are shown in Table 70. The higher the illness rate the bigger the score of the class. For the population typology, data showed that the class of small population size observed the biggest absolute score. Absolute scores indicated for the locational distance from the main stream that the smaller the distance from the main stream the bigger the absolute score. In addition three classes showed positive association (odds ratio > 1) with the illness prevalence rate (Stuart, 2006). The not available class of hydraulic work availability parameter, the no access class of hydraulic work accessibility parameter, and IRR+TFP+WBG class of the occupational activities parameter (Table 70).

On the other hand, details on the output of geographic parameters' classes nominative scoring using familial latrines availability rates as indicator of magnitude with respect to environmental contamination risk status are shown in Table 71. The higher the latrine rate the smaller the score of the class. Data showed the larger the population size, the bigger the absolute score attributed to the population size class. Conversly, the closer from the perenial water body the bigger the absolute score attributed to the locational distance class with respect to the main stream. Seven classes observed positive association with latrine vailability rate (odds ratio > 1) (Stuart, 2006): Very large poupualtion size, complete modern agricultural, capital of rural commune,… (Table 71).

Table 70: Details on absolute scores per class of geographic parameter with respect to human infestation risk status

Human infestation risk status: Absolute score per class of geographic parameter based on the illness rate							
Geographic parameter	**Class**	**Compounds with illness**	**Illness rate (%)**	**Odds ratio**	**95% CI lower**	**95% CI upper**	**Absolute score**
Population	Very large	514	25.04	0.11	0.25	0.25	2
	Large	368	22.41	0.08	0.22	0.22	1
	Small	237	28.69	0.16	0.29	0.29	4
	Very small	91	26.22	0.13	0.26	0.26	3
Spatial organization pattern	Clustered	848	23.06	0.09	0.23	0.23	1
	Random	172	29.40	0.17	0.29	0.29	2
	Dispersed	190	31.40	0.21	0.31	0.31	3
Geographic extension shapes	Round	140	30.91	0.20	0.31	0.31	3
	Oblong	564	22.83	0.09	0.23	0.23	1
	Elliptic	506	26.02	0.12	0.26	0.26	2
Locational distance	Very close	164	36.61	0.33	0.37	0.37	4
	Close	795	24.51	0.11	0.25	0.25	3
	Distant	218	22.09	0.08	0.22	0.22	2
	Very distant	33	17.46	0.04	0.17	0.18	1
Agricultural functions	Complete modern	240	30.11	0.19	0.30	0.30	3
	Semi-modern	474	20.55	0.07	0.21	0.21	1
	Traditional	496	28.12	0.15	0.28	0.28	2
Administrative functions	Capital of commune	249	21.80	0.08	0.22	0.22	1
	Village	938	25.68	0.12	0.26	0.26	2
	Hamlet	23	31.51	0.21	0.31	0.32	3
Hydraulic works availability	Normal	193	27.34	0.14	0.27	0.27	3
	Close to normal	372	21.57	0.08	0.22	0.22	1
	Insufficient	536	24.39	0.10	0.24	0.24	2
	Too insufficient	32	36.36	0.33	0.36	0.37	4
	Not available	77	50.99	1.08	0.51	0.51	5
Hydraulic works accessibility	Good	489	24.20	0.10	0.24	0.24	3
	Fairly-good	637	24.18	0.10	0.24	0.24	2
	Appalling	12	16.44	0.04	0.16	0.17	1
	No access	72	51.43	1.12	0.51	0.52	4
Access to modern health care	Good	909	23.58	0.10	0.24	0.24	1
	More or less good	193	27.97	0.15	0.28	0.28	2
	Appalling	108	33.44	0.25	0.33	0.34	3
Access to education	No attendant	110	37.80	0.37	0.38	0.38	3
	Low attendance	29	30.85	0.20	0.31	0.31	2
	High attendance	1071	23.89	0.10	0.24	0.24	1
Occupational status	IRR+WBG+TFP	57	61.96	2.65	0.62	0.62	6
	IRR+TFP	92	33.45	0.25	0.33	0.34	5
	TFP+WBG	8	29.63	0.18	0.29	0.30	4
	TFP	63	25.61	0.12	0.26	0.26	3
	IRR	696	23.97	0.10	0.24	0.24	2
	NTA	294	22.21	0.08	0.22	0.22	1
Freshwater potential	Lakeside	359	30.22	0.19	0.30	0.30	3
	Lowlands	663	26.57	0.13	0.27	0.27	2
	Highlands	188	15.86	0.04	0.16	0.16	1
Vegetation potential	Dense	10	18.18	0.05	0.18	0.18	2
	More or less dense	106	15.52	0.03	0.16	0.16	1
	Degraded	831	24.16	0.10	0.24	0.24	3
	Intermittent flood	263	38.06	0.38	0.38	0.38	4
Modern irrigation field	Paddy+poly-culture	514	24.51	0.11	0.25	0.25	2
	Paddy or poly-culture	302	27.26	0.14	0.27	0.27	3
	Not any	394	23.69	0.10	0.24	0.24	1
Illness prevalent setting	Low	2	4.88	0.00	0.05	0.05	1
	Moderate	972	22.58	0.09	0.23	0.23	2
	High	236	45.12	0.68	0.45	0.45	3

Table 71: Details on absolute scores per class of geographicparameter with respect to environmental contamination risk status

Environmental contamination risk status: Absolute score per class of geographic parameter based on the latrine rate							
Geographic parameters	**Class**	**Compounds with latrines**	**Latrines rate (%)**	**Odds ratio**	**95% CI lower**	**95% CI upper**	**Absolute score**
Population	Very large	1096	53.39	1.31	0.53	0.53	1
	Large	520	31.67	0.21	0.32	0.32	2
	Small	219	26.51	0.13	0.26	0.27	3
	Very small	79	22.77	0.09	0.23	0.23	4
Spatial organization pattern	Clustered	1648	44.81	0.66	0.45	0.45	1
	Random	150	25.64	0.12	0.26	0.26	2
	Dispersed	116	19.17	0.06	0.19	0.19	3
Geographic extension shapes	Round	114	25.17	0.11	0.25	0.25	3
	Oblong	904	36.60	0.33	0.37	0.37	2
	Elliptic	896	46.07	0.73	0.46	0.46	1
Locational distance	Very close	63	14.06	0.03	0.14	0.14	4
	Close	1502	45.12	0.68	0.45	0.45	1
	Distant	314	34.81	0.29	0.35	0.35	2
	Very distant	35	18.52	0.05	0.18	0.19	3
Agricultural functions	Complete modern	471	59.10	2.09	0.59	0.59	1
	Semi-modern	973	42.18	0.53	0.42	0.42	2
	Traditional	470	26.64	0.13	0.27	0.27	3
Administrative functions	Capital of commune	591	51.75	1.15	0.52	0.52	1
	Village	1307	35.78	0.31	0.36	0.36	2
	Hamlet	16	21.92	0.08	0.22	0.22	3
Hydraulic works availability	Normal	245	34.70	0.28	0.35	0.35	2
	Close to normal	557	32.29	0.23	0.32	0.32	3
	Insufficient	1105	50.27	1.02	0.50	0.50	1
	Too insufficient	0	0.00	-	0.00	0.00	5
	Not available	7	4.64	0.00	0.05	0.05	4
Hydraulic works accessibility	Good	1093	54.08	1.39	0.54	0.54	1
	Fairly-good	798	30.30	0.19	0.30	0.30	2
	Appalling	16	21.92	0.08	0.22	0.22	3
	No access	7	5.00	0.00	0.05	0.05	4
Access to modern health care	Good	1714	44.46	0.64	0.44	0.44	1
	More or less good	120	17.39	0.04	0.17	0.17	3
	Appalling	80	24.77	0.11	0.25	0.25	2
Access to education	No attendant	35	12.03	0.02	0.12	0.12	3
	Low attendance	16	17.02	0.04	0.17	0.17	2
	High attendance	1863	41.56	0.51	0.42	0.42	1
Occupational status	IRR+WBG+TFP	0	0.00	-	0.00	0.00	5
	IRR+TFP	0	0.00	-	0.00	0.00	5
	TFP+WBG	93	33.82	0.26	0.34	0.34	2
	TFP	60	24.39	0.10	0.24	0.24	4
	IRR	1416	48.76	0.91	0.49	0.49	1
	NTA	345	26.06	0.12	0.26	0.26	3
Freshwater potential	Lakeside	479	40.32	0.46	0.40	0.40	2
	Lowlands	1024	41.04	0.48	0.41	0.41	1
	Highlands	411	34.68	0.28	0.35	0.35	3
Vegetation potential	Dense	1	1.82	0.00	0.02	0.02	4
	More or less dense	193	28.26	0.16	0.28	0.28	2
	Degraded	1600	46.53	0.76	0.47	0.47	1
	Intermittent flood	120	17.37	0.04	0.17	0.17	3
Modern irrigation field	Paddy+ poly-culture	920	43.87	0.61	0.44	0.44	2
	Paddy or poly-culture	566	51.08	1.09	0.51	0.51	1
	Not any	428	25.74	0.12	0.26	0.26	3
Latrine availability	No access	0	0.00		0.00	0.00	5
	Not good	94	17.00	0.04	0.17	0.17	4
	Fairly-good	824	34.05	0.27	0.34	0.34	3
	Good	916	60.10	2.27	0.60	0.60	2
	Very good	80	79.21	14.51	0.79	0.79	1

7.1.2. Settlements individual absolute scores

The highest (1st), median (19th) and lowest (37th) ranked absolute score with respect to environmental contamination were observed in Touroukoro (score = 51), Bissan (34) and Guièdougou (16) as indicated in Figure 215a. Then, Touroukoro's score was 1.5 times and 2.83 times hihgher than those of Bissan and Guièdougou. Next, the spatial distribution revealed 12 different equal scores: 48 – 45 – 41 – 38 – 37 – 35 – 34 – 32 – 30 – 27 – 25 – 23.

With 49, 32 and 19 as absolute score for human infestation, Ouèrin, Toumani and Sono occupied the highest , the median and the lowest ranked places as shown in Figure 215b, respectively. Then, the score in Ouèrin was 1.5 times and 2.6 times higher than in Toumani and in Sono. The spatial distribution shows nine different equal scores: 46 – 36 – 34 – 32 – 31 – 30 – 29 – 26 - 25.

In terms of schistosomiasis transmission Figure 215c shows that with a absolute score of 2346, Touroukoro was the highest ranked settlement and was 2.2 times and 4.3 times higher than in Soro (19th with 1066) and in Di (37th with 551). However, the heterogeneity in space observed only two different equal scores: 1152 – 1088.

Comparing the order of magnitude between environmental contamination, human infestation and schistosomiasis transmission, results showed an apparent stability for settlements with large scores as indicated in Figure 215. Toma-Île, Touroukoro and Yayo (3/5) came three times among the first five highest scores. Conversely, only Yaran (1/5) came three times among the five median scores (17th – 21st). None of settlements (0/5) was repeated three times among the five lowest scores (33rd – 37th).

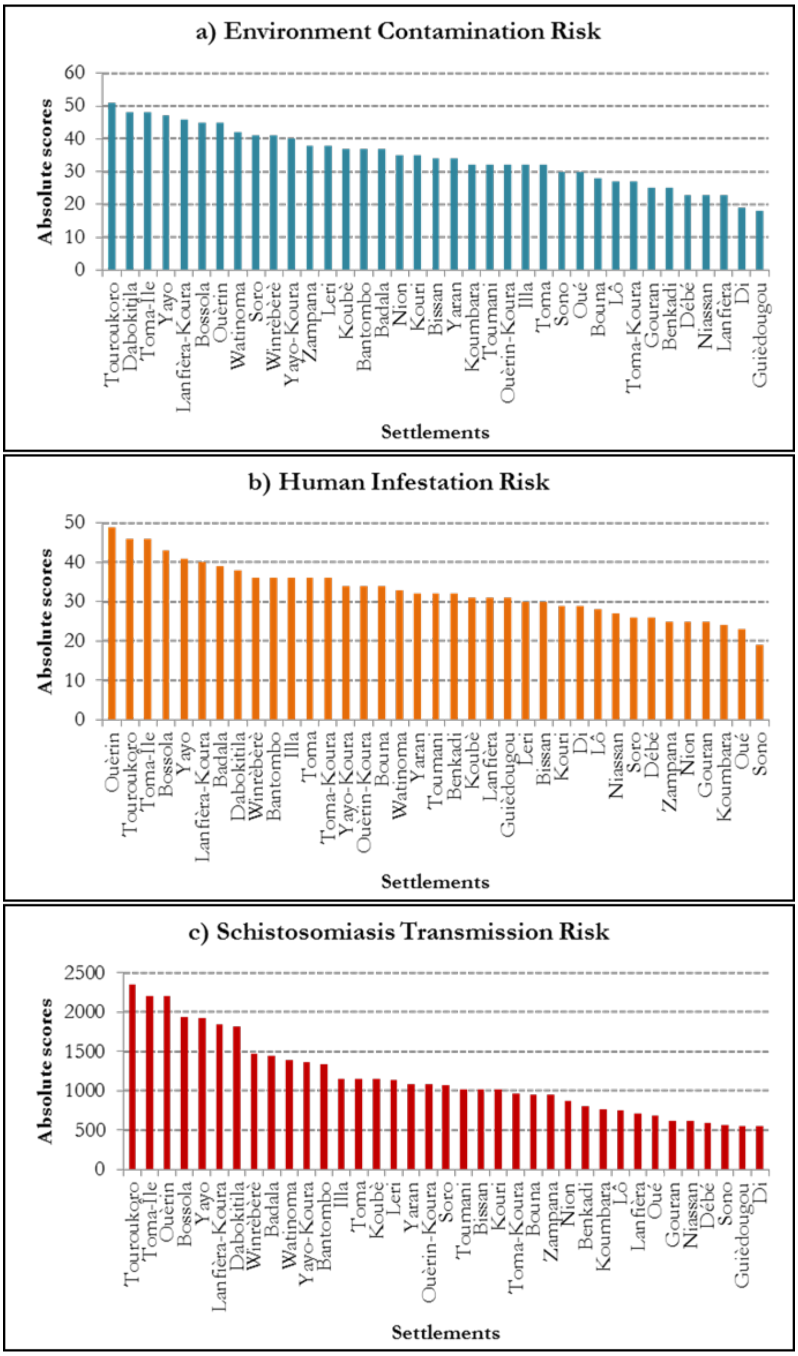


Figure 215: Absolute score distribution per settlements and risk status

7.1.3. Relationship between indicators and scores

Figure 216 shows that settlements' latrine rates were negative correlated to absolute score with respect to environmental contamination and schistosomiasis transmission (ST1). Conversely, there were positive correlations between the illness rates and absolute score for human infestation and schistosomiasis transmission (ST2) (Figure 216). Only the influence of latrine rate on absolute score for environmental contamination showed the highest coefficient of determination (r2 = 57%).

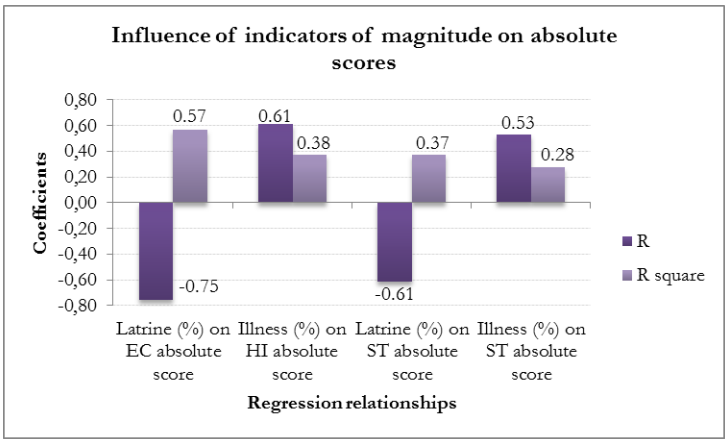


Figure 216: Linear Regression Relationship between individual indicators and scores at the settlement level

7.1.4. Randomness pattern of statistic indicator distribution

7.1.4.1. Randomness pattern of absolute scores spatial distribution

We analyzed the spatial autocorrelation based on settlement location and score using the global Moran's I statistic and the inverse distance conceptualization in ArcGIS. Moran's indexes show a positive autocorrelation for each of the three risk status as indicated in Table 72. Only scores for the enrivronment contamination risk observed an index closer to one and meaning a clustered spatial pattern for which results showed a less than 10% likelihood (p-value = 0.05). Conversely, indexes for human infestation and schistosomiasis transmission risks were closer to zero and meaning a random spatial pattern.

Table 72: Absolute scores: Moran's spatial autocorrelation statistics

Moran's I Spatial Autocorrelation Statistics using absolute scores			
Moran's I summary	**Environment Contamination**	**Human Infestation**	**Schistosomiasis Transmission**
Moran's index	0.58	0.16	0.29
z-score	1.94	0.61	1.02
p-value	0.05	0.54	0.31
Result	10%	-	-
Pattern	Clustered	Random	Random

7.1.4.2. Randomness of z-scores spatial distribution patterns

According to Moran's indexes in Table 73, all risk status showed a positive spatial autocorrelation using z-scores. The fixed distance band (FDB) for schistosomiasis transmission risk status showed a clustered pattern with a less than 5% likelihood instead of a dispersed pattern as observed in Table 72. Further, Table 73 indicates that spatial statistics for the inverse distance (ID) conceptual method are similar to those indicated in Table 72 per risk status.

Table 73: Spatial autoccorelation statistics

Moran's I Spatial Autocorrelation Statistics using z-scores values						
Moran's I summary	Conceptualization methods					
	Fixed distance band (FDB)			Inverse distance (ID)		
	Environment Contamination	*Human Infestation*	*Schistosomiasis Transimmission*	*Environment Contamination*	*Human Infestation*	*Schistosomiasis Transimmission*
Moran's index	1.19	0.54	0.63	0.59	0.16	0.29
z-score	3.85	1.55	2.10	1.96	0.61	1.02
p-value	0.000	0.120	0.036	0.050	0.540	0.306
result	1%	-	5%	10%	-	-
Pattern	Clustered	Random	Clustered	Clustered	Random	Random

7.1.4.3. Standard residuals spatial randomness patterns

Compared to Table 72, Table 74 shows negative autocorrelation for all risk status. In addition, Moran's indexes were closer to -1 for environmental contamination and meaning a dispersed pattern with a less than 5% likelihood. Similar to Table 72, Moran's indexes for human infestation and schistosomiasis transmission (ST2) were closer to zero and meaning random pattern. Table 74 also shows that spatial statistics were constant for human infestation following AICc and CV. Only schistosomiasis transmission (ST2) showed a positive autocorrelation.

Table 74: Standards residuals: Moran's I spatial autocorrelation statistics

Moran's I Spatial Autocorrelation Statistics using Geographic Weighted Regression Standard Residuals									
Moran's I summary	Kernel types	GWR_AICc				GWR_CV			
		EC	*HI*	*ST*	*ST2*	*EC*	*HI*	*ST*	*ST2*
Moran's index	Adaptive	-0.73	-0.15	-0.48	0.10	-0.78	-0.15	-0.48	0.12
	Fixed	-0.82	-0.14	-0.47	0.15	-0.78	-0.14	-0.46	0.18
z-score	Adaptive	-2.29	-0.41	-1.45	0.42	-2.44	-0.41	-1.45	0.49
	Fixed	-2.55	-0.36	-1.43	0.59	-2.43	-0.36	-1.39	0.69
p-value	Adaptive	0.022	0.681	0.147	0.671	0.015	0.681	0.147	0.623
	Fixed	0.011	0.720	0.153	0.558	0.015	0.720	0.164	0.492
Result	-	5%	-	-	-	5%	-	-	-
Pattern		Dispersed	Random	Random	Random	Dispersed	Random	Random	Random

EC: Environment Contamination; **HI:** Human Infestation; **ST:** Schistosomiasis Transmission

7.2. Human infestation-susceptible settlements and populations by integrating identified geographic parameters

7.2.1. Human infestation-susceptible settlements and populations based on absolute scores

Based on settlements' absolute scores with respect to the human infestation risk status, Table 75 shows proportions of settlements, compounds and populations per quantitative classification method and susceptible risk levels. The highest proportion of settlements (32.43%) fell into the medium risk level and was obtained with the equal interval and the natural breaks methods. While the highest proportions of compounds (59.29%) and populations (57.85%) were observed into the low risk level and provided by the equal interval (Table 75). In general, proportions of settlements, compounds and populations were unequally distributed within the same quantitative classification method. However, the quantile and the geometrical interval showed the same proportions (16.22, 4.50 and 4.63% of settlements, compounds and populations, respectively) with respect to the high-high risk level (Table 75).

Figure 217 presents the spatial distribution of settlements per risk level and quantitative classification method with reference to the main stream in the study area. First of all, Figure 217 allows to see the influence of quantitative classification methods on settlements susceptible risk level. For example, detected into the medium risk level with the equal interval, Bantombo, Illa and Winrèbèrè fell into the high risk level for the other three quantitative classification methods. Figure 217 also indicated that three settlements (Ouèrin, Toma-Île and Touroukoro) which fell into the high-high human infestation risk level, irrespective to the quantitative classification method. These settlements represent those with the highest absolute scores in terms of human infestation risk status (Figure 215b). Finally, Figure 217 demonstrates the evidence of the spatial overlapping between settlements with the high-high human infestation risk and settlements proximity to the main stream.

Table 75: Human infestation risk status based on absolute scores: Proportions of settlements (%S), compounds (%C) and populations (%P) per quantitative classification method and risk level

		Quantitative classification methods											
		Equal interval			Quantile			Natural breaks (Jenks)			Geometrical interval		
Risk status	**Risk level**	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*
Human Infestaion	High-High	8.11	2.44	2.65	16.22	4.50	4.63	10.81	2.55	2.74	16.22	4.50	4.63
	High	13.51	2.47	2.44	18.92	6.33	6.42	24.32	8.28	8.31	18.92	6.33	6.42
	Medium	32.43	14.30	15.30	18.92	8.38	9.34	32.43	29.46	31.96	10.81	1.68	2.28
	Low	29.73	59.29	57.85	24.32	51.62	50.18	24.32	45.73	43.22	27.03	44.74	46.74
	Low-Low	16.22	21.51	21.76	21.62	29.17	29.43	8.11	13.99	13.77	27.03	42.75	39.93

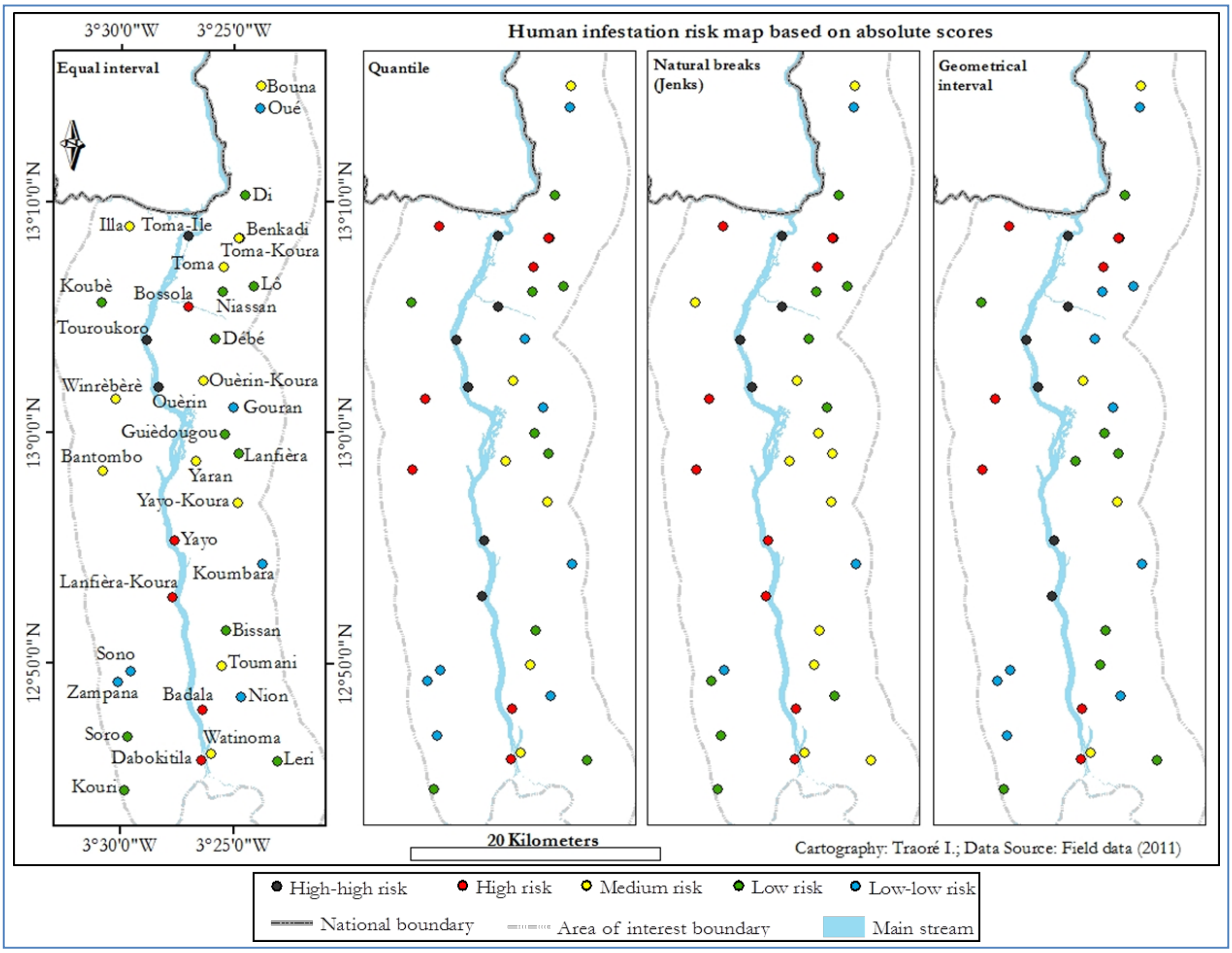


Figure 217: Spatial distribution of human infestation-susceptible settlements based on absolute scores

7.2.2. Human infestation-susceptible settlements and populations based on z-scores

Based on settlements' z-scores with respect to the human infestation risk status, Table 76 shows proportions of settlements, compounds and populations per quantitative classification method and susceptible risk level. First of all, proportions of settlements, compounds and populations depended on the hot spot conceptualization method. According to the fixed distance band (FDB), equal interval and natural breaks showed the same proportions for the low and low-low risk levels. For the same risk levels, proportions were equal between the quantile and the geometrical interval. The highest proportions of settlements (32.43%) and compounds (36.91%) fell into the high human infestation risk level and were obtained by the natural breaks. While the highest ranked proportion of populations (39.15%) was observed into the low risk level according to both equal interval and natural breaks methods (Table 76).

The inverse distance (ID) provided the same proportions (16.22, 4.50 and 4.63% of compounds, settlements and populations, respectively) with both quantile and geometrical interval methods with respect to the high-high and high risk levels (Table 75). The majority of settlements (32.43%) was detected into the medium risk level according to both the equal interval and the natural breaks methods. While the bulk of compounds (59.29%) and populations (57.85%) were concentrated into the low human infestation risk level and according to the equal interval method (Table 75).

We found that proportions from the inverse distance (ID) conceptual method in Table 76 were the same per risk level and quantitative classification method as ready observed for absolute scores in Table 75. This suggests a perfect overlapping of proportion of settlements, compounds and populations between the absolute scores and z-scores methods.

Figure 218 shows the difference in terms of spatial distribution of susceptible settlements between the FDB (Figure 218a) and ID (Figure 218b) conceptualization methods with reference to the main stream in the study area. However, Ouèrin and Touroukoro were the two settlements that fell into the human infestation high-high risk level, irrespective to the hot spot conceptualization method and the quantitative classification method (Figure 218). These settlements had the first highest ranked absolute scores according to Figure 215b. Figure 218 also associated the high-high human infestation risk level with the proximity to the main stream.

Table 76: Human infestation risk status based on z-scores: Proportions of settlements (%S), compounds (%C) and populations (%P) per quantitative classification method and risk level

Risk status	Hot spot conceptualization method	Risk level	Quantitative classification methods											
			Equal interval			Quantile			Natural breaks (Jenks)			Geometrical interval		
			% S	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*
Human infestation	Fixed distance band (FDB)	High-High	10.81	5.53	5.48	18.92	8.26	8.18	8.11	2.03	2.13	21.62	8.87	8.95
		High	29.73	33.42	31.17	18.92	29.52	27.36	32.43	36.91	34.53	18.92	30.07	27.71
		Medium	27.03	17.60	17.51	18.92	11.46	11.86	27.03	17.60	17.51	16.22	10.29	10.74
		Low	24.32	35.89	39.15	21.62	30.20	32.08	24.32	35.89	39.15	21.62	30.20	32.08
		Low-Low	8.11	7.56	6.68	21.62	20.56	20.53	8.11	7.56	6.68	21.62	20.56	20.53
	Inverse distance (ID)	High-High	8.11	2.44	2.65	16.22	4.50	4.63	10.81	2.55	2.74	16.22	4.50	4.63
		High	13.51	2.47	2.44	18.92	6.33	6.42	24.32	8.28	8.31	18.92	6.33	6.42
		Medium	32.43	14.30	15.30	18.92	8.38	9.34	32.43	29.46	31.96	10.81	1.68	2.28
		Low	29.73	59.29	57.85	24.32	51.62	50.18	24.32	45.73	43.22	27.03	44.74	46.74
		Low-Low	16.22	21.51	21.76	21.62	29.17	29.43	8.11	13.99	13.77	27.03	42.75	39.93

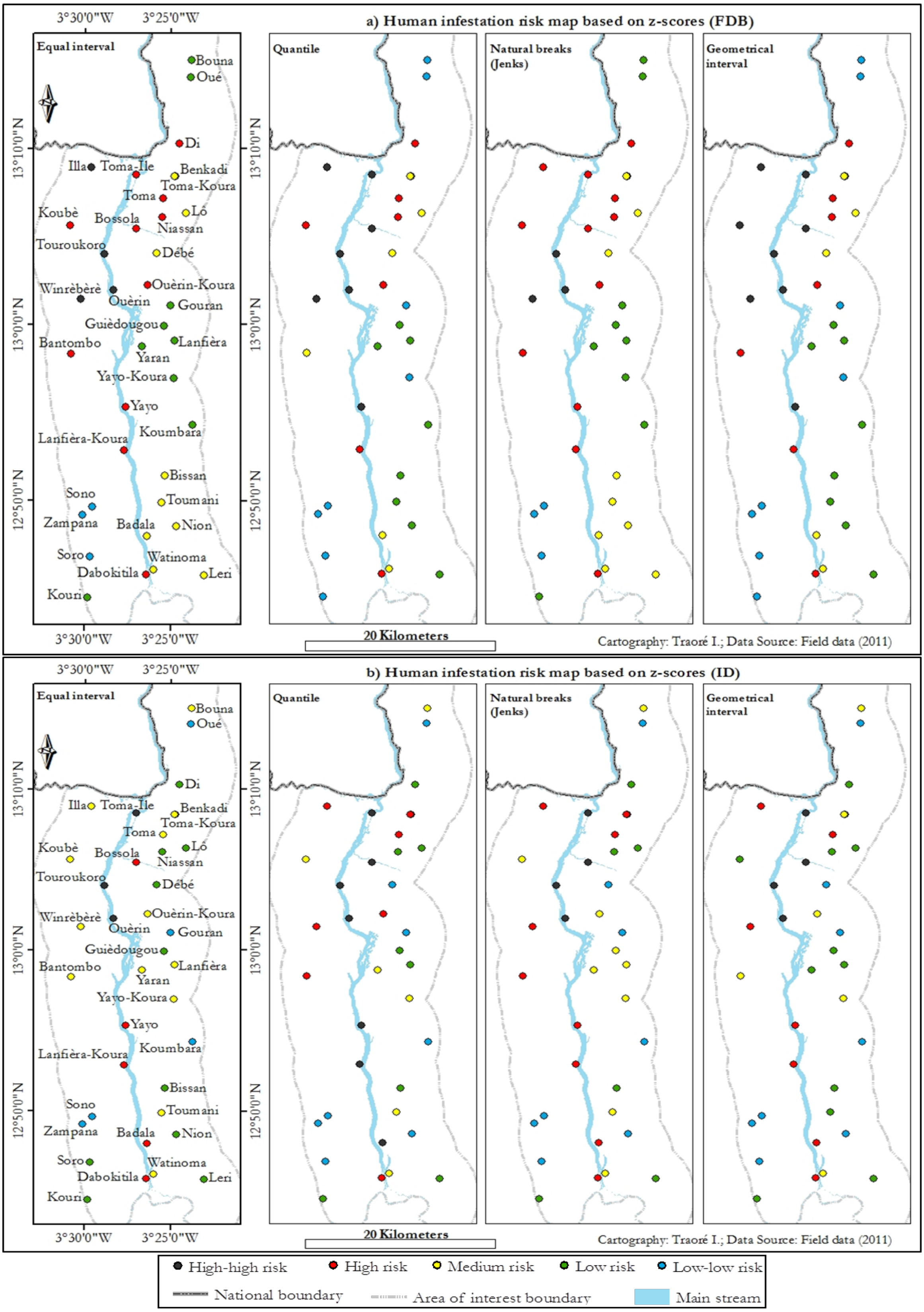


Figure 218: Spatial distribution of human infestation-susceptible settlements based on z-scores and according to the hot spot conceptualization method

7.2.3. Human infestation-susceptible settlements and populations based on standard residuals

The geographic weighted regression (GWR) measured the influence of settlements' urinary schistosomiasis-illness prevalence rates on their absolute scores. Based on the standard residuals derived from the GWR with respect to the human infestation risk status, Table 77 shows proportions of settlements, compounds and populations per GWR kernel type and bandwidth method, per quantitative classification method, and per susceptible risk level.

Except for the quantile, all quantitative classification methods showed the same proportions per risk level for the adaptive kernel type and irrespective to the bandwidth method (Table 77). The explanation of the difference observed in the quantile is given in Figure 219. In fact, the Adaptive_AICc detected Lanfièra-Koura into the medium risk level (Figure 219a) while the Adaptive_CV placed it into the low risk level (Figure 219b). The majority of settlements, compounds and populations 35.14, 56.61 and 59.83%, respectively, fell into the low human infestation susceptible risk level which was shown by the equal interval (Table 77).

The fixed kernel type observed the same proportions per risk level and quantitative classification method, irrespective to the bandwidth method (Table 77). The low risk level concentrated the highest proportions of settlements (50.53%) and compounds (53.40%) which were obtained by the equal interval. While the highest proportion of populations (37.84%) was observed into the medium risk level with the natural breaks (Table 77). Figure 220 shows the spatial distribution of settlements according to the Fixed_AICc (Figure 220a) and Fixed_CV (Figure 220b).

Yayo-Koura and Zampana were the two settlements that fell into the high-high risk level, irrespective to the quantitative classification method, the kernel type and bandwidth method (Figure 219, Figure 220). The greatest number of settlements (n = 7) falling into the high-high human infestation risk level was observed by the quantile, irrespective to the kernel type and bandwidth. These settlements were Touroukoro, Yayo, Winrèbèrè, Yayo-Koura, Watinoma, Yaran and Zampana (Figure 219, Figure 220). They were ranked 2nd, 5th, 9th, 14th, 17th, 18th and 32nd, respectively, according to their absolute score (Figure 215b). There was no clear association between the high-high risk level and the settlement proximity to the main stream in the study area.

Table 77: Human infestation risk status based on standard residuals: Proportions of settlements (%S), compounds (%C) and populations (%P) per quantitative classification method and risk level

Risk status	GWR Kernel type_ Bandwidth method	Risk level	Quantitative classification methods											
			Equal interval			Quantile			Natural breaks (Jenks)			Geometrical interval		
			% S	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*
Human infestation	Adaptive_ Akaike information criterion (Adaptive_AICc)	High-High	5.41	0.49	0.37	18.92	7.56	7.52	16.22	7.00	6.84	13.51	6.72	6.61
		High	16.22	8.07	8.04	18.92	10.07	9.53	27.03	16.33	16.07	13.51	3.14	3.38
		Medium	29.73	30.30	27.01	18.92	24.36	21.16	29.73	43.61	42.15	16.22	13.48	12.91
		Low	35.14	56.61	59.83	21.62	45.15	48.01	18.92	30.01	31.55	29.73	43.61	42.15
		Low-Low	13.51	4.52	4.75	21.62	12.86	13.78	8.11	3.04	3.40	27.03	33.05	34.95
	Adaptive_ Cross validation (Adaptive_CV)	High-High	5.41	0.49	0.37	18.92	7.56	7.52	16.22	7.00	6.84	13.51	6.72	6.61
		High	16.22	8.07	8.04	18.92	10.07	9.53	27.03	16.33	16.07	13.51	3.14	3.38
		Medium	29.73	30.30	27.01	16.22	24.22	20.98	29.73	43.61	42.15	16.22	13.48	12.91
		Low	35.14	56.61	59.83	24.32	45.30	48.19	18.92	30.01	31.55	29.73	43.61	42.15
		Low-Low	13.51	4.52	4.75	21.62	12.86	13.78	8.11	3.04	3.40	27.03	33.05	34.95
	Fixed_ Akaike information criterion (Fixed_AICc)	High-High	5.41	0.49	0.37	18.92	7.56	7.52	5.41	0.49	0.37	16.22	7.00	6.84
		High	21.62	9.37	9.63	18.92	10.07	9.53	21.62	9.37	9.63	10.81	2.86	3.16
		Medium	32.43	34.02	30.12	18.92	24.36	21.16	37.84	38.76	34.86	16.22	13.48	12.91
		Low	24.32	50.53	53.40	21.62	45.15	48.01	24.32	46.96	50.48	29.73	43.61	42.15
		Low-Low	16.22	5.59	6.48	21.62	12.86	13.78	10.81	4.42	4.67	27.03	33.05	34.95
	Fixed_ Cross validation (Fixed_CV)	High-High	5.41	0.49	0.37	18.92	7.56	7.52	5.41	0.49	0.37	16.22	7.00	6.84
		High	21.62	9.37	9.63	18.92	10.07	9.53	21.62	9.37	9.63	10.81	2.86	3.16
		Medium	32.43	34.02	30.12	18.92	24.36	21.16	37.84	38.76	34.86	16.22	13.48	12.91
		Low	24.32	50.53	53.40	21.62	45.15	48.01	24.32	46.96	50.48	29.73	43.61	42.15
		Low-Low	16.22	5.59	6.48	21.62	12.86	13.78	10.81	4.42	4.67	27.03	33.05	34.95

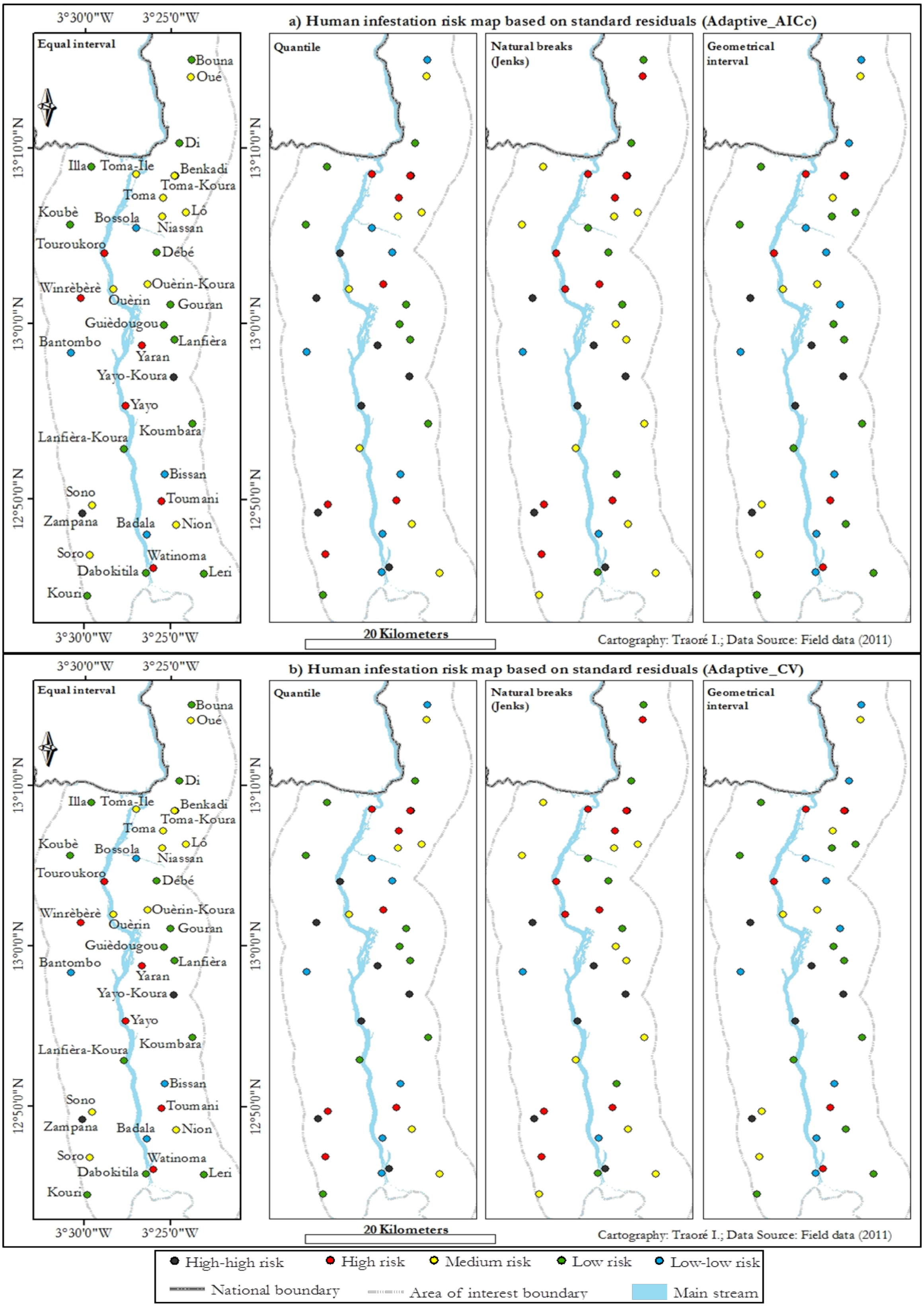


Figure 219: Spatial heterogeneity of human infestation risk status per statistical method based on standard residuals using the adaptive kernel type

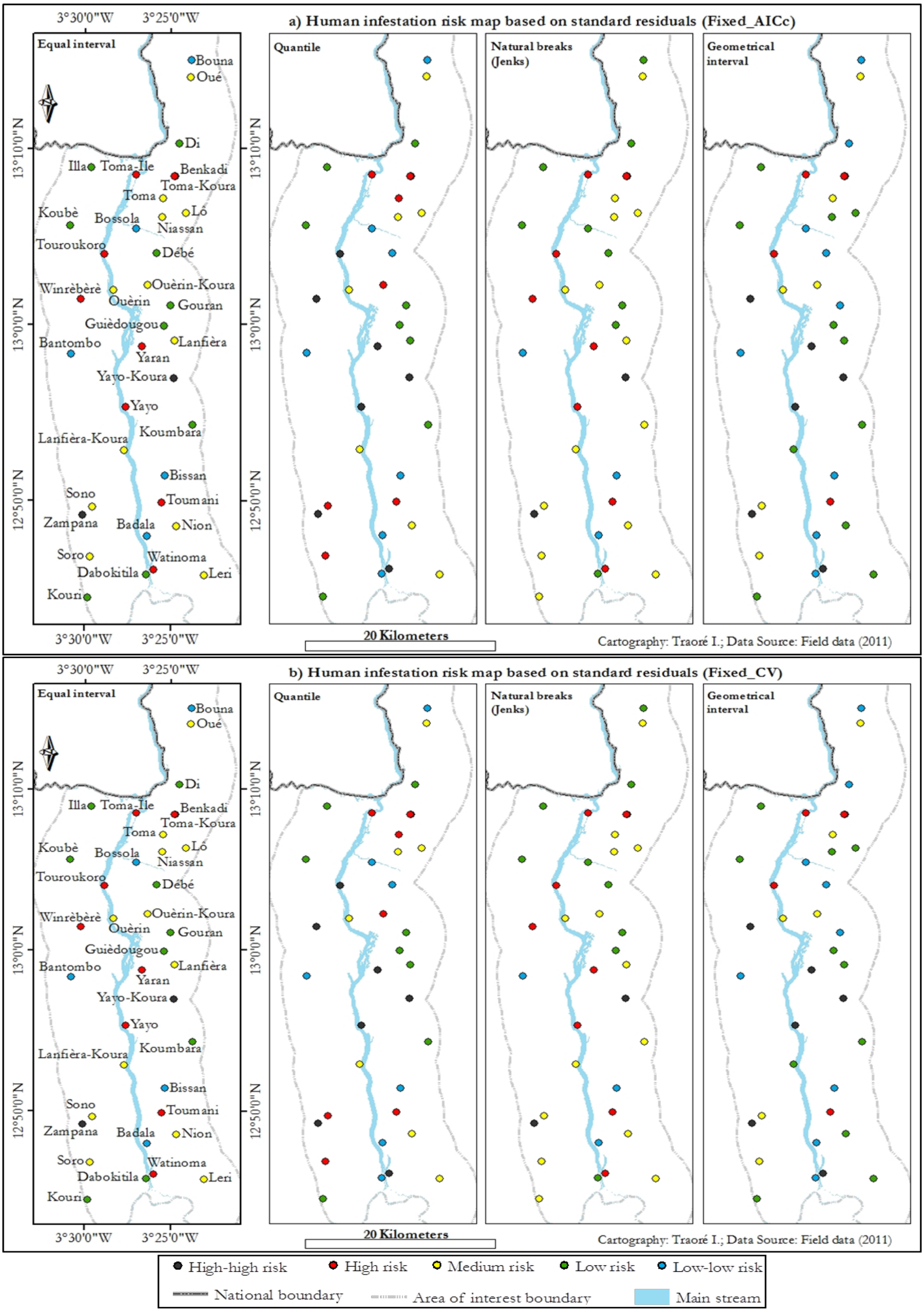


Figure 220: Spatial heterogeneity of human infestation risk status per statistical method based on standard residuals using the fixed kernel type

7.3. Environmental contamination-susceptible settlements and populations by integrating identified geographic parameters

7.3.1. Environmental contamination-susceptible settlements and populations based on absolute scores

Based on settlements' absolute scores with respect to the environmental contamination risk status, Table 78 shows proportions of settlements, compounds and populations per quantitative classification method and susceptible risk levels. There were the same proportions of 18.92, 4.72 and 4.82% of settlements, compounds and populations, respectively, detected into the high-high risk level according to the equal interval, the natural breaks and the geometrical interval (Table 78). However, the highest proportion of settlements (32.43%) fell into the medium environmental contamination risk level according to the equal interval while the majority of compounds and populations (59.08 and 59.46%, respectively) fell into the low-low risk level following the quantile.

Figure 221 depicts settlements environmental contamination-susceptible risk level depending on the quantitative classification method with reference to the main stream in the study area. The spatial distribution showed five settlements (Dabokitila, Lanfièra-Koura, Toma-Île, Touroukoro and Yayo) which fell into the high-high risk level, irrespective to the quantitative classification method. These settlements represented the five highest ranked absolute scores in terms of environment contamination risk status (Figure 215a). Figure 221 also pointed out and association between the high-high risk level and the proximity to the main stream in the study area.

Table 78: Environmental contamination risk status based on absolute scores: Proportions of settlements (%S), compounds (%C) and populations (%P) per quantitative classification method and risk level

		Statistical methods											
		Equal interval			Quantile			Natural breaks (Jenks)			Geometrical interval		
Risk status	Risk level	% S	% C	% P	% S	% C	% P	% S	% C	% P	% S	% C	% P
Environment Contamination	High-High	18.92	4.72	4.82	13.51	3.55	3.66	18.92	4.72	4.82	18.92	4.72	4.82
	High	16.22	4.79	4.13	21.62	5.96	5.29	10.81	1.44	1.23	24.32	6.76	6.29
	Medium	32.43	19.12	19.25	18.92	11.28	11.18	24.32	14.63	14.08	24.32	17.15	17.09
	Low	18.92	20.25	21.16	21.62	20.13	20.41	27.03	21.22	21.54	18.92	20.25	21.16
	Low-Low	13.51	51.11	50.64	24.32	59.08	59.46	18.92	57.99	58.33	13.51	51.11	50.64

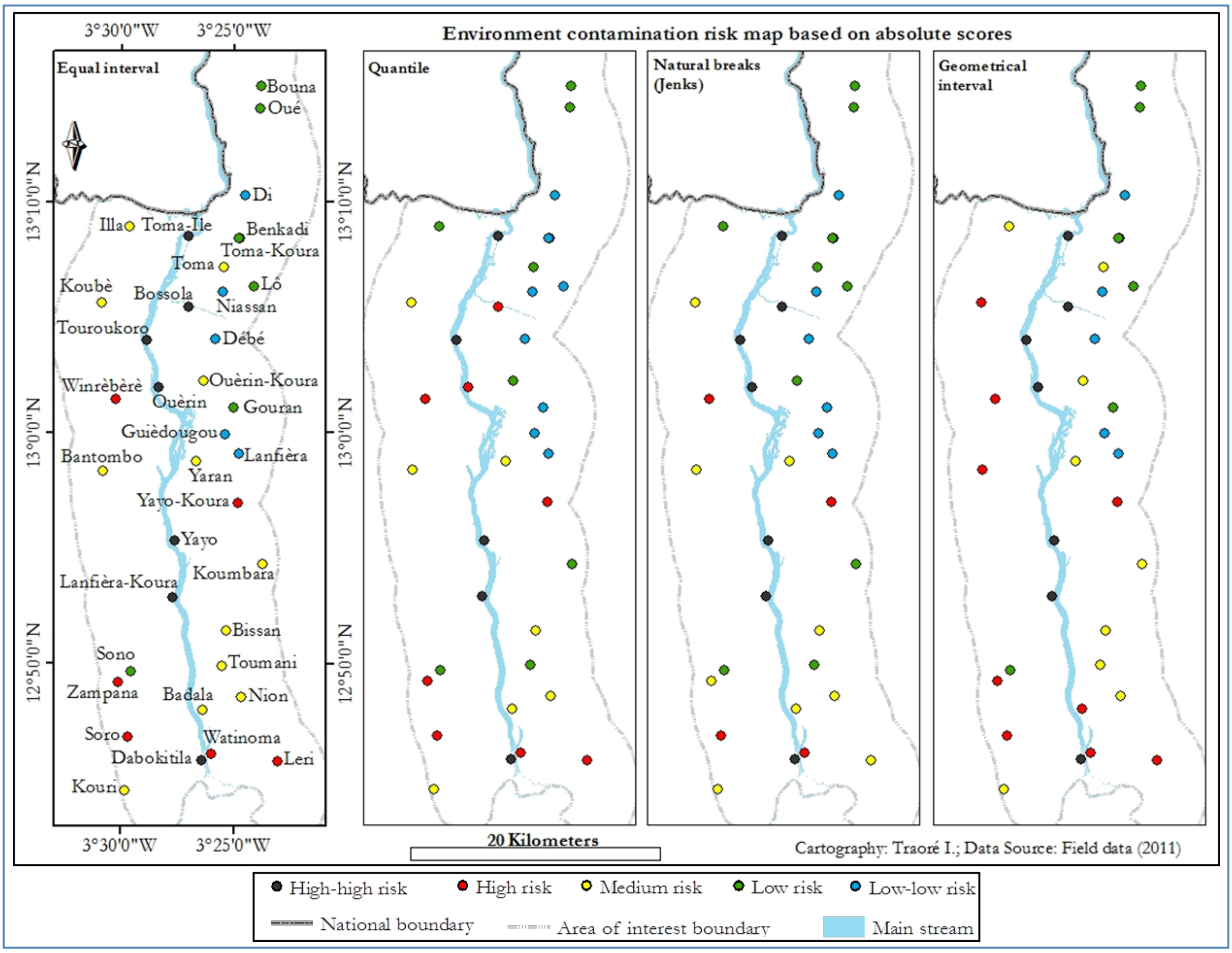


Figure 221: Spatial heterogeneity of environmental contamination risk status per statistical method based on absolute scores

7.3.2. Environmental contamination-susceptible settlements and populations based on z-scores

Based on settlements' z-scores with respect to the environmental contamination risk status, Table 79 shows proportions of settlements, compounds and populations per quantitative classification method and susceptible risk level. First of all, proportions of settlements, compounds and populations depended on the hot spot conceptualization method.

According to the fixed distance band (FDB) (Table 79), the majority of settlements (32.43%) fell into the high risk level and observed by the equal interval. While highest proportions of compounds and populations (42.24 and 40.80%, respectively) were classified into the low risk level by both the natural breaks and the geometrical interval methods (Table 79). Except for the quantile proportions of settlements, compounds and population were the same for the high-high risk level. In fact, Figure 222a indicates that only the quantile classified Watinoma into the high risk level.

According to the inverse distance (ID) (Table 79), the majority (32.43%) of settlements fell into the medium risk level and also obtained by the equal interval. While highest proportions of compounds and populations (58.46 and 59.02%, respectively) fell into the low-low risk level and observed by the quantile. Proportions of settlements classified into the high-high risk level remained the same irrespective to the quantitative classification method (Table 79).

Results in Figure 222b suggest that whatever the conceptualization method and the quantitative classification method seven settlements were categorized into the high-high risk level in terms of environment contamination risk status. These settlements are Touroukoro, Dabokitila, Toma-Île, Yayo, Lanfièra-Koura, Bossola and Ouèrin which represented the first seven highest ranked absolute scores, cited descending, according to Figure 215a.

Table 79: Proportions of settlements (%S), compounds (%C) and populations (%P) per statistical method and risk level for the environment contamination risk status based on z-scores

Risk status	Hot spot Conceptualization method	Risk level	Quantitative classification methods											
			Equal interval			Quantile			Natural breaks (Jenks)			Geometrical interval		
			% S	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*
Environment Contamination	Fixed distance band (FDB)	High-High	21.62	5.12	5.21	18.92	4.83	4.98	21.62	5.12	5.21	21.62	5.12	5.21
		High	32.43	23.56	22.14	18.92	11.46	10.41	10.81	7.83	7.35	18.92	13.13	12.21
		Medium	5.41	1.21	1.13	18.92	13.39	12.84	24.32	16.74	15.68	16.22	11.44	10.82
		Low	21.62	42.03	40.56	21.62	42.11	40.73	24.32	42.24	40.80	24.32	42.24	40.80
		Low-Low	18.92	28.08	30.96	21.62	28.20	31.04	18.92	28.08	30.96	18.92	28.08	30.96
	Inverse distance (ID)	High-High	18.92	4.72	4.82	18.92	4.72	4.82	18.92	4.72	4.82	18.92	4.72	4.82
		High	16.22	4.79	4.13	18.92	4.97	4.39	10.81	1.44	1.23	24.32	6.76	6.29
		Medium	32.43	19.12	19.25	18.92	14.59	14.27	24.32	14.63	14.08	24.32	17.15	17.09
		Low	18.92	20.25	21.16	21.62	17.26	17.49	27.03	21.22	21.54	18.92	20.25	21.16
		Low-Low	13.51	51.11	50.64	21.62	58.46	59.02	18.92	57.99	58.33	13.51	51.11	50.64

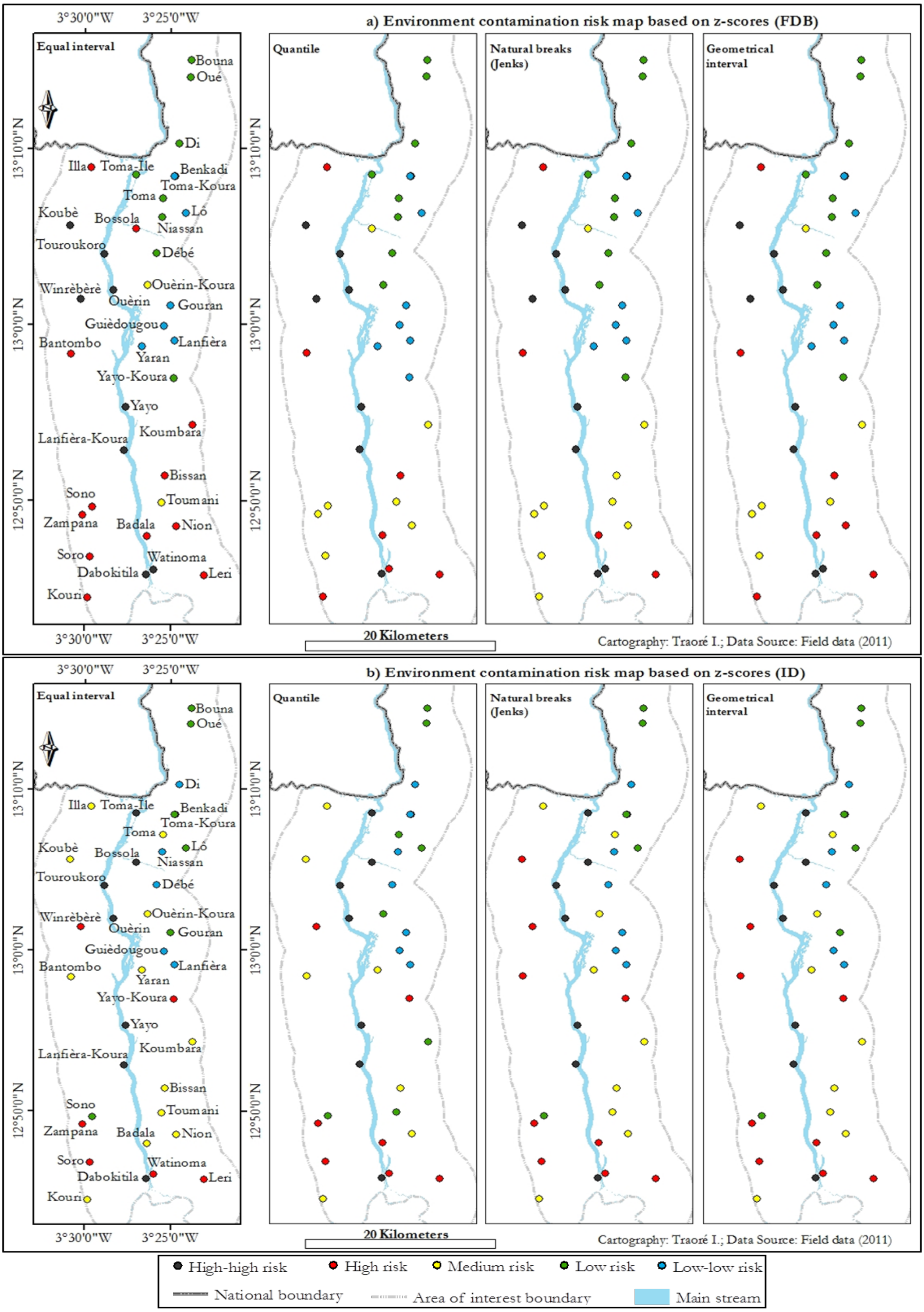


Figure 222: Spatial heterogeneity of environment contamination risk status per statistical method based on z-scores per conceptualization method

7.3.3. Environmental contamination-susceptible settlements and population based on standard residuals

A comparison between risk levels in Table 80 indicates that proportions were the same for the quantile method irrespective to the kerlnel type and bandwidth method. The three other quantitative classification methods were likely to provide different proportions for the same risk level according to the bandwidth method. However, Table 80 shows for the natural break statistical method that three three bandwidths (Adaptive_AICc, Adaptive_CV and Fixed_CV) observed the same proportions (5.41, 0.49 and 0.37% of settlements, compounds and populations, respectively) for the high-high risk level. For the adaptive kernel type, Figure 223 shows the spatial distribution of the risk level per settlement and staisitcal method according to the Akaike information criterion (Adaptive_AICc) (Figure 223a) and the cross validation (Adaptive_CV) (Figure 223b) bandwidth methods. Similarly, Figure 224 shows it for the fixed kernel type, respectively. As Table 80 shows, the lowest proportion of environment contamination high-high risk level was observed for Adaptive_AICc and obtained from the equal interval method. Only Zampana is indicated in Figure 223a. The highest proportion is observed by the geometrical interval statistical method for the Fixed_AICc (Table 80). In Figure 224a, settlements of concern are Touroukoro, Yayo, Watinoma, Winrèbèrè, Yayo-Koura, Zampana, and Yaran. These settlements were ranked 1st, 4th, 8th, 10th, 11th, 12th and 20th, respectively in Figure 215a.

Table 80: Proportions of settlements (%S), compounds (%C) and populations (%P) per statistical method and risk level for the environment contamination risk status based on standard residuals

Risk status	GWR Kernel type_ Bandwidth method	Risk level	Quantitative classification methods											
			Equal interval			Quantile			Natural breaks (Jenks)			Geometrical interval		
			% S	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*
Environment contamination	Adaptive_ Akaike information criterion (Adaptive_AICc)	High-High	2.70	0.37	0.29	18.92	7.56	7.52	5.41	0.49	0.37	5.41	0.49	0.37
		High	21.62	8.67	8.81	18.92	10.07	9.53	29.73	16.93	16.44	29.73	16.93	16.44
		Medium	40.54	39.59	35.75	18.92	24.36	21.16	32.43	31.82	28.82	18.92	24.42	21.22
		Low	27.03	48.34	51.75	21.62	45.15	48.01	21.62	46.34	49.71	18.92	25.10	27.02
		Low-Low	8.11	3.04	3.40	21.62	12.86	13.78	10.81	4.42	4.67	27.03	33.05	34.95
	Adaptive_ Cross validation (Adaptive_CV)	High-High	5.41	0.49	0.37	18.92	7.56	7.52	5.41	0.49	0.37	18.92	7.56	7.52
		High	18.92	8.55	8.73	18.92	10.07	9.53	18.92	8.55	8.73	18.92	10.07	9.53
		Medium	40.54	39.59	35.75	18.92	24.36	21.16	35.14	34.84	31.01	16.22	24.22	20.98
		Low	29.73	50.02	53.76	21.62	45.15	48.01	29.73	51.71	55.22	21.62	30.30	32.70
		Low-Low	5.41	1.36	1.39	21.62	12.86	13.78	10.81	4.42	4.67	24.32	27.86	29.27
	Fixed_ Akaike information criterion (Fixed_AICc)	High-High	5.41	0.49	0.37	18.92	7.56	7.52	18.92	7.56	7.52	21.62	8.57	8.41
		High	24.32	9.74	10.05	18.92	10.07	9.53	21.62	11.13	10.61	18.92	10.13	9.72
		Medium	37.84	39.01	35.21	18.92	24.36	21.16	29.73	34.04	30.85	13.51	23.15	19.90
		Low	27.03	49.40	52.98	21.62	45.15	48.01	24.32	45.91	49.63	24.32	45.30	48.19
		Low-Low	5.41	1.36	1.39	21.62	12.86	13.78	5.41	1.36	1.39	21.62	12.86	13.78
	Fixed_ Cross validation (Fixed_CV)	High-High	10.81	6.31	6.25	18.92	7.56	7.52	5.41	0.49	0.37	13.51	6.72	6.61
		High	13.51	2.73	2.86	18.92	10.07	9.53	27.03	10.35	10.61	24.32	10.91	10.43
		Medium	29.73	32.81	28.93	18.92	24.36	21.16	35.14	38.39	34.65	16.22	24.22	20.98
		Low	37.84	55.12	58.57	21.62	45.15	48.01	21.62	46.34	49.71	24.32	45.30	48.19
		Low-Low	8.11	3.04	3.40	21.62	12.86	13.78	10.81	4.42	4.67	21.62	12.86	13.78

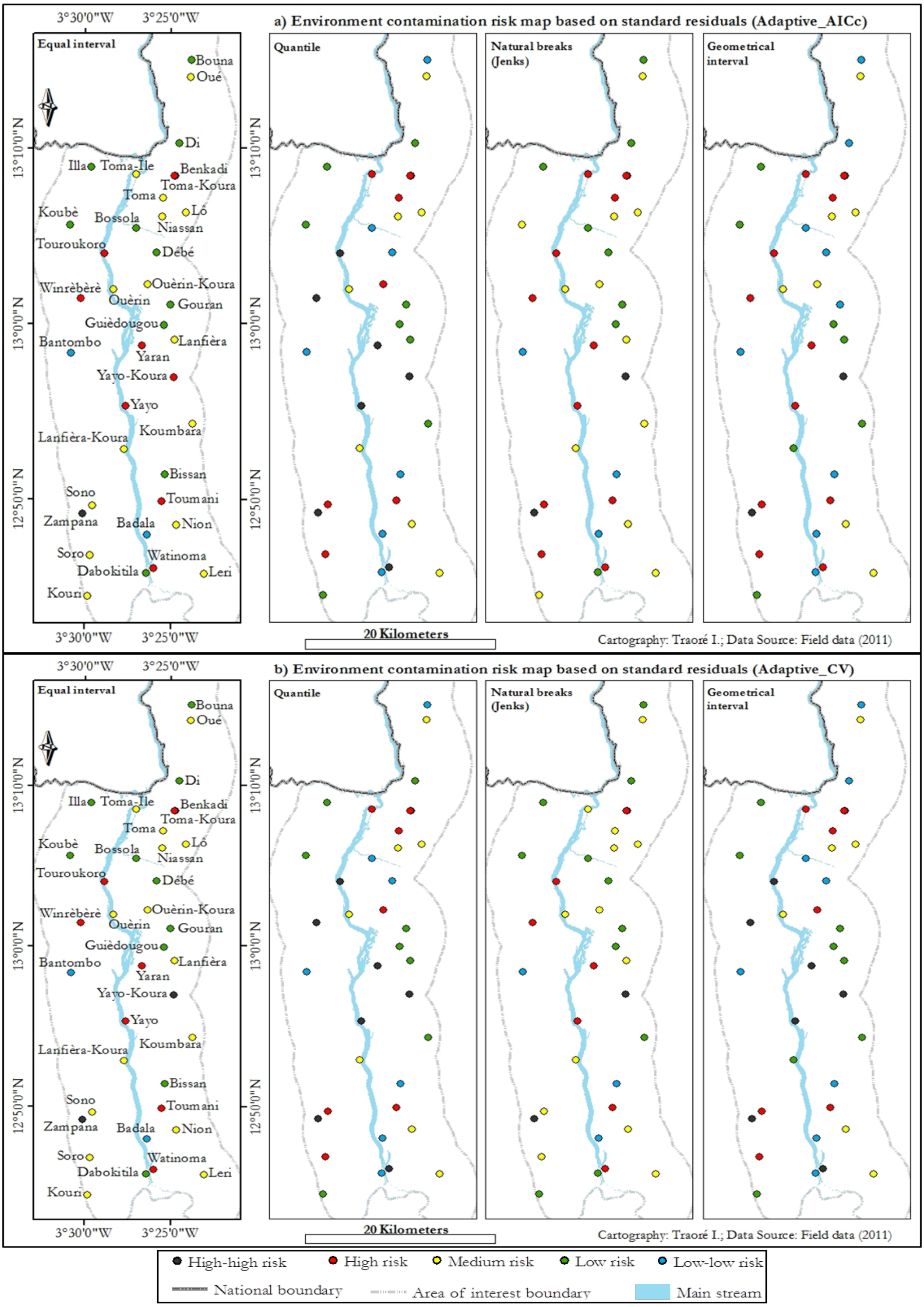


Figure 223: Spatial heterogeneity of environment contamination risk status per statistical method based on standard residuals using the adaptive kernel type

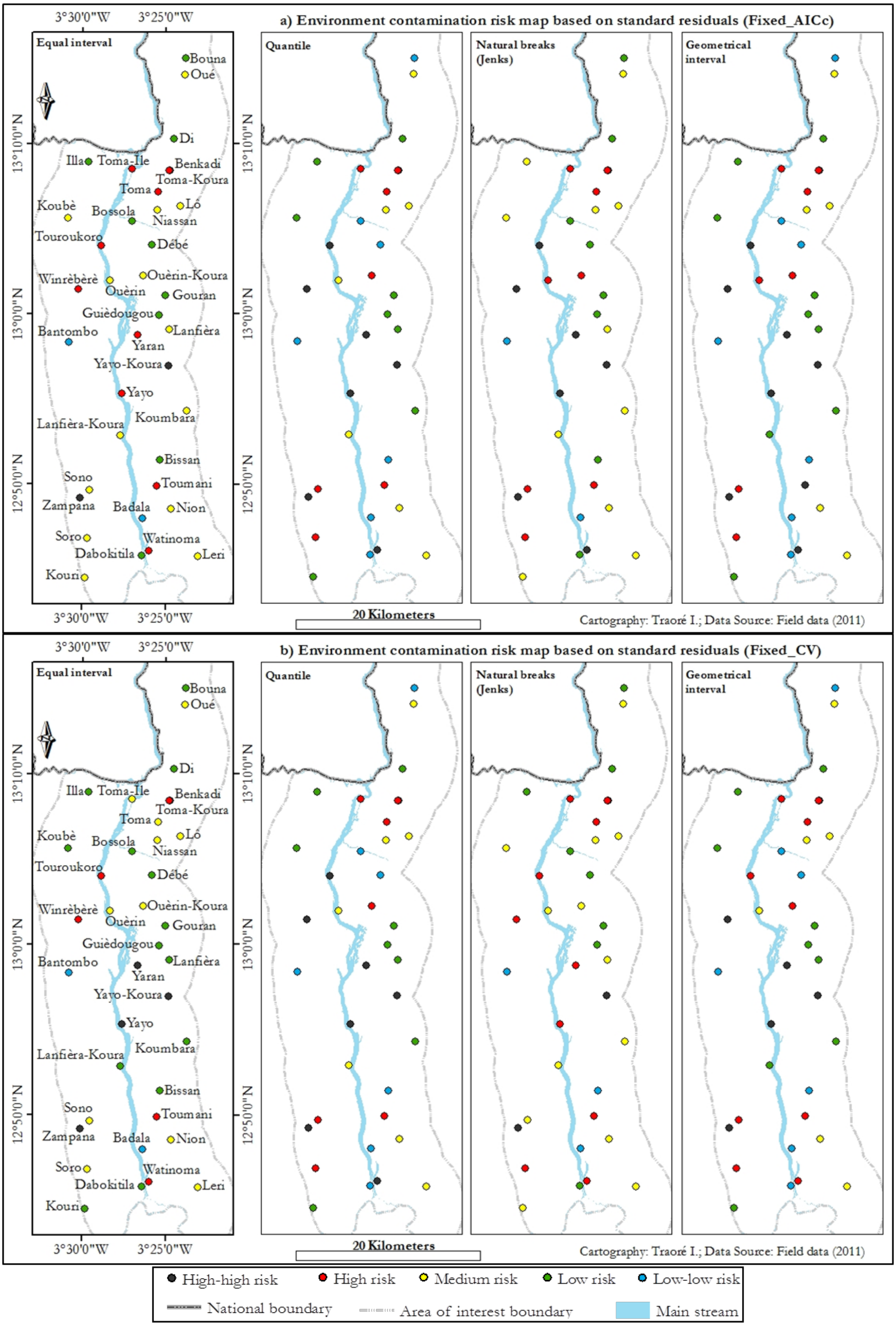


Figure 224: Spatial heterogeneity of environment contamination risk status per statistical method based on standard residuals using the fixed kernel type

7.4. Schistosomiasis transmission-susceptible settlements and populations by integrating identified geographic parameters

7.4.1. Schistosomiasis transmission-susceptible settlements and populations based on absolute scores

Similar to the environment contamination risk status, three statistical methods (quantile, natural breaks and geometrical interval) show identical proportions for the high-high risk level with 18.92% of settlements, 4.72% of compounds and 4.82% of populations as shown in Table 81. However, only the low-low risk level showed equal proportions (16.22%, 60.99% and 60.24%, respectively) with the natural break and geometrical interval methods. Similar to the quantile method in human infestation risk status, the equal interval method showed different proportions compared to others in terms of schistosomiasis transmission risk status. The difference between the equal interval method and others is shown in Figure 225 which indicates that four settlements (Bossola, Dabokitila, Lanfièra-Koura and Yayo) have changed risk level from high to high-high, respectively.

Whatever the statistical method, three settlements (Ouèrin, Toma-Île and Touroukoro) fell always into the high-high schistosomiasis transmission risk level. These settlements account for the first three highest absolute scores in terms of schistosomiasis transmission risk status (Figure 215c). This means that there was a similarity between Figure 215c and Figure 225.

Table 81: Proportions of settlements (%S), compounds (%C) and populations (%P) per statistical method and risk level for the schistosomiasis transmission risk status based on absolute scores

		Quantitative classification methods											
		Equal interval			Quantile			Natural breaks (Jenks)			Geometrical interval		
Risk status	Risk level	% S	% C	% P	% S	% C	% P	% S	% C	% P	% S	% C	% P
Schistosomiasis Transmission	High-High	8.11	2.44	2.65	18.92	4.72	4.82	18.92	4.72	4.82	18.92	4.72	4.82
	High	10.81	2.28	2.17	18.92	6.04	5.84	13.51	2.18	2.06	24.32	9.63	9.21
	Medium	13.51	2.18	2.06	18.92	10.81	10.50	35.14	18.55	18.56	27.03	13.04	13.43
	Low	35.14	18.55	18.56	21.62	10.91	11.92	16.22	13.56	14.31	13.51	11.61	12.30
	Low-Low	32.43	74.55	74.56	21.62	67.52	66.93	16.22	60.99	60.24	16.22	60.99	60.24

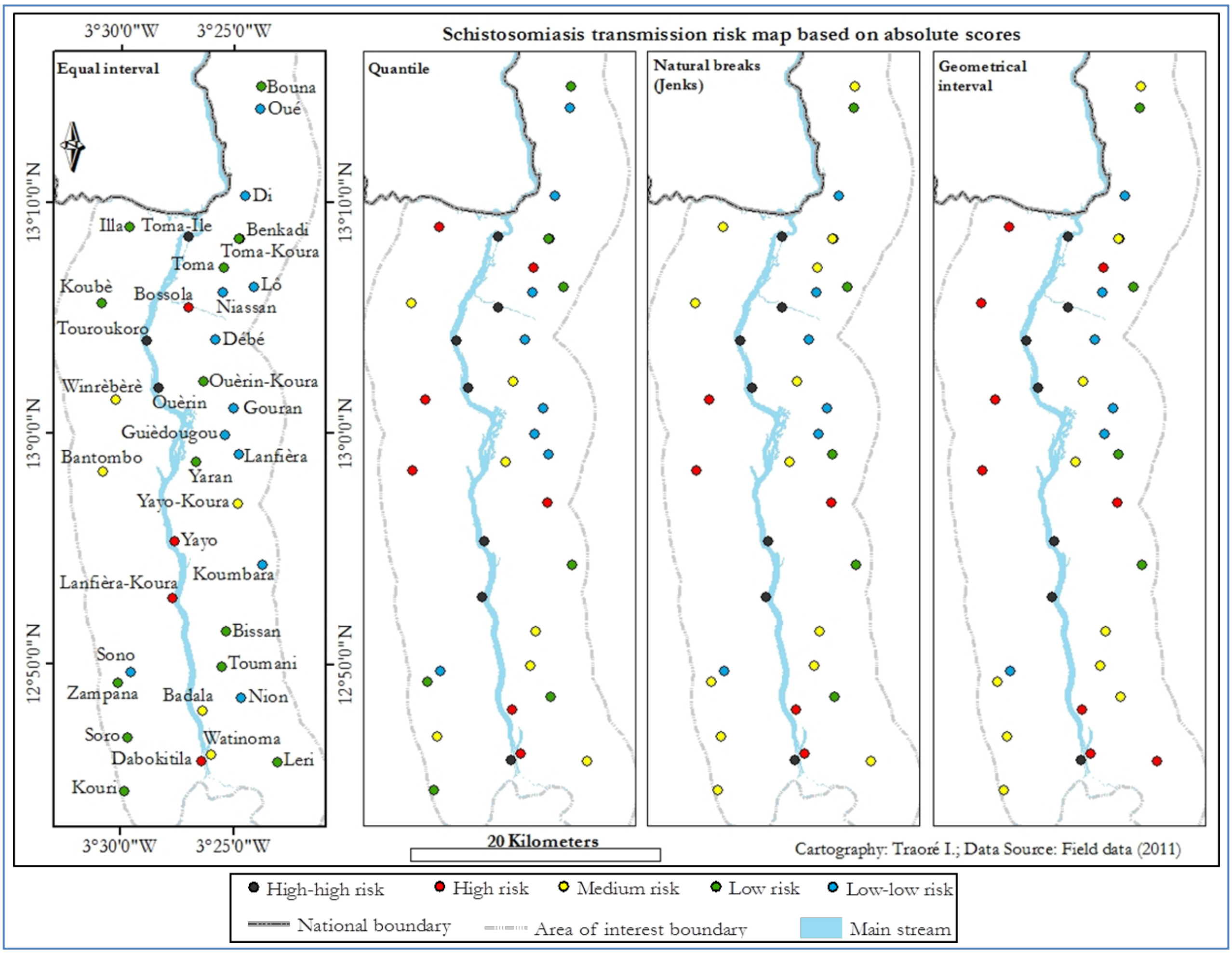


Figure 225: Spatial heterogeneity of schistosomiasis transmission risk status per statistical method based on absolute scores

7.4.2. Schistosomiasis transmission-susceptible settlements and population based on z-scores

The quantile and the geometrical interval statistical methods observed the same proportions (18.92% of settlements, 8.09% of compounds and 8.15% of populations) concerning the high-high risk level of the schistosomiasis transmission risk status using the fixed distance band (FDB) as indicated in Table 82. The difference between the equal interval and natural breaks statistical methods is shown in Figure 226a which indicates that Koubè passed from high to high-high, respectively. Table 82 also shows the same proportions (18.92%, 4.72% and 4.82%, respectively) for the high-high irsk level obtained from the quantile, natural breaks and geometrical interval based on the inverse distance conceptual method. Figure 226b shows that the equal interval statistical method detected only three settlement inot the high-high risk level, while the others detected seven, each.

Once again, the inverse distance (ID) shows a perfect overlapping between Table 81 and Table 82 with the same proportions per risk level and according to the statistical method. Whatever the statistical method, the first three settlements in Figure 215c (Touroukoro, Toma-Île and Ouèrin) were always attributed the high-high risk level in term of schistosomiasis transmission risk status (Figure 226b). Therefore, the assessment of schistosomiasis transmission risk status using absolute scores was similar to results showed using the z-scores.

Table 82: Proportions of settlements (%S), compounds (%C) and populations (%P) per statistical method and risk level for the schistosomiasis transmission risk status based on z-scores

Risk status	Conceptualization method	Risk level	Statistical methods											
			Equal interval			Quantile			Natural breaks (Jenks)			Geometrical interval		
			% S	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*	*% S*	*% C*	*% P*
Schistosomiasis transmission	Fixed distance band (FDB)	High-High	10.81	3.84	3.84	18.92	8.09	8.15	13.51	4.46	4.62	18.92	8.09	8.15
		High	13.51	4.58	4.58	18.92	5.16	4.74	18.92	5.61	5.42	18.92	5.16	4.74
		Medium	21.62	8.98	8.64	18.92	39.52	37.26	32.43	48.46	45.73	27.03	45.28	42.88
		Low	29.73	48.99	47.92	18.92	13.62	14.84	24.32	16.17	16.41	21.62	16.04	16.33
		Low-Low	24.32	33.61	35.02	24.32	33.61	35.02	10.81	25.31	27.82	13.51	25.43	27.90
	Inverse distance (ID)	High-High	8.11	2.44	2.65	18.92	4.72	4.82	18.92	4.72	4.82	18.92	4.72	4.82
		High	10.81	2.28	2.17	18.92	6.04	5.84	13.51	2.18	2.06	24.32	9.63	9.21
		Medium	13.51	2.18	2.06	18.92	10.81	10.50	35.14	18.55	18.56	27.03	13.04	13.43
		Low	35.14	18.55	18.56	21.62	10.91	11.92	16.22	13.56	14.31	13.51	11.61	12.30
		Low-Low	32.43	74.55	74.56	21.62	67.52	66.93	16.22	60.99	60.24	16.22	60.99	60.24

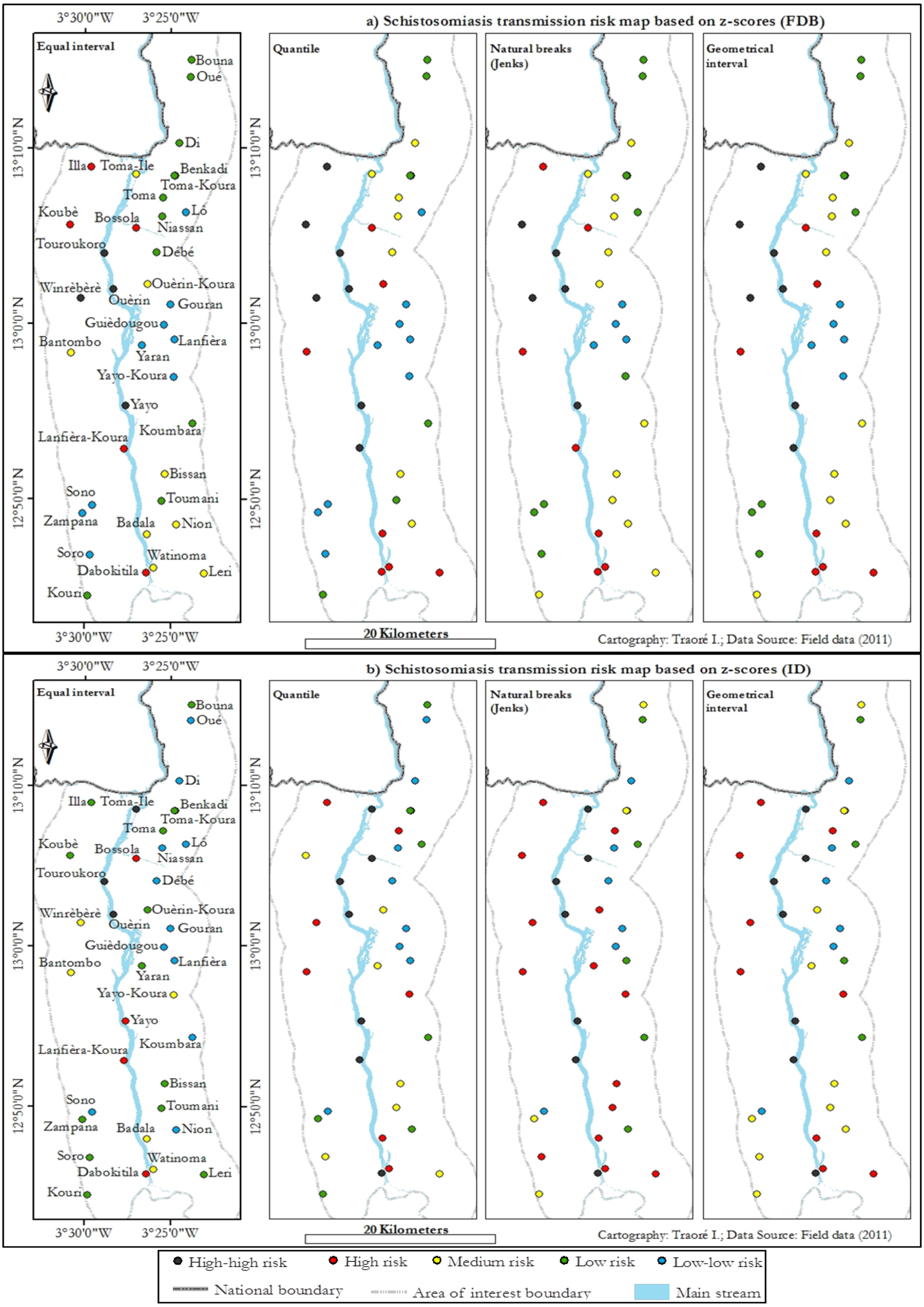


Figure 226: Spatial heterogeneity of schistosomiasis transmission risk status per statistical method based on z-scores per conceptualization method

7.4.3. Schistosomiasis transmission-susceptible settlements and populations based on standard residuals

Comparing results on the schistosomiasis transmission (ST1) in Table 83 to those for the schistosomiasis transmission (ST2) in Table 84, data show that only the quantile statistical method provided the same proportions per risk level, whatever the kernel type and the bandwidth method. The spatial distribution of settlements, according to the adaptive and fixed kernel types, is shown in Figure 227 and Figure 228 for the first risk status and, in Figure 229 and Figure 230 for the second one, respectively.

However, the schistosomiasis transmission (ST1) risk status indicates for the high-high risk level the same proportions (10.81% of settlements, 6.31% of compounds, 6.25% of populations) between the natural breaks and geometrical interval statistical methods (Table 83). Conversely, proportions from the geometrical interval overtook those from the natural breaks in terms of the schistosomiasis transmission (ST2) risk status (Table 84). The equal interval statistical method shows for the high-high risk level that proportions from the adaptive type were always smaller than those from the fixed one in Table 83 while, there was not difference in Table 84. These results suggest that only the quantile statistical method offered a similarity between the two schistosomiasis transmission risk statuses. It also means that the change of the explanatory variable did not always impact on the result in terms of schistosomiasis transmission risk status.

Whatever the risk status, Zampana was always classified in the high-high risk level as Figure 227 and Figure 228 show for the schistosomiasis transmission (ST1), and Figure 229 and Figure 230 show for the schistosomiasis transmission (ST2). The maximum number of settlements detected to be in the high-high risk level was seven: Touroukoro, Yayo, Winrèbèrè, Watinoma, Yayo-Koura, Yaran and Zampana. In terms of individual absolute scores, these settlements were ranked 1^{st}, 5^{th}, 8^{th}, 10^{th}, 11^{th}, 17^{th} and 25^{th}, respectively, in Figure 215c.

Table 83: Proportions of settlements (%S), compounds (%C) and populations (%P) per statistical method and risk level for the schistosomiasis transmission (ST1) risk status based on standard residuals

Risk status	Kernel type_ Bandwidth method	Risk level	Statistical methods: Equal interval			Quantile			Natural breaks (Jenks)			Geometrical interval		
			%S	*%C*	*%P*	*%S*	*%C*	*%P*	*%S*	*%C*	*%P*	*%S*	*%C*	*%P*
Schistosomiasis transmission (ST1)	Adaptive_ Akaike information criterion (Adaptive_AICc)	High-High	5.41	0.49	0.37	18.92	7.56	7.52	10.81	6.31	6.25	10.81	6.31	6.25
		High	18.92	8.55	8.73	18.92	10.07	9.53	18.92	3.92	4.17	18.92	3.92	4.17
		Medium	24.32	29.21	25.88	18.92	24.36	21.16	27.03	31.76	27.79	24.32	31.61	27.61
		Low	21.62	14.48	13.99	21.62	45.15	48.01	18.92	30.16	32.53	21.62	30.30	32.70
		Low-Low	29.73	47.27	51.02	21.62	12.86	13.78	24.32	27.86	29.27	24.32	27.86	29.27
	Adaptive_ Cross validation (Adaptive_CV)	High-High	5.41	0.49	0.37	18.92	7.56	7.52	10.81	6.31	6.25	10.81	6.31	6.25
		High	18.92	8.55	8.73	18.92	10.07	9.53	18.92	3.92	4.17	18.92	3.92	4.17
		Medium	21.62	16.25	15.82	18.92	24.36	21.16	27.03	31.76	27.79	16.22	24.22	20.98
		Low	24.32	27.44	24.06	21.62	45.15	48.01	18.92	30.16	32.53	21.62	30.30	32.70
		Low-Low	29.73	47.27	51.02	21.62	12.86	13.78	24.32	27.86	29.27	24.32	27.86	29.27
	Fixed_ Akaike information criterion (Fixed_AICc)	High-High	8.11	2.30	2.08	18.92	7.56	7.52	10.81	6.31	6.25	10.81	6.31	6.25
		High	18.92	7.56	7.91	18.92	10.07	9.53	18.92	3.92	4.17	18.92	3.92	4.17
		Medium	18.92	15.43	14.93	18.92	24.36	21.16	24.32	31.61	27.61	24.32	31.61	27.61
		Low	27.03	41.66	40.13	21.62	45.15	48.01	18.92	25.10	27.02	21.62	30.30	32.70
		Low-Low	27.03	33.05	34.95	21.62	12.86	13.78	27.03	33.05	34.95	24.32	27.86	29.27
	Fixed_ Cross validation (Fixed_CV)	High-High	8.11	2.30	2.08	18.92	7.56	7.52	10.81	6.31	6.25	10.81	6.31	6.25
		High	18.92	7.56	7.91	18.92	10.07	9.53	18.92	3.92	4.17	27.03	11.32	10.80
		Medium	16.22	13.48	12.91	18.92	24.36	21.16	32.43	35.62	31.27	16.22	24.22	20.98
		Low	27.03	29.40	26.08	21.62	45.15	48.01	16.22	41.29	44.53	21.62	30.30	32.70
		Low-Low	29.73	47.27	51.02	21.62	12.86	13.78	21.62	12.86	13.78	24.32	27.86	29.27

Table 84: Proportions of settlements (%S), compounds (%C) and populations (%P) per statistical method and risk level for the schistosomiasis transmission (ST2) risk status based on standard residuals

Risk status	Kernel type_ Bandwidth method	Risk level	Statistical methods: Equal interval			Quantile			Natural breaks (Jenks)			Geometrical interval		
			%S	*%C*	*%P*	*%S*	*%C*	*%P*	*%S*	*%C*	*%P*	*%S*	*%C*	*%P*
Schistosomiasis transmission (ST2)	Adaptive_ Akaike information criterion (Adaptive_AICc)	High-High	2.70	0.37	0.29	18.92	7.56	7.52	2.70	0.37	0.29	18.92	7.56	7.52
		High	10.81	6.35	6.32	18.92	10.07	9.53	24.32	9.49	9.70	18.92	10.07	9.53
		Medium	13.51	3.14	3.38	18.92	24.36	21.16	35.14	35.99	31.69	29.73	31.61	28.58
		Low	43.24	42.87	38.99	21.62	45.15	48.01	21.62	48.56	51.83	13.51	44.95	47.70
		Low-Low	29.73	47.27	51.02	21.62	12.86	13.78	16.22	5.59	6.48	18.92	5.81	6.67
	Adaptive_ Cross validation (Adaptive_CV)	High-High	2.70	0.37	0.29	18.92	7.56	7.52	2.70	0.37	0.29	18.92	7.56	7.52
		High	10.81	6.35	6.32	18.92	10.07	9.53	24.32	9.49	9.70	16.22	9.86	9.29
		Medium	13.51	3.14	3.38	18.92	24.36	21.16	35.14	35.99	31.69	35.14	35.31	32.17
		Low	40.54	39.38	35.63	21.62	45.15	48.01	18.92	48.34	51.64	10.81	41.45	44.35
		Low-Low	32.43	50.76	54.38	21.62	12.86	13.78	18.92	5.81	6.67	18.92	5.81	6.67
	Fixed_ Akaike information criterion (Fixed_AICc)	High-High	2.70	0.37	0.29	18.92	7.56	7.52	13.51	6.72	6.61	18.92	7.56	7.52
		High	13.51	6.64	6.55	18.92	10.07	9.53	13.51	3.14	3.38	16.22	9.86	9.29
		Medium	10.81	2.86	3.16	18.92	24.36	21.16	37.84	38.76	34.86	32.43	31.82	28.82
		Low	40.54	39.38	35.63	21.62	45.15	48.01	18.92	45.79	48.66	16.22	45.17	47.89
		Low-Low	32.43	50.76	54.38	21.62	12.86	13.78	16.22	5.59	6.48	16.22	5.59	6.48
	Fixed_ Cross validation (Fixed_CV)	High-High	2.70	0.37	0.29	18.92	7.56	7.52	13.51	6.72	6.61	18.92	7.56	7.52
		High	13.51	6.64	6.55	18.92	10.07	9.53	13.51	3.14	3.38	21.62	11.13	10.61
		Medium	10.81	2.86	3.16	18.92	24.36	21.16	35.14	35.99	31.69	27.03	30.55	27.50
		Low	40.54	39.38	35.63	21.62	45.15	48.01	18.92	48.34	51.64	13.51	44.95	47.70
		Low-Low	32.43	50.76	54.38	21.62	12.86	13.78	18.92	5.81	6.67	18.92	5.81	6.67

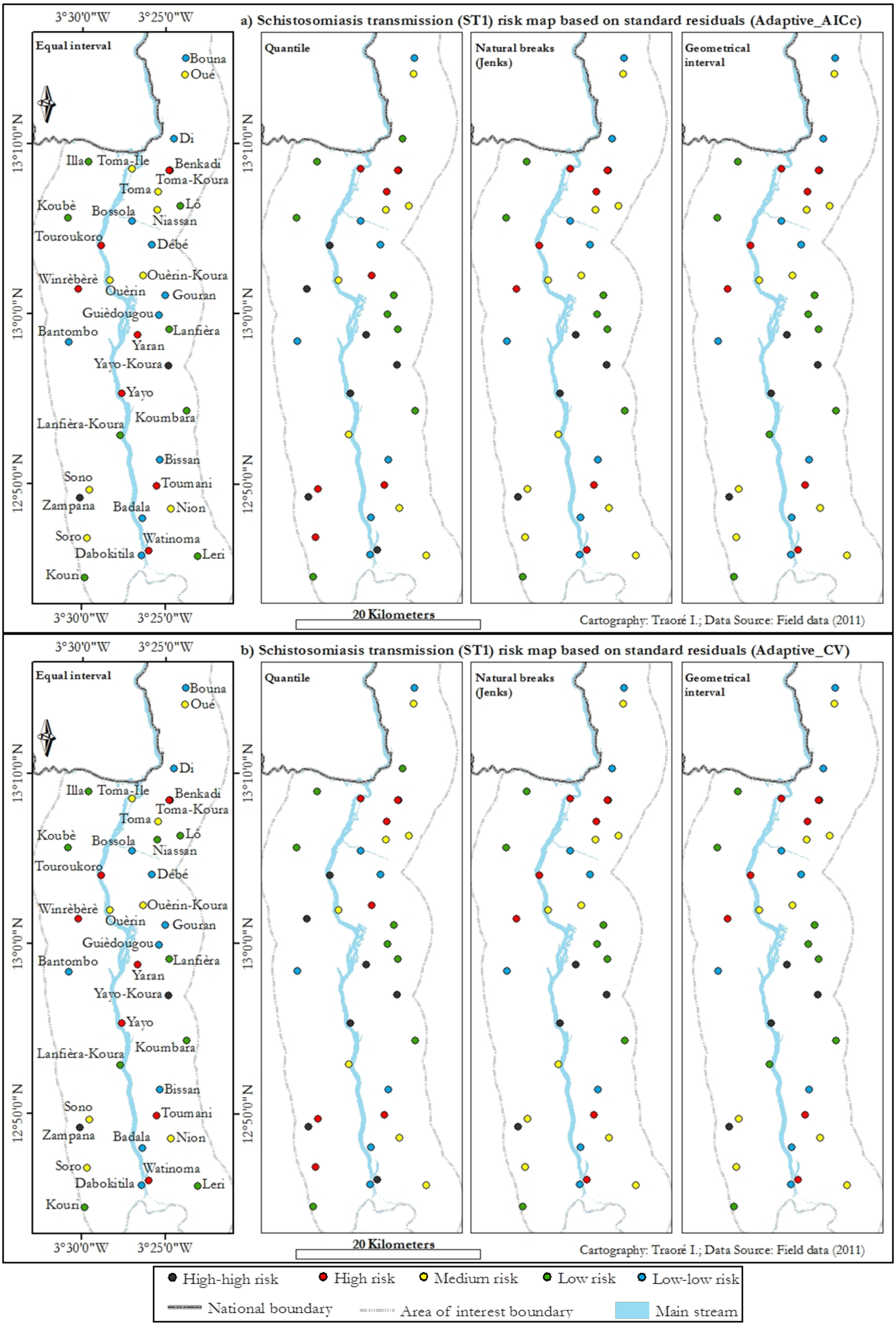


Figure 227: Spatial heterogeneity of schistosomiasis transmission (ST1) risk status per statistical method based on standard residuals using the adaptive kernel type

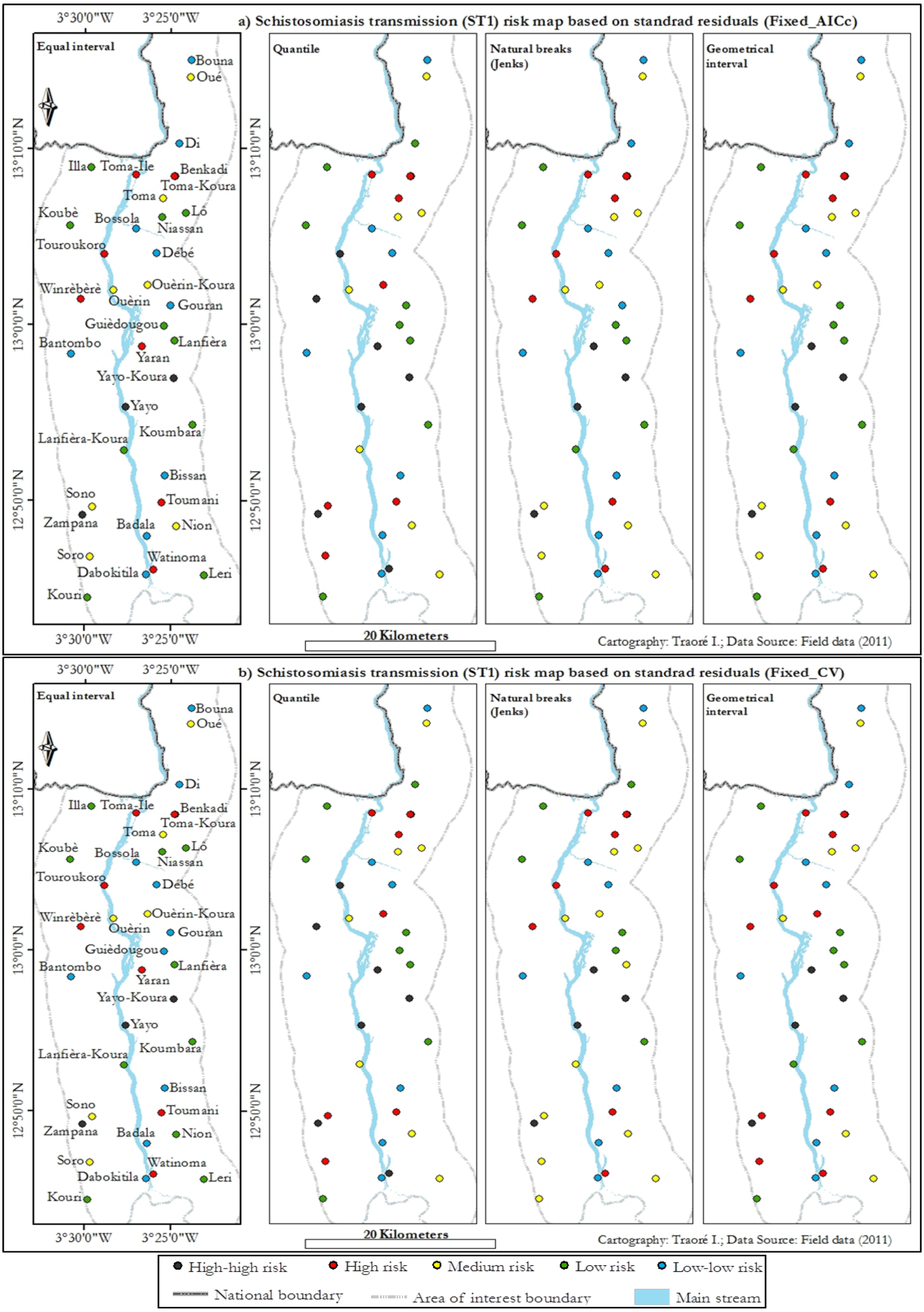


Figure 228: Spatial heterogeneity of schistosomiasis transmission (ST1) risk status per statistical method based on standard residuals using the fixed kernel type

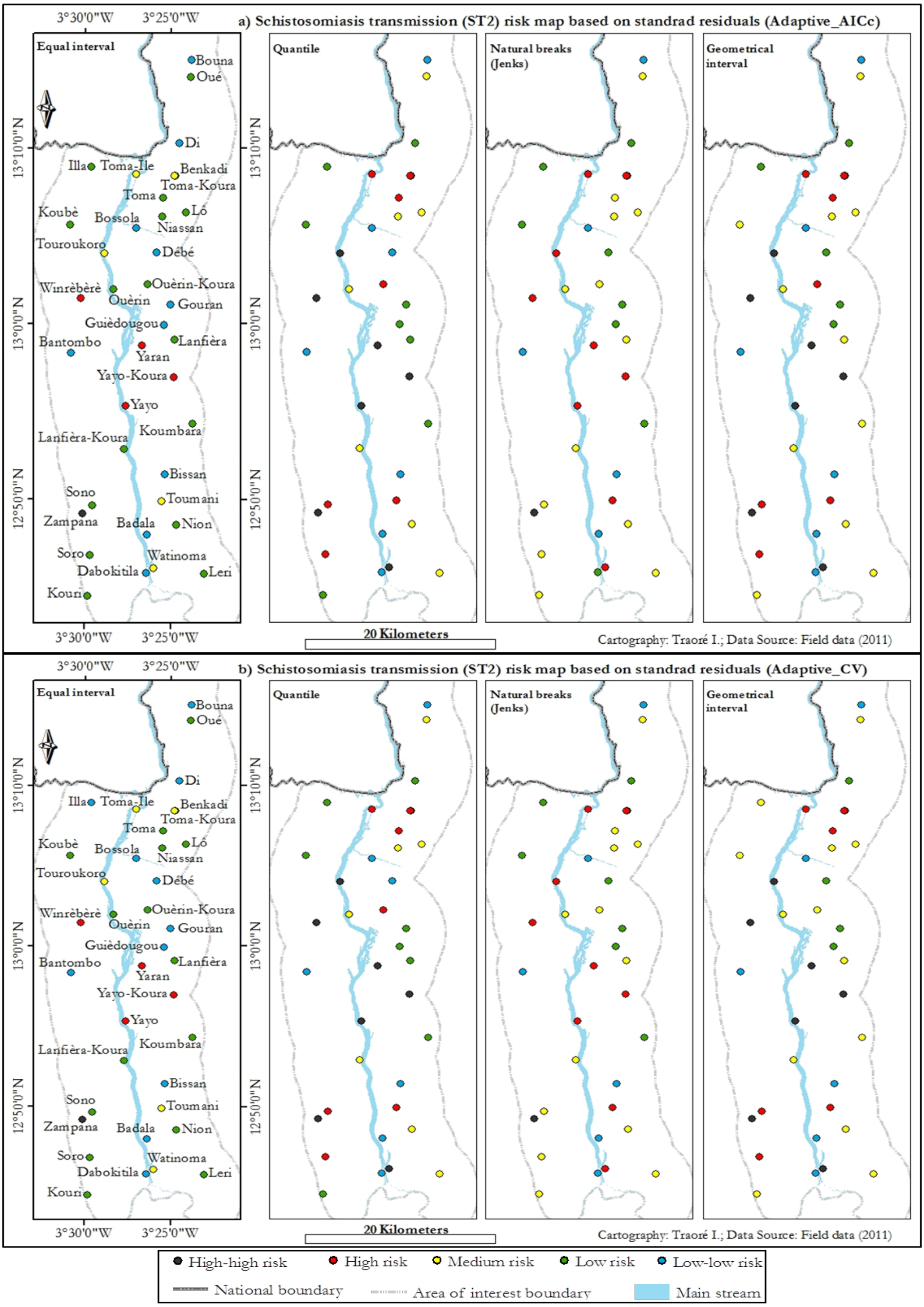


Figure 229: Spatial heterogeneity of schistosomiasis transmission (ST2) risk status per statistical method based on standard residuals using the adaptive kernel type

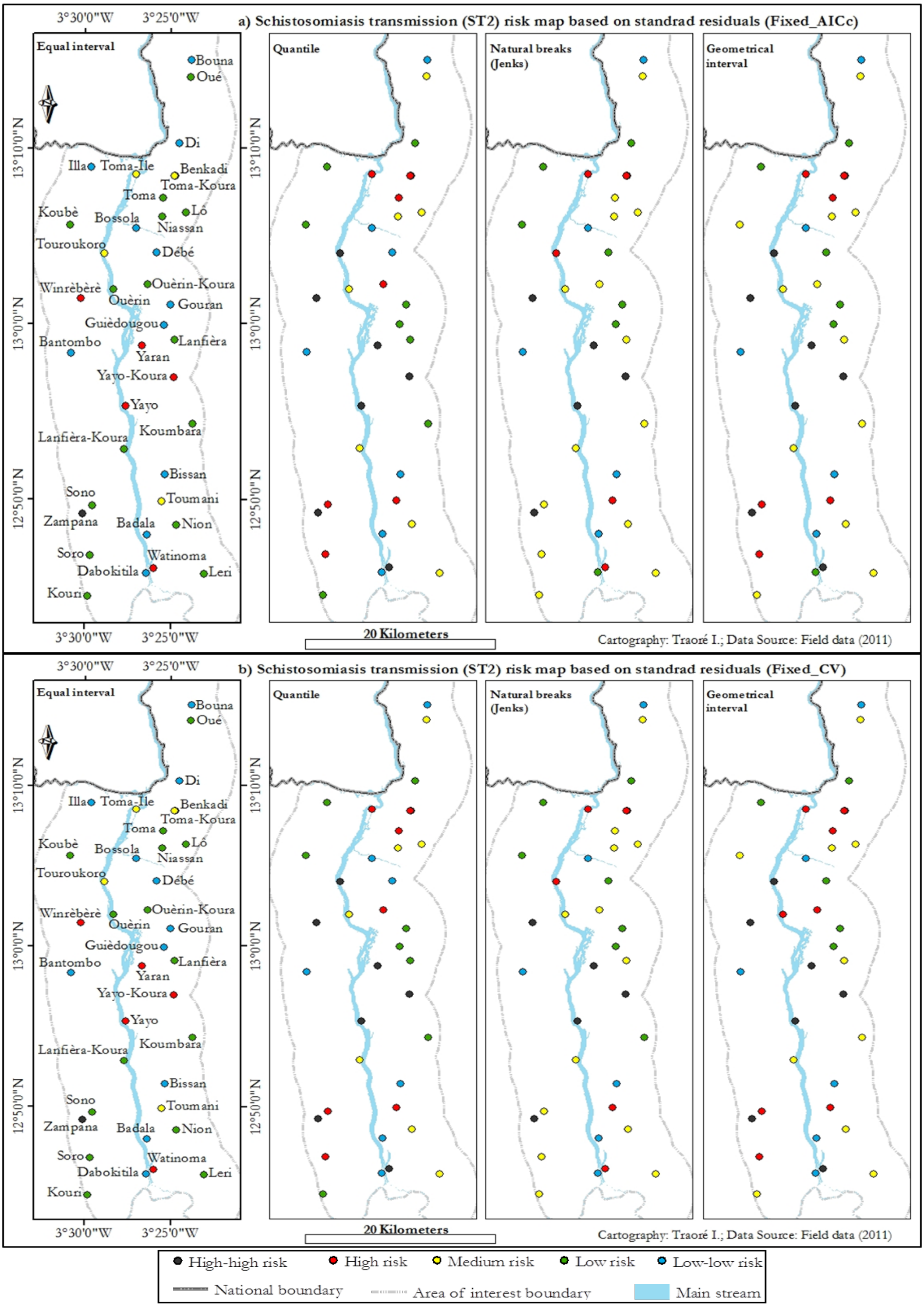


Figure 230: Spatial heterogeneity of schistosomiasis transmission (ST2) risk status per statistical method based on standard residuals using the fixed kernel type

Chapter 8. Discussion – Conclusion

8.1. Discussion

8.2. Urinary schistosomiasis-illness: What is the status?

Although the health state of an individual is the result of a complex multifactor system and healthy/illness status is an eminently variable appreciation, many researchers wish to emphasize on the individual meaning, the subject experience of health and illness what is less readily measured and quantified (Amat-Roze, 1998; Gatrell, 2002). Geographers have referred to these perspectives as "humanistic" philosophy, since they address implicitly human beliefs, values, meanings and intentions. The task for the researcher is to uncover or interpret these understandings and meanings that make it "rational" to act in a particular way, i.e. to see things from their point of view. Such an approach sees people as continually engaged in the construction of health and health care knowledge (Stainton, 1991, cited, Gatrell, 2002, 32). A corollary of this is that the views of ordinary people (referred to as "lay" or commonsense views) have as much status as those of the health professional.

Urinary-schistosomiasis-illness data gathering was based on reports of blood in urine, since it is not a symptom of other common diseases. The blood in urine associated with *S. haematobium* is too common in endemic areas that it is easily perceived individually and collectively (Lengeler et al., 1991a, b; Ansell et al., 1997; Amat-Roze, 1998; Lengeler et al., 2002; Poda et al., 2006). It has been well established that the presence of blood in urine is a reliable, indirect indicator of infection. The self-report questionnaire method has been extensively replicated and successfully validated in different geographical settings throughout SSA such as in Cameroon, Côte d'Ivoire, Malawi, Nigeria, Congo, R.D. Congo, Tanzania, Zambia, and Zimbabwe (Ansell et al., 1997; Guyatt et al., 1999; Lengeler et al., 2002; Brooker et al., 2009). Indeed, the WHO (1995) recognized this approach as standard in rapid identification of schools with high prevalence for warranting MDA with praziquantel. Furthermore, it is difficult to say that results obtained by the parasitological approach were more objective than those obtained using the self-report questionnaire because eggs were identified in the laboratory by human eye. Based on our results, we could assume that urinary schistosomiasis-disease cases recorded at CSPS level reflect the influence of the individual and community knowledge which is limited to the urinary form of the illness. Since, CSPS do not have any equipment for urine examinations; the infection status is based on the blood passing in urine reported by patients. Therefore, the urinary-illness data collected at the compounds level for this research have much status as urinary-disease data recorded at CSPS level, because both of them were based on simple statements without any parasitological verifications of presence of eggs in urine. Since, urinary schistosomiasis-illness cases were collected following a geographic philosophy this layer of information could be classified as a geographic parameter.

8.2.1. Schistosomiasis-susceptible concept: an unstandardized concept?

The grading criteria and study methods have not been standardized in academia, the classification keys vary from an author to another (Zhao et al., 2006). Zhang et al. (1990, cited, Zhao et al., 2006, 45) categorized schistosomiasis-susceptible area into three grades. They defined grass beaches with the density of infected snails > $0.005/0.11m^2$ and reported acute patients as susceptible area. Less susceptible area referred to grass beaches with the density of infected snails < $0.005/0.11m^2$, or snails' density >$2/0.11m^2$, but not or very few acute patients occur. Non-susceptible area refers to areas with no infected snails, or snail density <$2/0.11m^2$, no infected or acute patients occur. Chen et al. (1995, cited, Zhao et *al.*, 2006, 45) defined schistosomiasis-susceptible area as areas with infected snails, and suggested to annihilate the snails in the marshlands that are within 500 meters around residential areas. Gao et al. (1995, cited, Zhao et *al.*, 2006, 45) pointed out moisture, feces pollution, contact frequency and period in water are the main factors of forming schistosomiasis-susceptible area. However, based on different definitions in the literature, Zhao et *al.* (2006) suggested that methods for determining schistosomiasis susceptible areas should take into account five criteria: feces pollution, infected snails, cercariae, contact frequency with water and human infection. In landscape epidemiology a potential hazard exists wherever the cultural landscape maintains conditions sufficient for a focus of disease, whether or not the disease agent is actually present at a particular time (Meade, 1997). These examples show that the concept could be adapted in our case. In the present study, we measured the schistosomiasis-susceptible risk by integrating natural and social data which underlay the risk of schistosomiasis transmission in the Sourou Valley. The 16 geographic parameters we used in our model crossed directly or indirectly the five criteria conceptualized by Zhao et al. (2006).

The use of indicators of magnitude was the easiest way for us to integrate the identified geographic parameter in order to map schistosoniasis-susceptible settlements. Absolute score were attributed to classes depending on the magnitude of the risk status. Without indicator of magnitude it would have not been possible to calculate the quantitative values we used for the mapping. For Hotez et al. (2008), rather than the absence or presence of infection, the assessment of the epidemiological situation of schistosomiasis imposes to combine the prevalence and the intensity of infection. Although intensity is an important determinant both of transmission dynamics and morbidity, the two indicators of greatest relevance to the design of disease control strategies; numerous attempts to predict the distribution of schistosomiasis have until now been based on the use of point prevalence data rather than estimates of infection intensity (Anderson, 1987, cited, Brooker, 2007, p. 4). Our indicator of magnitude for human infestation was based only on the presence/absence of urinary schistosomiais-illness within compounds. Since compounds sample was robust (n = 4868) this can strengthen conclusion (Gatrell, 2002). In addition other source of epidemiologic data such as disease cases recorded at the CSPS level and those reported at schools level could not be spatialized, because they covered only 43.24 and 70.27% of settlements, respectively. Only urinary schistosomiasis-illness cases reported at the compounds level covered 100% of settlements and could, therefore, be spatialized. The second indicator of magnitude with respect to environmental contamination was the presence/absence of familial latrine within compounds. It is admitted in any community where some households do not have sanitary waste disposal that everyone who has contact with contaminated water risks schistosomiasis infection (Weil & Kvale, 1985). Based on these two indicators of magnitude we were able to quantified schistosomiasis-susceptible risk at the settlement level.

8.2.2. Schistosomiasis risk mapping: what about statistic indicators and outcomes?

8.2.2.1. Nominative absolute scores and hot spot z-scores methods followed the same pattern

Both the nominative and the hot spot methods attributed autiomatically the high-high risk level to settlements with the biggest absolute scores, irrespective to the quantitative classification method. These two statistic methods followed a quantitative pattern with a dose-response orientation. In fact all settlements detected into the high-high risk level were located on the main stream in the study area. This association between the proximity from the Sourou River and the high-high risk level was observed irrespective to the schistosomiasis risk status.

8.2.2.2. The geographic weighted regression standard residuals method followed a random pattern

There was a big difference between the method using standard residuals and that based on absolute scores in detection of the high-high risk level. The standard residuals method classified settlements into the high-high risk level neglecting the magnitude of absolute scores. Settlements were randomly classified into this risk level. There was no clear pattern in terms of the association between high-high risk level and the proximity to the main stream. This fact could be explained by the low values of coefficients of determination the linear regression showed. Therefore, the standard residual was not a good satistic indicator of schiostosomiasis-susceptible settlements.

However, based on the highest proportions for the high-higher risk level, comparison of results demonstrated that the equal interval method was minimalistic while geometrical interval method was maximalistic. GWR_Adaptive_AICc showed the lowest proportions of settlements with high risk while HotSpot_FDB recorded the highest proportions.

8.2.3. High-higher human infestation-susceptible risk overlapped spatially to settlements without any hydraulic work

One of the key circumstances leading to local population exposure to contaminating water bodies remains the availability and utilization of hydraulic works. Results of the geographic inventory of hydraulic works showed that lakeside settlements had no clean water equipment which resulted in the daily contact with the river. These communities have integrated the river in their cosmogony. Interestingly, human infestation-susceptible risk maps based on absolute score and z-score pointed to the same communities to be in the high-high risk level. Out of the 37 settlements and despite the short horizontal distance (14 km), 100% of high-high human infestation-susceptible settlements were those without any hydraulic work. This implies that the availability of hydraulic work could be used to predict human infestation-susceptible communities and populations. In Nigeria, Akogun (1990) found a significant association between the availability of wells and prevalence of both *S. haematobium* and *S. mansoni*.

8.2.4. High-high environmental contamination-susceptible risk overlapped spatially to settlements without any familial latrine

The availability and use of familial latrines was one of the key circumstances leading to environmental contamination by local population and particularly schistosomiasis-ill persons. Results of the compounds survey indicated that none of compounds had latrines within settlements located on the river which results into the open air defecation. Depending on the season and the flood of the river, excreta are deposed directly into the flood water. Interestingly, environmental contamination-susceptible risk maps based on absolute scores and z-scores classified the same communities into the high-high risk level. Out of the 37 settlements and despite the relative short vertical distance of the study area (14 km), 100% of high-high environmental contamination-susceptible settlements were those found without familial latrines. This suggests that the availability of familial latrine at the compound level could be used to predict the environmental contamination-susceptible communities and populations.

8.2.5. The proximity to permanent water bodies remain the major geographic parameter with respect to schistosomiasis transmission in the Sourou Valley

Results from the integration of geographic parameters for mapping schistosomiasis-susceptible settlements based on absolute scores and z-scores indicated lakeside settlements into the high-high risk level, irrespective to the quantitative classification method. All high-high risk level with respect to human infestation, environmental contamination and schistosomiasis transmission risk status were found located within 1 km buffer zone from the main stream. The influence of the proximity of settlements to perennial water bodies on their higher exposure risk to Schistosomiasis was also reported by Dianou et al., 2004 in the study area. Predictions at the regional and national scale, done by Clements e al. (2008), Clements et al. (2009) confirmed the clustering of higher risk along main streams. Clennon e al. (2004), Clennon et al., (2006) found high infestation levels of urinary Schistosomiasis with a significant focal distribution around transmission sites in Kenya. This means that despite the complex integration of the various geographic parameters, our results were similar to findings in the literature. This suggests several implications. First of all, at both the regional, national and local scales the proximity to perennial water bodies is a major indicator the Schistosomiasis transmission. Second, our results corroborated with the Tobler's (1970) first spatial autocorrelation law, "everything is related to everything else, but nearest things are more related than distance things". Absolute score and z-scores risk maps showed, in general, a North-South similarity in risk level between lakeside settlements and, a East-West difference in risk level when comparing lakeside settlements to others. Third, results also demonstrated that geographic parameters we used in the model were adapted and indicators of magnitude were good. Finally, results strongly suggested that geographic determinants alone can be use to assess the spatial heterogeneity of schistosomiasis transmission risk at the local scale.

8.2.6. Schistosomiasis a recreational disease: Peaks of children swimming coincide with peaks of eggs and cercariae emission

The daily peak of human pressure of water exposure was observed at the hottest hours of the daytime (13:00 and 15:00). According to McMahon (1976) and Doehring et *al.* (1985), the circadian rhythm of schistosome ova excretion in the urine was reported from different geographical areas in Egypt, in East and West Africa and even out of African. *S. mansoni* and *S. haematobium* cercariae are released from their intermediate hosts during the daytime showed mean shedding times ranging between 10:00 and 16:00 hours (Nojima & Sato, 1982; Theron, 1984; N'Goran et al., 1997). Likeside settlements' children were more exposed to schistosomiasis due to temperature variability. The heterogeneity in space was based on the postulate that at equal range of air temperature, the proximity of the perennial water bodies determined the spatial vulnerability. Therefore, the accessibility to freshwater bodies remained the key determinant of the spatial vulnerability. It means that the use of freshwater as natural cooling depended strongly on the settlement particular location and relative distance to a permanent water body. This condition was fulfilled only by the Sourou River during the dry season in the AOI.

During the school period, school-goers are occupied by the school attendance and therefore removed from occupational and recreational activities. However, during holidays and break periods pupils, free from school attendance, are involved in occupational and recreational activities. School attendants take advantage of each break time to do recreational activities even during school periods. Therefore school children do not totally escape from schistosomiasis risk during school terms.

8.2.7. Schistosomiasis a professional disease: Irrigation and traditional fishing in ponds lead to massive water contact

Get-rich-quick is the mean dream of all farmers and above all the migrants linked to irrigation development projects. The two harvests opportunity modern irrigation offers to farmers and the organization of the products commercialization through the agricultural co-operative should bring this hope to reality. The cultural dimension is all the more important in the occurrence of traditional fishing that it is regulated by costumes. Each year, before the starting of the fishing, sacrifices are done by the *Kôtigui* or wises in responsible for the ponds in local language. Days as well as ponds to be fished are indicated only by the *Kôtigui*. It then demonstrates that the bulk of community exposure to schistosomiasis due to traditional activities in ponds occurs in the dry warm season from March to May. The human position distribution shows that individual visited several micro-environments within the same water body. This could increase the change to meet with the infesting free swimming cercariae. Within the same type of environment the difference in terms of infestation will, probability, depend on the contact duration. All water contact took between 3.7 times and 20.5 times longer than the time infesting cercariae need to complete human-being body.

Results showed that human water contact took place in freshwater bodies with dense aquatic vegetation covers. The association between freshwater and aquatic vegetation offers appropriate biotope for snail intermediate host (Madsen, 1992a; Madsen, 1992a; Lodge et *al.,* 1998; Jones et *al.*, 1992). All freshwater contact activities were diurnal following the convex path of the sun. Similarly, daily peak of water exposure coincided perfectly to the higher bombardment of cercariae (Shiff et al., 1972; N´Goran et *al.*, 1997).

8.2.8. Settlement aspect governs the unequal access to socio-economic and health infrastructures in the Sourou Valley

8.2.8.1. Access to health care services

In the tropical rural areas, the improvement of access to health care relies on the postulate that a better access to health services conducts to an appropriate use was discussed by Richard (1995). The concept of access to healthcare, in its simplest sense, refers to entry or use of the healthcare system (Duncan & Clark, 1983). In fact, for the local people the use is the proof of presence of access. Access is most frequently viewed as a concept that somehow relates to clients ability or willingness to enter into the healthcare system (Penchansky & Thomas, 1981). Inequitable access occurs when social structure (ethnicity), health beliefs and enabling resources (income) determine who gets medical care (Andersen, 1995). In its geographical acceptation, availability refers to the sanitary coverage which can be seen when three conditions are reached: the physical presence of the infrastructures (dispensary, hospital, clinic); the adequacy of the supply of physicians, and other providers (their effective presence); and providing services (quality and permanence) adapted to the patients' needs (including medicaments) (Thomas & Penchansky, 1984; Richard, 1995).This dimension is viewed in the form of equal access to health care for people in equal need. Therefore, equity of access is purely a supply side consideration, in the sense that equal services are made available to patients in equal need (Goddard & Smith, 2001). The equity, in the provision of health services, is an attribute of a system that provides roughly similar services to those with similar health problems, and appropriately dissimilar service to those with dissimilar problems (Vladeck, 1981). The organisation of the health system based on the reference system (Cadot & Harang, 2006) of the patient from a low to upper level or therapeutic itinerary presents some weakness and strengthen of the health system. Weakness because the system is not in the position to satisfy the patient needs. It means lack of competence both in terms of personnel and medical equipment. Strengthen, when the patient gets the information that at the upper level the demand can be supply.

According to Goddard & Smith (2001), availability of information means also access, e.g. certain services is known with equal clarity by all population groups.

- Trilogy in the supply of treatments against schistosomiasis could explain the less use of modern health care center in the AOI

Schistosomiasis ill persons are comparable to clients who are coveted by three different providers of medicine against their illness. Modern health care professionals, TH are specialists in providing alternative or traditional medicine. SM dealers are non-qualified in modern care provision. Vernacular words such as *farafing fula* meaning Blackman medicine and *tubabu fula* meaning Whiteman medicine are locally used by communities to make a racial difference between traditional medicine and modern medicine, respectively. Relative recent availability of modern health care infrastructures in the AOI is of concern. Indexed to 2011, CSPS were celebrating their 51st, 27th, 20th, 13th, 4rd and 3rd year of health care provision. From what preceded, we can say without any doubt that traditional healers still hold the monopoly of schistosomiasis treatment provision in the AOI. The youth village among the nine sites of CSPS was settled in 1785, i.e., Lanfièra. From the settlement year to the supply of the health care center the time lag varied between 175 and 223 years before concerned communities had a direct accessibility to a CSPS. Tablets sold for treating schistosomiasis are similar in design to the praziquantel provided by the CSPS at the only difference that on the first is written down 400 mg, while it is 600 mg for the praziquantel. Worst again, since the national program of schistosomiasis control was organizing mass drug treatments, all drugstores managed at the CSPS level have stopped to sell the praziquantel. Similarly, none of the two private drugstores in Lanfièra and Niassan had praziquantel in their store. This break in the supply of the modern treatment at the CSPS level and the private drugstores will promote the utilization of street medicaments. We emphasized on modern health care services because the effectiveness of the praziquantel was scientifically and medically proven in the AOI (Toure et *al.* 2008; Poda et al., 2006).

8.2.8.2. Access to water and sanitation

Infection risk is strongly associated with limited-resource living conditions that favour freshwater exposure, such as the daily use of streams and ponds for activities such as washing, laundering, swimming and irrigating, and with a lack of sanitary systems that can protect water sites from contamination (King & Dangerfield-Cha, 2008). White et *al.* (1972) were the first to attempt to simply the relationship between water supplies and health in developing countries; and worked out the general model. The water supply, to be effective in controlling human schistosomiasis, must be so convenient as to discourage water activities such as laundry and bathing (Cairncross & Valdmanis, 2006). *S. haematobium* and *S. mansoni* percentage reduction rates expected from excellent water supply are assumed to 80% and 40% respectively (White et *al.,* 1972). The Global Water Supply and Sanitation Assessment group accepted in their 2000 report only sewerage, septic tanks with soakaways, pour-flush latrines, and pit latrines as improved technologies that provide adequate access to sanitation whether they are private or shared (but not public) and hygienically separated human excreta from human contact (Cairncross & Valdmanis, 2006). Public latrines do not provide an adequate solution to the excreta disposal needs of a community, because they are not usually accessible at night or by the elderly, by those with disabilities and at times, by children. Consequently some promiscuous defecation continues to be practiced in community where public latrines are the only level of service available (Cairncross & Valdmanis, 2006).

Results from the direct field observation of water drawing sites and sources selection showed that in the Sourou Valley, the clean water supply did not succeed discouraging people from the use of contaminated freshwater. For many reasons, water drawn from contaminated water bodies were used in almost all water utilization domains. It means that freshwater is convenient for all sectors of use, while water from hydraulic works appears too selective. People travel greater distances to reach water bodies than they do for hydraulic works in study area. There was a relationship between the availability of transportation means, the water container to be transported, the water drawer gender and the selection of the water source. Availability and accessibility to water equipment, alone, did not mean use. Results demonstrated that a lack of a simple rope to draw water from well led to contact with contaminated water bodies.

Our results showed that most of settlements in our AOI were characterized by informal housing without proper water reticulation and sanitation facilities. These circumstances give rise to the situation where the local residents were forced to make use of surface water for domestic and recreational purposes. The same reasons explained the open air defecation behaviour. The absence of familial latrines will express the no access to and no use of latrines in the 10 settlements within which all compounds had no latrines. Therefore, we can assume that in these particular communities all people are involved in the open air defecation. However, for the 27 other settlements within which some of compounds had latrines, we can precise that a total of 2684 compounds had no latrines, but it might be wrong to infer from that the non-use of latrines. Results showed that the majority of latrines owners were sharing them with nearest neighbors. This implies that in the rural context, it is very difficult to assess with accuracy the defecation behavior. The link between familial latrines and health was observed in the study area. But research on the relationship between the use of latrines and the prevention of environmental contamination with respect to schistosomiasis was limited.

8.2.9. Geographic determinants did not act independently

Worldwide, the macrogeographic distribution of human schistosomiasis is influenced by climate and the distribution of freshwaterbodies, appropriate habitats for snail intermediate hosts of parasites. On the other hand, the prevalence of infection within endemic communities is strongly determined by the microgeographic variation in the physical environment, human settlement patterns, the distribution of freshwater habitat for snails and the intensity of exposure and contaminative contact by humans and the prevalence of pathogenic worms and snail intermediate host (Kloss & David, 2002According to Raso et *al.* (2005, cited, Brooker, 2007, p. 4), at the local scale (community level, about few kilometres), schistosomiasis transmission risk is related to the spatial heterogeneity in human demography and socioeconomic status. Results showed that although the water was available in the environment, children in Toma-Île started swimming in the river only when the daily mean air temperature reach 25 °C. Researches also revealed that water contact taking place into ponds were strongly influenced by the amount of rainfall, 600 to 850 mm being the range for activities to take place. The work and place places of local population were associated with freshwater bodies and aquatic vegetation. Behaviors of local population were therefore linked to the climate and the environment. Children constituted the backbone of water contact activities.

8.2.10. Furtur hydroagricultural modification, climate change and re-emergence of schistosomiasis in the Sourou Valley

Human schistosomiasis remains the water-related disease whose importance in public health and prevalence has dramatically increased due to hydrologic modification in Africa (Traoré, 2000). The advent of irrigated agriculture and the concomitant rapid population growth (both human and snail hosts) greatly favoured the spread of human schistosomiasis (Weil & Kvale, 1985; Kloos & David, 2002). While clearly ancient, schistosomiasis can emerge as a new infectious disease in a given location under certain man-made changes in environmental conditions and economic- or migrations of people (Colley, 1996). Particularly, changes in the distribution and characteristics of water have an in-depth effect on actual and potential snail intermediate host habits and the transmission of human schistosomiasis. The Kainji dam in Nigeria, built in 1970, has induced an increase of *S. haematobium* over 62% in the nearest bank villages vs. less than 20% in villages that was located fare away from the dam (Traoré, 2000). Mali, Niger as well as Burkina Faso have an experience in the exponential increase of the prevalence of human schistosomiasis due to hydrological development (Traoré, 1994; Sellin, 1996, Poda et *al.* 2001).

The new development and conditioning of the 2037 ha sponsored by the Millenium Challenge Corporation in the Sourou Valley and the predicted increase of temperature about 0.8 °C by 2025 (SPCNEDD, 2007) will concomitantly increase habitats for snail intermediate host of schistosomiasis and human water contacts which will result in a dramatic increase of schistosomiasis prevalence rate in the Sourou Valley.

8.2.11. Combination of GPS, RS and GIS for determining schistosomiasis exposure activities

GPS is a multifunctional device. Schutz & Chambaz (1997) highlighted the following potential advantages of utilizing GPS: portable (light and small size); non-invasive non obtrusive free living measurements; continuous measurement with 'on line' data obtained in a miniature screen, hence feedback for the subject; free access to the GPS satellites in any part of the world; reasonable cost of the GPS receiver; data could be stored and subsequently retrieved if required; the technique can be used to independently validate measurements of velocity of walking and running. Since, GPS technology has been used for tracking subject’s location during environmental exposure (Margaret et al., 2001; Elgethun et al., 2003; Seto et al., 2007; Rainham et al., 2008; Maddison & Mhurchu, 2009; van der Spek et al., 2009; Vazquez-Prokopec et al., 2009; Margaret et al., 2001; Wu et al., 2011). In our case the GPS served to catch residential units and associated infrastructures, not only, but it also allowed sensing human water contact activities. By combining GPS data with high spatial resolution satellite image and GIS, we are able to geo-visulalize the distribution of the exposure activities in the water bodies. Data showed that it possible to distinguish water contact activities based on their track (ground signature), the frequency of break points, the speed and duration of activities.

8.3. Conclusion

In order to change things we have to first understand them (Harvey, 1974). To understand events associated with diseases, we must first understand the population, settlement, movement and transportation geographies of these areas, both presently and historically;

the political economy of land development; the natural ecology of the areas, and their regional entomologies and zoogeographies (Mayer, 2000).

The holistic and eco-geographical approaches were employed in this thesis for a better understanding of the geographic determinants of human schistosomiasis transmission in the Sourou valley, north-western Burkina Faso. Through the application of geographic methods and techniques to schistosomiasis we were able, by crossing several layers of information, to put into perspective the complex dynamic and functional relationships between natural and social geographic elements promoting the development of the disease in the Sourou valley.

8.3.1. Access to hydraulic works was the most important geographic determinant of human infestation risk in the Sourou Valley

Chapter 5 pointed out two main centers of gravity in terms of human exposure to infection risk. The first center of gravity was the physical environment whose components were formed by the natural and man-made water bodies colonized by snail intermediate host. Without these freshwater sources, the transmission of parasites is broken down. The second center of gravity comprised humans whose components include movement towards contaminated water sources. Visitation to contaminated water bodies is a prerequisite for successful transmission of schistosomes. Since neither the cercariae nor its snail intermediate host can thrive outside the water body, human population movement to contaminated water bodies plays a key role in the continuation of transmission cycle. Therefore, arresting this stage in the transmission cycle plays a critical role in stopping schistosome infestation. Other factors that could influence the infestation of human water contacts include complex settlement aspects (Chapter 4) possibly linked to the socio-economic, cultural and perceptional background of the local inhabitants. The density of freshwater bodies and high involvement of children as backbone in water contact activities were mainly highlighted.

This means that our first specific question was answered, the underlying hypothesis verified and the related specific objective was achieved

8.3.2. Access to familial latrines was the most important geographic determinant of local environmental contamination risk in the Sourou Valley

Chapter 6 identified two centers of gravity in terms of contamination of the local environment. The availability of familial sanitation represented the first center of gravity.

The peasant logic of space-sanitation is based on open air defecation rather than indoor use of latrines. Components of the peasant logic included the physical environment (use of vegetation as hiding place), and social features such as the poverty, age-dependent dimension, and setting particular location. Without the open air contaminated excreta disposal, schistosome transmission is broken down. The access to treatment against schistosomiasis represented the second center of gravity. Within a trilogy of medicines provision, the behavior local population in terms of seeking health care is mainly based on the traditional therapy. The best away to overcome the environmental contamination is to get a treatment whose effectiveness is proven such as praziquantel. The behavior of local communities in terms of excreta disposal and therapeutic choice was embedded in multi-environmental and social geographic determinants (Chapter 4). The low access to sanitation and modern health care services by children was mainly highlighted.

This means that we were able to answer our second specific question, verified the underlying hypothesis. Therefore, our second specific objective was achieved.

8.3.3. Proximity to perennial water bodies was the most important geographic determinant of schistosomiasis transmission risk in the Sourou Valley

Chapter 7 tried to map out comprehensively the two central pillars of schistosomiasis transmission system. The integration of the several natural and social geographic determinants (Chapter 4) highlighted similarities and differences between settlements in terms of abilities to contaminate their local environment and to expose themselves to the risk of infestation. Schistosomiasis transmission risk was mapped as the product of environmental contamination and human infestation. Thus, mathematically, if one of these central pillars is given a value of zero all the transmission will be stopped at this particular setting. Risk maps systematized settlements with a North-South similarity along the Sourou River and an East-West difference as one goes away from the Sourou River. Higher schistosomiasis-susceptible settlements were highlighted through the model.

This verified our third specific hypothesis and means that we provided useful answers to our first specific question. Therefore, we have achieved our third specific objective.

8.3.4. Contribution of this thesis

We studied the direct impact of natural and social geographic parameters on human health and particularly on human schistosomiasis at the fine local scale.

Based on the failure of the curative and preventive medicine in the developing countries, Froment (1997) has claimed that the tropical medicine strongly deep-rooted in the natural sciences could not conduct a reflexion on the environment, the human biology and behaviours, that the matter overtakes the field of the medical geography or even of the epidemiology *stricto sensu*. This point of view could be questionable. First, geographers bring their specific expertise to the public health domain by contributing through the development of operational indicators of risks. These indicators (non-medical above all) can be spatialized, at diverse scales, in order to identify spaces at risks and those that are susceptible (Handschlimacher et *al.*, 2003). Second, in a perspective of public health, the geography sets itself up as an applied science, supporting decision-making. Its role is the exact localization of problems and needs that they cause, and in its explanation (Vigneron, 1999, cited, Menard, 2002, 272). Third, the geographer highlights this territorialisation according to the fitting together of different scales for a better specification, and offering a surplus of information concerning the targeted populations by more adapted health actions. These information can direct control programme planning at middle term (Vigneron, 1999, cited Menard, 2002, 272).

Our model, based on the nominative absolute score, presented many of the qualities outlined by Cvjetanovic et al. (1978) and recommended by Unger et al. (1999) and both insisted on the need for direct epidemiologic models for decision-making and the anticipation of the impact of control measures. Our model is simple and mimes the reality. Results showed that whatever the model and the method, the highest-risk status was attributed to lakeside settlements. Our model highlighted opportunities for intervention or control because it indicated higher-risk communities. It is a reliable support tool for decision-making in terms of priority intervention. Steps of our method are clearly identifiable because we used a vertical approach to categorize settlements. It also has something in common with the natural history of the disease because classes were nominative scored following an analytic approach viewing environment contamination and human infestation in isolation. Our model also offers falsification opportunities. New geographic parameters can be identified and added to the model. We found the illness based mapping to be simple and cost effective. The cost for illness data gathering by fieldworkers at the 4868 compounds level was 1790 US Dollar. The cost for parasitological examinations on the basis of one sample of urine per compound would cost 7789 US Dollar (only examinations fees, other costs were not included). This mean that the illness based mapping was 4.4 times cheaper that using the disease. Furthermore, the illness approach saves time and fits more for rapid mapping while the disease approach is time consuming.

8.3.5. Recommandations

At the light of our results following from a holistic approach we are able to share some useful information with the local community, the local government, the national control program. Here, information are shared as recommendations whose application could contribute to improve the socio-economic and health status of local communities in the Sourou Valley, and elsewhere in Burkina Faso or in SSA countries. Recommandations are mainly addressed to the National Schistosomiasis Control Program; to health districts in Nouna, Toma and Tougan; to Non Governmental Organizations, to political decision-makers.

8.3.5.1. Increase communities' awareness about schistosomiasis transmission route

This study demonstrated that the peasant philosophy of defecation-space is awkwardly placed with environment contamination doubled with a limited individual and collective knowledge about human infestation route. Therefore, any control action should be preceded if not coupled with an education for health targeting to introduce new way of thinking at both individual and collective levels.

8.3.5.2. Initiate a network between traditional healers and health care centre for a better monitoring of Schistosomiasis morbidity

Results demonstrated a trilogy in providing medicine against Schistosomiasis in the Sourou Valley. Now, the question is, how among the three medicine providers will report data on patients? Obviously, only cases recorded at the CSPS level are monitored. Yet, traditional heal still hold the monopoly. This means that the bulk of Schistosomiasis cases are not reported and monitored. Therefore, a network should be established between traditional healers and their CSPS of reference. This report of cases will work provided traditional healers receive an appropriate training about the monitoring system.

8.3.5.3. Initiate a MDA in the Sourou Valley and in similar ecological areas in Burkina Faso

Despite its limitations, this study indicated communities with high-risk of schistosomiasis transmission. Therefore, it could be a starting point for warning a MDA. This MDA should be based on the community level, because results showed that most of high-prevalence settings have a limited access to school. For other wetlands, ecologically similar to the

Sourou Valley, a rapid mapping based on the illness perspective is a perquisite for targeting higher-risk communities.

8.3.5.4. Recommendations for future studies

- Despite the relative short period (62 days) of direct field observation, results showed a strong influence of air temperature on children recreational swimming temporal patterns.

  "With temperature such an important environmental factor, its further effects should be investigated both in the laboratory and in the field. The results of such work should contribute to a better conception of optimal conditions for maintenance of snail and parasite in the laboratory, to a more intelligent evaluation of ecological data relative to the dissemination of the human schistosomes, and to more economical application of controls of this parasite in the field." (Stirewalt, 1954, p. 515)

  We suggest that future researches should try a long term observation (at least one year) in order to confirm or infirm the threshold of 25 °C we found to be the starting point of children exposure to contaminated water through swimming.

- Based on a nominative method we integrated several geographic parameters for mapping schistosomiasis-susceptible communities and populations in the Sourou Valley. One of the indicators of magnitude was the urinary schistosomiasis-illness prevalence rate which is subject to question. We recommend for future studies to use parasitological data for validation of the method. These parasitological data should take into account both urinary and intestinal schistosomiasis prevalence data so that the nominative method could be tested for both forms of the disease.
- In the present study we put our focus on the description of geographic parameters identified and circumstances leading to schistosomiasis transmission in the Sourou Valley. Considering this work as a firs step, future researches should put their focus on looking for more complex statistic methods in order to better assess the role of geographic determinants of schistosomiasis transmission. This can be done within a multi-disciplinary framework.

9. Summary

Schistosomiasis (also known as Bilharzia or Bilharziasis) is the second most prevalent neglected tropical disease (NTD) after hookworm and is caused by infection with blood flukes of the genus *Schistosoma*. More than 85% of the estimated 779 million people at risk worldwide are concentrated in Sub-Saharan Africa (SSA). Of the 207 million infested persons worldwide, more than 97% are concentrated in SSA. The geographic study of human schistosomiasis comes within the framework of geography of health with the target of putting into perspective the natural and social determinants of the states of health within an area of interest. The complexity and multiplicity of factors contributing to the endemicity of human schistosomiasis suggests that patterns are readily predicted at regional and national scales and that more complex models are required to predict patterns at local scales. This local fine scale approach was adopted in this research to assess schistosomiasis-susceptibility at the community level by integrating natural and social geographic determinants in Burkina Faso in general and the Sourou Valley in particular. Therefore, the present study, in its conception, aimed to collect useful background information for analysing human schistosomiasis ecology and diffusion as well as the access to health care services and associated infrastructures at the community level.

This study tried to provide answers to three specific questions: *i*) what are the natural and social geographic determinants of the disease and how do they interact in terms of infestation of local populations? *ii*) how do the determinants of the disease interact in terms of local environmental contamination? and *iii*) could natural and social geographic determinants be integrated to geographically map high schistosomiasis-susceptible communities in the Sourou Valley in Burkina Faso? These research questions have three underlying specific hypothesis: i) human infestation depends on diverse natural and social geographic determinants occurring through multiple factors and complex interactions; ii) local environmental contamination depends on diverse natural and social geographic determinants through a complex of interactions between multiple factors; and iii) the comprehensive, rapid and accurate mapping of high schistosomiasis-susceptible communities and sub-communities in the Sourou Valley is depends on the integration of diverse natural and social geographic determinants collected at the community level. Three specific objectives were defined to verify these hypotheses: i) to identify natural and social geographic elements at the local community level in order to understand their complex interactions with respect to human infestation; ii) to identify natural and social geographic elements at the local community level for understanding their complex interaction with

respect to environmental contamination; and iii) to integrate identified natural and social geographic elements for geographic mapping of schistosomiasis-susceptible communities in the Sourou Valley.

The global and eco-systemic approach used in this work required us to dispose of a multitude of layers of information. In fact, the determination of communities favorable to schistosomiasis transmission requires the crossing of different spatialized data. Data gathering following the holistic perspective included geographic data (natural and social) as well as epidemiologic data. Some were readily available from archive sources, but most of them were ground collected data, particularly human and illness-related data. In this thesis, physical data were collected for assessing the heterogeneity and patterns of the vulnerability in time and space. Climatic variables were used to measure the temporal vulnerability of local populations while environmental layers were used to measure the spatial vulnerability of local populations. Human data such as population size and movement as well as access to infrastructures were collected to assess vulnerable communities within the AOI. Epidemiologic data was needed to assess and highlight the magnitude of the vulnerability to schistosomiasis at the community level. The spatial analysis followed a vertical approach. Sixteen geographic parameters were identified and integrated using GIS tool for mapping and understanding the varying pattern of schistosomiasis risk within the AOI.

Several natural and social geographic determinants explain the dysfunction between local populations and their environment which results in human infestation by schistosomes. The study demonstrated that the access to clean water, education, health and other related socio-economic infrastructures was strongly influenced by the settlement functions and its population size. The clean water supply did not succeed in discouraging people from the use of contaminated freshwater. Local populations travel greater distances to reach water bodies than they do for hydraulic works in the study area. Furthermore, results indicated that within the same community and for the same gender, women were more vulnerable to schistosomiasis due to their involvement in domestic activities that enhance their chances of coming in contact with water bodies. Within the same community and for the same age group, children vulnerability to schistosomiasis through recreational swimming was critically influenced by variability in air temperature. The role played by water bodies in the daily life of the respondents could be linked to poverty, socio-professional status, location of the settlements, culture, age and gender. These geographic determinants interact in a complex way resulting in vulnerability of local populations to schistosomiasis infestation.

Several natural and social geographic determinants influence defecation pattern of local populations which leads to environmental contamination. In the rural context, the defecation space utilization is mainly based on open air defecation. The demand for familial latrines in our AOI was strongly determined by land cover and proximity to the bush. In the peasant philosophy of defecation space utilization, defecation in the open air is a normal occurrence and feces encountered outdoors are mainly from children. Therefore, this defecation pattern contributes to environmental contamination. Children who are known to be heavily infected have less access to modern health care services. Traditional healers hold the monopoly for delivery of schistosomiasis treatment, hence, the expression "*farafing fula* (Blackman medicine) is preferred to *tubabu fula* (Whiteman medicine)". The persistence of defecation in the open air is associated with poverty, socio-economic status, location of settlement, culture and age These geographic determinants interact in a complex that result in contamination of the local environment by its schistosomiasis-ill inhabitants

Through the application of geographic methods and techniques, we were able to assess schistosomiasis risk by crossing several layers of information putting into perspective the complex dynamic and functional relationships between natural and social geographic elements which promote the development of the disease in the Sourou valley. Risk maps were able to categorize settlements with a North-South similarity along the Sourou River from those with an East-West difference as one goes away from the Sourou River. Our model pointed to lakeside settlements as high schistosomiasis-susceptible settings. Furthermore, we demonstrated that the illness based mapping was cost effective: 4.4 times cheaper than the disease based mapping. Despite its limitations, this study was able to reveal communities with high-risk of schistosomiasis transmission. Therefore, it could be an indication that MDA is needed for control of schistosomiasis in the Sourou Valley.

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11. Annexes

Annex 1: Global outcomes of compounds survey per quarter, settlement, village, rural commune and province

Province	Rural commune	Village	Settlement	Quarter	TNC	TNP	TA	WBG	TFP	IRR	TI
KOSSI	BARANI	ILLA	Illa	Doubankina	4	40	1	2	4	4	1
				Guekina	27	263	7	6	27	26	19
				Kekina	8	92	3	1	8	8	6
				Massakina	11	108	2	1	9	9	9
				Noumoukina	26	340	12	6	22	23	13
				Parakina	58	572	13	26	54	53	26
				Zembakôrô	36	314	12	6	32	32	14
			Total	*7*	*170*	*1729*	*50*	*48*	*156*	*155*	*88*
		KOUBE	Koubè	Doubekina	3	70	0	2	3	1	1
				Massakina	27	328	5	9	22	17	6
			Toatl	*2*	*30*	*398*	*5*	*11*	*25*	*18*	*7*
		WINREBERE	Winrèbèrè	Winrèbèrè	20	190	0	1	14	1	5
			Total	*1*	*20*	*190*	*0*	*1*	*14*	*1*	*5*
	Total BARANI	3	3	10	220	2317	55	60	195	174	100
	SONO	BANTOMBO	Bantombo	Malienkin	19	200	4	3	19	0	9
				Ouékakin	38	379	5	7	34	2	18
			Total	*2*	*57*	*579*	*9*	*10*	*53*	*2*	*27*
		KOURI	Kouri	Foulakin	1	19	0	0	0	0	0
				Massakin	33	283	9	2	6	1	19
				Pélékinso	12	112	3	0	1	0	6
				Samogokin	22	197	3	1	4	2	16
				Zourakinso	28	200	6	0	2	1	18
			Total	*5*	*96*	*811*	*21*	*3*	*13*	*4*	*59*
		LANFIERA-KOURA	Lanfièra-Koura	Lanfèra-Koura	7	92	0	0	0	0	2
			Total	*1*	*7*	*92*	*0*	*0*	*0*	*0*	*2*
		SONO	Dabokitila	Dabokitila	11	98	0	0	0	5	5
			Total	*1*	*11*	*98*	*0*	*0*	*0*	*5*	*5*
			Sono	Bagazourakinso	76	741	25	5	18	15	8
				Bitabè	52	400	19	0	0	12	3
				Darabè	27	223	5	1	8	5	2
				Goulabè	32	237	14	3	12	2	2
				Mandoubè	65	773	11	9	47	5	8
				Sansirakan	36	332	15	1	10	4	10
				Sirakôrô	21	162	10	2	8	3	4
				Soumabè	6	95	4	1	5	2	3
				Zouanbè	5	42	0	0	2	0	1
			Total	*9*	*320*	*3005*	*103*	*22*	*110*	*48*	*41*
		SORO	Soro	Dafingkin	5	21	0	0	1	0	3
				Foulakin	1	10	0	0	0	0	0
				Mossikin	15	149	0	0	0	6	8
				Samogokin	9	109	1	0	0	1	3
			Total	*4*	*30*	*289*	*1*	*0*	*1*	*7*	*14*
		ZAMPANA	Zampana	Dafingkin	13	106	1	0	10	0	1
				Mossikin	5	44	0	0	0	4	0
			Total	*2*	*18*	*150*	*1*	*0*	*10*	*4*	*1*
	Total SONO	6	7	24	539	5024	135	35	187	70	149
TOTAL KOSSI	2	9	10	34	759	7341	190	95	382	244	249
NAYALA	GASSAN	LERI	Léri	Komokin	16	137	5	0	7	0	3
				Massakin	31	271	16	0	15	1	7
				Sérékin	4	28	0	0	1	0	0
				Sérémékin	34	284	12	0	15	1	3
				Zanakin	60	623	17	0	36	3	16
TOTAL NAYALA	1	1	1	5	145	1343	50	0	74	5	29

IRR: number of compounds participating in modern IRRigation activities; **TA:** Total number of compounds with Access to larine; **TI:** Total number of compounds having reported Illness cases; **TFP:** number of compounds participating in Traditional Fishing in Ponds; **TNC:** Total Number of Compounds; **TNP:** Total Number of Populations; **WBG:** number of compounds participating in Water lily Bulbs Gathering;

SOUROU	DI	BENKADI	Benkadi	Benkadi	55	671	9	0	2	52	32
				Sababougnouma	27	365	3	2	2	27	26
			Total	*2*	*82*	*1036*	*12*	*2*	*4*	*79*	*58*
		BOUNA	Bouna	Bounakina	10	178	3	1	4	4	5
				Kiénadara	9	139	2	0	2	5	10
				Saminadara	4	62	1	1	3	2	2
				Somossakina	14	273	9	1	7	8	4
				Zakinadara	15	241	9	0	8	7	5
			Total	*5*	*52*	*893*	*24*	*3*	*24*	*26*	*26*
		DEBE	Bossola	Bossola	5	44	0	0	0	0	5
			Total	*1*	*5*	*44*	*0*	*0*	*0*	*0*	*5*
			Débé	Bassinéré	45	372	15	0	0	35	18
				Débé-Koro	30	421	8	1	2	30	24
				Télékorokin	16	130	1	9	12	11	5
				Zone 1	27	410	14	0	0	27	15
				Zone 2	23	214	3	3	3	23	15
				Zone 3	73	832	34	0	1	73	67
				Zone 4	72	698	12	0	0	71	43
				Zone 5	57	587	12	0	0	57	30
			Total	*8*	*343*	*3664*	*99*	*13*	*18*	*327*	*217*
		DI	Di	Irakina	268	2421	165	0	20	143	90
				Kolon	89	916	35	1	31	64	14
				Mandou	145	1617	70	0	69	126	44
				Missin	128	1611	88	1	32	102	35
				Mossikina	46	700	26	0	2	39	10
				Pinikina	27	415	17	3	20	24	15
				Sobassô	10	93	2	0	8	10	0
				Sourougoukina	17	208	12	0	10	16	6
			Total	*8*	*730*	*7981*	*415*	*5*	*192*	*524*	*214*
		LO	Lô	Cité	10	30	9	0	0	10	0
				Kébé	12	131	3	0	1	6	3
				Leni	2	20	1	0	0	1	1
				Samogokin	6	43	2	0	0	5	3
			Total	*4*	*30*	*224*	*15*	*0*	*1*	*22*	*7*
		NIASSAN	Niassan	Gakina	56	553	22	5	15	53	52
				Gorakina	46	488	9	3	14	39	33
				Kouroukan	44	288	8	0	0	35	40
				Niassan-Koura	157	1394	44	4	6	155	82
				Pèrekin	34	208	6	0	0	26	33
				Silamèkin	93	540	26	0	0	89	37
				Sorokadi	108	729	75	0	0	107	46
				Soukina	93	988	46	0	18	85	66
			Total	*8*	*631*	*5188*	*236*	*12*	*53*	*589*	*389*
		OUE	Oué	Bouakina	46	464	12	14	25	12	15
				Foulakin	5	114	1	0	0	1	6
				Gnessakina	57	657	20	3	37	33	13
				Namkina	43	370	15	5	22	7	15
				Titinikan	15	188	5	1	5	6	5
				Yorolena	16	186	7	2	5	6	13
				Youbakina	20	262	10	4	15	5	7
				Zoulakina	24	221	4	2	11	5	11
			Total	*8*	*226*	*2462*	*74*	*31*	*120*	*75*	*85*
		TOMA-ÎLE	Toma	Toma	18	217	8	6	9	16	16
			Total	*1*	*18*	*217*	*8*	*6*	*9*	*16*	*16*
			Toma-Île	Drabokina	1	17	0	0	1	1	1
				Fofanakina	3	60	0	1	3	3	2
				Inassekina	1	13	0	1	1	1	1
				Loubasso	3	22	0	2	3	3	2
				Sabokina	11	137	0	6	10	10	7
				Serikina	5	62	0	3	3	4	1
				Sobasso	16	149	0	9	11	16	12
			Total	*7*	*40*	*460*	*0*	*22*	*32*	*38*	*26*
		TOMA-KOURA	Toma-Koura	Toma-Koura	23	357	14	0	22	23	15
			Total	*1*	*23*	*357*	*14*	*0*	*22*	*23*	*15*
		TOUROUKORO	Touroukoro	Koinrébè	10	123	0	5	9	2	4
				Seribè	9	130	0	5	7	3	2
				Winrebè	8	99	0	6	6	3	2
			Total	*3*	*27*	*352*	*0*	*16*	*22*	*8*	*8*
	Total DI	**10**	**12**	**56**	**2207**	**22878**	**897**	**110**	**497**	**1727**	**1066**

SOUROU	LANFIÈRA	BISSAN	Bissan	Bankobekin	24	225	9	4	11	0	3
				Kamarakin	8	75	2	1	0	0	2
				Korabekin	15	171	2	2	11	0	3
				Zonobekin	20	181	6	2	9	0	5
			Total	*4*	*67*	*652*	*19*	*9*	*31*	*0*	*13*
		GOURAN	Gouran	Amdalaye	20	215	8	0	0	2	2
				Cité SATOM	12	46	11	0	0	9	11
				Kankan-Koura	56	412	18	0	0	39	2
				Loukônô	25	320	8	1	9	21	2
				Massakina	50	723	29	1	26	49	10
				Pérékina	34	449	13	1	18	32	5
				Yirabè	30	470	12	2	4	27	6
				Zorabè	26	294	6	2	13	20	4
			Total	*8*	*253*	*2929*	*105*	*7*	*70*	*199*	*42*
		GUIEDOUGOU	Guièdougou	Al-Hamdililaye	313	3193	161	0	31	259	91
				Bèrèkan	125	1709	90	0	22	109	45
				Dougoutiguikin	43	762	38	0	11	40	14
				Ouahigouyakin	66	1163	59	0	1	54	17
				Yinyinkin	145	1455	97	0	14	141	48
			Total	*5*	*692*	*8282*	*445*	*0*	*79*	*603*	*215*
		KOUMBARA	Koumbara	Dirabè	13	168	3	0	8	1	3
				Flakan	7	59	1	0	1	0	1
				Guissibara	16	162	3	0	3	0	6
				Kaibekin	2	22	0	0	0	0	0
				Kanabekin	4	45	1	0	1	0	1
				Koirebè	41	533	12	0	2	1	8
				Noumoukin	12	169	3	0	3	0	3
				Worobara	40	473	10	0	15	3	5
			Total	*8*	*135*	*1631*	*33*	*0*	*33*	*5*	*27*
		LANFIERA	Lanfièra	Doulekina	40	418	35	0	4	27	9
				Lanfièdara	52	566	38	0	1	31	13
			Total	*2*	*92*	*984*	*73*	*0*	*5*	*58*	*22*
		NION	Badala	Badala	9	138	7	0	4	9	0
			Total	*1*	*9*	*138*	*7*	*0*	*4*	*9*	*0*
			Nion	Bibiou	10	142	0	0	0	5	4
				Foulakin	9	88	0	0	0	0	1
				Goulabè	25	248	7	0	14	12	4
				Kalan	14	148	0	0	1	7	2
				Kéré	4	49	0	0	1	2	0
				Massabè	8	77	2	0	4	4	1
				Samogokin	1	20	0	0	0	0	0
				Tago	17	203	2	0	0	15	6
				Zoromekin	7	65	0	0	1	2	2
			Total	*9*	*95*	*1040*	*11*	*0*	*21*	*47*	*20*
			Watinoma	Watinoma	14	115	0	0	0	10	3
			Total	*1*	*14*	*115*	*0*	*0*	*0*	*10*	*3*
		OUERIN	Ouèrin	Boronkobè	31	308	0	19	17	12	23
				Massakanabè	15	184	0	11	11	8	10
				Yabè	6	63	0	3	2	4	2
			Total	*3*	*52*	*555*	*0*	*33*	*30*	*24*	*35*
			Ouèrin-Koura	Ouérin-Koura	10	125	1	2	2	9	3
			Total	*1*	*10*	*125*	*1*	*2*	*2*	*9*	*3*
		TOUMANI	Toumani	Darabè	16	152	7	0	8	0	2
				Foulakin	3	21	0	0	0	0	0
				Kambelemabè	13	101	5	0	7	2	1
				Korabè	8	82	7	0	1	0	4
				Tiénébè	9	102	8	0	2	0	2
			Total	*5*	*49*	*458*	*27*	*0*	*18*	*2*	*9*
		YARAN	Yaran	Dèrèbè	17	268	8	0	3	13	9
				Forobè	23	284	9	0	1	11	3
				Korabè	97	951	30	13	29	21	31
				Massanabè	23	285	3	1	3	15	5
				Sababè	35	357	6	2	4	19	8
			Total	*5*	*195*	*2145*	*56*	*16*	*40*	*79*	*56*
		YAYO	Yayo	Darabè	11	126	0	1	1	0	4
				Diarrabè	22	263	0	4	5	2	10
				Larabè	22	195	0	8	5	0	7
				Missirabè	20	169	0	10	8	0	8
				Simblabè	13	131	0	5	2	0	3
			Total	*5*	*88*	*884*	*0*	*28*	*21*	*2*	*32*
			Yayo-Koura	Yayo-Koura	6	40	0	0	3	0	1
			Total	*1*	*6*	*40*	*0*	*0*	*3*	*0*	*1*
	Total LANFIÈRA	10	14	58	1757	19978	777	95	357	1047	478
TOTAL SOUROU	2	20	26	114	3964	42856	1674	205	854	2774	1544
TOTAL AOI	5	30	37	153	4868	51540	1914	300	1310	3023	1822

Annex 2: AOI settlements connectivity matrix

	Badala	Bantombo	Benkadi	Bissan	Bossola	Bouna	Dabokitila	Débé	Di	Gouran	Guièdougou	Illa	Koubè	Koumbara	Kouri	Lanfièra	Lanfièra-Koura	Leri	Lô	Niassan	Nion	Oué	Ouèrin	Ouèrin-Koura	Sono	Soro	Toma	Toma-Île	Toma-Koura	Toumani	Touroukoro	Watinoma	Wèrimbèrè	Yaran	Yayo	Yayo-Koura	Zampana
Badala		21	38	7	32	50	4	30	41	24	22	39	33	13	9	21	9	7	34	33	3	48	26	26	7	6	35	38	38	4	30	4	26	20	14	17	7
Bantombo	21		22	16	15	35	24	14	25	12	10	20	14	15	26	11	12	27	19	17	21	32	8	11	16	21	19	20	22	18	11	24	6	7	8	11	17
Benkadi	38	22		31	7	12	42	8	4	14	16	9	12	26	45	17	29	42	4	5	37	11	14	12	36	41	3	4	0	34	11	41	16	18	25	21	37
Bissan	7	16	31		26	44	10	23	35	18	16	33	28	6	15	14	5	11	28	27	5	42	20	20	8	12	29	32	31	3	24	10	21	14	8	10	10
Bossola	32	15	7	26		19	36	3	10	9	11	8	7	21	39	12	23	37	5	3	31	17	7	6	29	35	4	6	7	29	4	36	9	12	19	16	30
Bouna	50	35	12	44	19		54	21	9	26	28	15	22	38	57	29	42	54	16	17	49	2	26	24	48	53	15	13	12	47	22	54	28	31	37	34	49
Dabokitila	4	24	42	10	36	54		34	45	28	26	43	34	16	7	25	13	6	38	37	6	52	30	30	9	6	39	42	42	8	34	1	30	24	18	21	9
Débé	30	14	8	23	3	21	34		12	6	8	11	10	18	37	9	21	34	5	4	29	19	6	3	27	33	6	8	8	26	6	33	9	10	17	13	29
Di	41	25	4	35	10	9	45	12		17	19	10	14	30	49	21	33	45	7	8	40	7	17	15	39	44	6	6	4	38	14	45	19	22	28	25	40
Gouran	24	12	14	18	9	26	28	6	17		2	17	14	13	32	4	16	29	10	9	23	24	6	3	23	28	11	14	14	21	9	28	10	5	12	8	24
Guièdougou	22	10	16	16	11	28	26	8	19	2		18	14	11	30	2	14	26	12	11	21	26	7	5	20	25	13	16	16	19	10	26	9	3	10	6	22
Illa	39	20	9	33	8	15	43	11	10	17	18		6	29	45	20	30	44	11	10	39	14	13	14	36	41	8	5	9	36	9	43	14	20	25	24	37
Koubè	33	14	12	28	7	22	34	10	14	14	14	6		25	39	16	24	39	12	10	34	20	8	10	30	35	10	9	12	31	5	37	8	15	20	19	30
Koumbara	13	15	26	6	21	38	16	18	30	13	11	29	25		21	9	8	16	22	22	11	37	16	15	14	18	24	27	26	9	20	16	18	10	7	5	15
Kouri	9	26	45	15	39	57	7	37	49	32	30	45	39	21		28	16	13	42	41	12	56	32	33	10	4	43	45	45	13	36	8	31	27	20	25	9
Lanfièra	21	11	17	14	12	29	25	9	21	4	2	20	16	9	28		13	25	13	13	20	28	9	6	19	24	15	18	17	17	12	24	11	4	9	4	21
Lanfièra-Koura	9	12	29	5	23	42	13	21	33	16	14	30	24	8	16	13		16	26	25	10	40	17	17	7	8	27	29	29	7	21	13	16	11	4	9	8
Leri	7	27	42	11	37	54	6	34	45	29	26	44	39	16	13	25	16		38	38	6	52	31	31	14	12	40	43	42	9	35	5	32	25	19	21	14
Lô	34	19	4	28	5	16	38	5	7	10	12	11	12	22	42	13	26	38		3	33	14	11	9	32	35	3	7	4	31	10	38	14	15	21	17	33
Niassan	33	17	5	27	3	17	37	4	8	9	11	10	10	22	41	13	25	38	3		32	15	9	7	31	36	2	5	5	30	7	37	12	14	20	17	32
Nion	3	21	37	5	31	49	6	29	40	23	21	39	34	11	12	20	10	6	33	32		47	26	25	9	10	34	37	37	3	30	5	26	19	14	16	10
Oué	48	32	11	42	17	2	52	19	7	24	26	14	20	37	56	28	40	52	14	15	47		24	22	46	51	13	12	11	45	21	52	26	29	35	32	47
Ouèrin	26	8	14	20	7	26	30	6	17	6	7	13	8	16	32	9	17	31	11	9	26	24		4	23	28	11	12	14	23	4	30	4	7	12	11	24
Ouèrin-Koura	26	11	12	20	6	24	30	3	15	3	5	14	10	15	33	6	17	31	9	7	25	22	4		24	29	9	12	12	23	6	30	7	6	13	10	25
Sono	7	16	36	8	29	48	9	27	39	23	20	36	30	14	10	19	7	14	32	31	9	46	23	24		5	33	35	36	7	26	9	22	18	11	16	1
Soro	6	21	41	12	35	53	6	33	44	28	25	41	35	18	4	24	8	12	37	36	10	51	28	29	5		38	40	41	9	32	7	27	23	16	21	4
Toma	35	19	3	29	4	15	39	6	6	11	13	8	10	24	43	15	27	40	3	2	34	13	11	9	33	38		4	3	32	8	39	14	16	22	19	34
Toma-Île	38	20	4	32	6	13	42	8	6	14	16	5	9	27	45	18	29	43	7	5	37	12	12	12	35	40	4		4	35	9	41	14	18	24	22	36
Toma-Koura	38	22	0	31	7	12	42	8	4	14	16	9	12	26	45	17	29	42	4	5	37	11	14	12	36	41	3	4		34	11	41	16	18	25	21	37
Toumani	4	18	34	3	29	47	8	26	38	21	19	36	31	9	13	17	7	9	31	30	3	45	23	23	7	9	32	35	34		27	7	23	16	11	13	8
Touroukoro	30	11	11	24	4	22	34	6	14	9	10	9	5	20	36	12	21	35	10	7	30	21	4	6	26	32	8	9	11	27		33	5	10	16	15	27
Watinoma	4	24	41	10	36	54	1	33	45	28	26	43	37	16	8	24	13	5	38	37	5	52	30	30	9	7	39	41	41	7	33		29	23	17	20	9
Wèrimbèrè	26	6	16	21	9	28	30	9	19	10	9	14	8	18	31	11	16	32	14	12	26	26	4	7	22	27	14	14	16	23	5	29		8	12	13	23
Yaran	20	7	18	14	12	31	24	10	22	5	3	20	15	10	27	4	11	25	15	14	19	29	7	6	18	23	16	18	18	16	10	23	8		7	5	19
Yayo	14	8	25	8	19	37	18	17	28	12	10	25	20	7	20	9	4	19	21	20	14	35	12	13	11	16	22	24	25	11	16	17	12	7		6	12
Yayo-Koura	17	11	21	10	16	34	21	13	25	8	6	24	19	5	25	4	9	21	17	17	16	32	11	10	16	21	19	22	21	13	15	20	13	5	6		17
Zampana	7	17	37	10	30	49	9	29	40	24	22	37	30	15	9	21	8	14	33	32	10	47	24	25	1	4	34	36	37	8	27	9	23	19	12	17	

Orange highlighted cells indicate nearest neighbor distances

Annex 3: Dominant type of transportation means per settlement

Settlement	Transportation means (%) per Settlement according to the Type																					Sum
	0	*1*	*2*	*3*	*4*	*5*	*12*	*13*	*14*	*15*	*23*	*24*	*25*	*123*	*124*	*125*	*126*	*142*	*145*	*1234*	*1245*	
Badala	0	0	0	0	0	0	44	0	0	0	0	0	0	0	56	0	0	0	0	0	0	100
Bantombo	5	33	2	0	0	0	2	0	35	0	0	0	0	0	21	0	0	2	0	0	0	100
Benkadi	0	7	2	0	0	0	4	0	48	0	0	0	0	0	35	0	0	0	0	0	4	100
Bissan	0	85	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Bossola	0	40	0	0	0	20	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	100
Bouna	0	10	2	0	0	0	0	0	31	0	0	0	0	0	48	0	0	4	0	2	4	100
Dabokitila	0	45	0	0	0	0	18	0	18	0	0	0	0	0	9	0	0	0	0	0	9	100
Débé	0	11	2	0	0	0	1	0	22	1	0	0	0	0	58	0	0	1	1	0	1	100
Di	1	50	2	0	0	0	8	0	19	0	0	0	0	0	18	0	0	0	0	0	0	100
Gouran	4	26	3	0	0	0	13	0	14	0	0	0	0	0	40	0	0	0	0	1	0	100
Guièdougou	0	19	1	0	0	0	6	0	28	0	0	0	0	0	45	0	0	0	0	1	0	100
Illa	4	35	2	0	0	0	2	0	23	4	0	0	0	0	19	0	0	0	2	0	9	100
Koubè	0	47	7	0	0	0	3	0	20	7	0	0	0	0	13	0	0	0	3	0	0	100
Koumbara	1	33	0	0	0	0	2	0	33	0	0	0	0	0	30	0	0	0	0	1	0	100
Kouri	3	58	1	0	0	0	9	0	14	0	0	0	0	0	15	0	0	0	0	0	0	100
Lanfièra	0	18	13	0	0	0	11	0	7	0	1	0	0	2	42	0	0	0	0	5	0	100
Lanfièra-Koura	0	57	0	0	0	0	0	0	14	0	0	0	0	0	29	0	0	0	0	0	0	100
Léri	1	86	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Lô	0	30	30	0	0	0	3	0	17	0	0	0	0	0	20	0	0	0	0	0	0	100
Niassan	1	30	4	1	0	0	7	0	23	0	0	0	0	0	32	0	0	0	0	0	0	100
Nion	0	84	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Oué	2	69	0	0	0	0	11	0	7	0	0	0	0	0	4	1	0	0	1	0	4	100
Ouèrin	2	2	0	0	0	2	0	0	0	54	0	0	2	0	0	17	0	0	2	0	19	100
Ouèrin-Koura	0	10	0	0	0	0	0	0	0	10	0	0	0	0	0	10	0	0	30	0	40	100
Sono	2	87	2	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Soro	3	47	0	0	0	0	23	0	17	0	0	0	0	0	10	0	0	0	0	0	0	100
Toma	0	33	0	0	0	0	0	0	17	6	0	0	0	0	17	0	0	0	0	0	28	100
Toma-Île	0	3	0	0	0	0	0	0	0	50	0	0	0	0	0	35	0	0	0	0	13	100
Toma-Koura	0	4	0	0	0	0	0	0	9	4	0	0	0	0	0	0	0	0	52	0	30	100
Toumani	4	71	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Touroukoro	0	0	0	0	0	4	0	0	0	41	0	0	0	0	19	26	0	0	4	0	7	100
Watinoma	0	93	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Winrèbèrè	0	45	0	0	5	0	15	0	5	0	0	0	0	0	30	0	0	0	0	0	0	100
Yaran	8	31	2	0	0	0	7	0	16	0	0	1	0	0	33	0	0	1	0	1	1	100
Yayo	5	9	0	0	0	2	10	0	0	38	0	0	0	1	0	34	0	0	0	0	1	100
Yayo-Koura	0	50	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Zampana	0	94	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
AOI	**2**	**39**	**2**	**0**	**0**	**0**	**8**	**0**	**17**	**2**	**0**	**0**	**0**	**0**	**26**	**1**	**0**	**0**	**1**	**0**	**1**	**100**

0: Not any; **1:** Bicycle; **2:** Motobike; **3:** Car; **4:** Cart; **5:** Canoe

Annex 4: Individual water contact characteristics sensed using a GPS

Details Data on sensed Human Activities									
GPS holders	*Average altitude (m)*	*Track length (m)*	*Activity duration (mn)*	*Average speed (mph)*	*Total Track points*	*% of break points*	*% of break time*	% of negative altitude	Place
Traditional fishing (TFP)									
1	250.56	4068	216	1140	432	32.41	32.41	0.00	Pond
2	256.45	2515	215	710	431	10.9	10.84	0.00	
3	261.26	1686	162	830	244	4.1	3.09	0.00	
4	262.81	1426	120	730	240	4.58	4.42	0.00	
5	245.73	2922	215.3	830	431	17.17	17.19	0.00	
6	255.81	1216	106.3	700	213	33.8	33.87	0.00	
Mean	**255.44**	**2305.5**	**172.43**	**823.33**	**331.83**	**17.16**	**16.97**	**0.00**	
Water lily bulbs gathering (WBG)									
1	260.77	105	146	50	292	59.93	59.79	0.00	Pond
2	260.15	139	149	60	298	52.35	52.35	0.00	
3	260.1	289	143.3	120	287	21.6	21.63	0.00	
4	261.26	1358	228	370	456	7.68	7.59	0.00	
5	259.36	148	231	40	462	69.91	69.83	0.00	
6	259.45	179	219	50	438	60.05	59.95	0.00	
7	260.51	251	222.3	70	445	47.87	47.82	0.00	
8	273.56	2862	285	610	570	4.21	4.21	0.00	
9	250.66	3015	276	660	552	26.81	26.81	0.00	
10	260.34	207	133.3	90	267	36.7	36.76	0.00	
11	252.3	2118	271	480	542	32.66	32.58	0.00	
12	260.71	1425	153.3	570	307	4.89	4.76	0.00	
Mean	**259.93**	**1008**	**205.27**	**264.17**	**409.67**	**35.39**	**35.34**	**0.00**	
Irrigated rice weeding (IRR)									
1	295.58	1353	148.3	550	297	1.35	1.35	0.00	Irrigated field
2	259.36	365	217	90	434	25.12	25.02	0.00	
3	258.67	385	222.3	90	445	18.2	18.13	0.00	
4	257.86	355	190	110	380	15.53	15.42	0.00	
5	280.19	1205	186.3	380	373	2.68	2.68	0.00	
6	260.08	274	173.3	90	347	22.77	22.68	0.00	
7	254.75	140	114.3	80	229	36.24	36.13	0.00	
8	297.32	1026	144.3	420	289	1.73	1.59	0.00	
9	259	287	160	110	320	20	20	0.00	
10	256.34	347	199.3	100	399	25.31	25.24	0.00	
11	260.11	198	174.3	70	349	34.1	34.02	0.00	
12	256.25	298	197	90	394	26.9	26.9	0.00	
Mean	**266.29**	**519.42**	**177.2**	**181.67**	**354.67**	**19.16**	**19.1**	**0.00**	
Laundry (CLW)									
1	260.84	719	162.39	0.274	325	47.38	47.44	0.00	River
2	260.11	553	155.39	0.222	312	50.00	50.22	0.00	
3	259.72	662	115.26	0.343	231	51.95	52.06	0.00	
Mean	**260.22**	**644.67**	**144.35**	**0.28**	**289.33**	**49.78**	**49.90**	0.00	
Children recreatinal swimming (CRS)									
1	125.89	507	31.38	973	64	73.44	74.25	4.69	River
2	112.14	404	50.58	476	102	71.57	71.77	3.92	River
3	229.85	616	39.08	948	79	0.00	0.00	0.00	River
4	70	435	31.14	822	63	57.14	55.94	17.46	River
5	187.09	775	37.05	1257	75	42.67	43.18	2.67	River
6	149.86	681	40.00	1032	80	51.25	50.75	5.00	River
7	45.36	546	32.34	986	66	71.21	72.05	37.88	River
8	240.08	475	64.36	449	130	3.08	3.11	0.77	River
9	252.25	536	60.36	532	122	22.13	7.17	0.82	River
10	217.23	1900	40.16	3991	1383	10.41	8.52	0.36	River
11	162.11	787	33.35	1820	1458	42.11	34.66	4.60	River
14	171.84	1059	23.15	3360	984	20.02	22.72	1.93	River
12	191.04	623	14.29	3600	482	9.54	7.63	6.02	Canal
13	179.29	77	18.14	320	510	75.88	61.03	0.00	Canal
Mean	**166.72**	**672.93**	**37.21**	**1469.01**	**399.86**	**39.32**	**36.63**	**6.15**	

CLW: Laundr; **CRS:** Children Recreational Swimming; **IRR:** IRRigated rice parcel weeding; **TFP:** Traditional Fishing in Ponds; **WBG:** Water lily Bulbs Gathering.

12. Curriculum Vitae

Personal details

Surname : Issouf

Fisrt name : Traoré

Date of Birth : 08-10-1975

Nationality : Burkina Faso

Marital status : Married

Schooling and Academic Education

- **Since 2010: PhD (Candidate),** Subject: Geography focus on Health, Institut of Geography, University of Göttingen, Germany

DAAD scholarship

- **2009: Master of Adanced Studies,** Subject: Wetlands Management, University of Ougadougou, Burkina Faso

INDEPTH fellowship

- **2004: Diploma,** Subject: Geography focus on Health, Univserty of Ouagadougou, Burkina Faso

Grant of “Schistosomose en Orbite”

- **2001: Bachelor,** Subject: Geography focus on Rural, University of Ouagdougou, Burkina Faso

- **1997: “Baccalaureat”** (High School Certificate), Secondary and high school of Nouna, Burkina Faso

- **1994: “BEPC”** (Secondary School Certificate), Secondary and high school of Nouna, Burkina Faso

Papers within the framework of this thesis

Published

Traoré I., Sié A., Coulibaly B., Yé M., Karthe D., Kappas M., (2012), "Rapid screening and mapping of urinary schistosomiasis prevalence at the village scale in the Sourou Valley, Burkina Faso: Adapting the school-base questionnaire method", in M. Kappas, U. Groß, D. Kelleher, (eds.) Global Health. A Challenge for Interdisciplinary Research; Universitätverlage Göttingen, p. 255-281.

Abstract accepted

Traoré I., Sié A. Kappas M. "Geographic Determinants of Access to health care: Application to schistosomiasis in the Sourou Valley, Burkina Faso", Social Science & Medicine (Elsevier), ISSN: 0277-9536, Impact factor: 2011: 2.699 (Thomson Reuters Journal Citation Reports 2012).

Conferences within the framework of this thesis

Oral communications

Traoré I.; Sié A.; Karthe D.; Kappas M., (2011), "Geographic Determinants of Human Schistosomiasis Transmission in the Sourou Valley, Burkina Faso: Influence of air temperature on human water contact patterns in Toma-Île", Annual Conference of German Hydrology Circle, Magdeburg (Germany): 17th – 19th November 2011.

Traoré I.; Sié A.; Karthe D.; Kappas M., (2011), "Access to water as a key geographic determinant of schistosomiasis transmission in the Sourou Valley, Burkina Faso", Practice of Research in Geography of Health, Berlin (Germany): 24th – 25th November 2011:

Traoré I.; Sié A.; Karthe D.; Kappas M., (2012), "Clean Water Issues in an Irrigated Agriculture Village: Guièdougou in the Sourou Valley, Burkina Faso", Goettingen International Health Network (GIHN) workshop: *"Cross-Cutting Agriculture and Health",* May 19th - 24th 2012 in Accra – Ghana.

Traoré I.; Sié A.; Kappas M., (2012), "Peasant logic of Space-sanitation as a Determinant of Environmental Contamination in the Transmission of Human Schistosomiasis in the Sourou Valley, Rural Burkina Faso", 2nd Health and Space International Colloquium: "Health and Space", September 19th – 21st 2012 in Marseille – France.

Traoré I.; Sié A.; Kappas M., (2012), "To Couple GPS and GIS for Sensing Human Water Activities and Determining Schistosomiasis Exposure Risk in the Sourou Valley, Rural Burkina Faso", 9th International Conference of the African Association of Remote Sensing and the Environment (AARSE): "Earth Observation & Geo-information Sciences for Environment and Development in Africa: Global Vision and Local Action Synergy", October, 29th - November 2nd 2012 in El Jadida – Morocco (Accepted but we could not participate).

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Traoré I.; Sié A.; Kappas M., (2013), "How does the Couple Climate & Environment Impact on Children Vulnerability to Schistosomiasis in Time and Space in the Sourou Valley, Burkina Faso?" The African Climate Conference 2013, Arusha (Tanzania): 15th – 18th 2013: (abstract submitted).

Poster

Traoré I., Sié A., Kappas M, (2011), "Water supply and human schistosomiasis-susceptible area: Mapping communities at risk through their water access levels, Sourou Valley, north-west Burkina Faso", Annual Conference of German Hydrology Circle, Magdeburg (Germany): 17th – 19th November 2011.

Papers not in the framework of this thesis

Karthe D., **Traoré I.**, Sié A., Kappas M., (2012), "Malaria in Kossi Province, Burkina Faso: An inverstigation of spatio-temporal incidence pattern", in: M. Kappas, U. Gross, D. Kelleher, (eds), Global Health. A Challenge for Inter-disciplinary Research. Universitätsverlag Göttingen. p. 305-320. 2012

Karthe D., **Traoré I.**, Reeh T., Ouédraog F.C. & Pörtge K.-H, (2011), „Das Bewässerungsprojekt im Sourou-Tal/Burkina Faso – eine nachhaltige Maßnahme zur Ernährungssicherung?" Zentralblatt für Geologie und Paläontologie - Teil 1.

Traoré I., Ouédraogo F.C., Yé M., Sié A. & Karthe D, (2011), « Distribution spatiale de la mortalité palustre dans le district sanitaire de Nouna, au Nord-Ouest du Burkina Faso », Journal Africain des Sciences de l'Environnement vol.1. nr.1, p.27–49.

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Yé Y., Hoshen M., Louis V., Simboro S., **Traoré I.**, Sauerborn R., (2006), "Housing conditions and Plasmodium falciparum infection: Protective effect of iron sheet roof", Malaria Journal, 5: 8.

Conference not in the framework of this thesis

Traoré I., Ouédraogo F.C., Yé M., Sié A., Karthe D., (2012), « Distribution spatiale de la mortalite palustre dans le district sanitaire de nouna, au nord-ouest du burkina faso », 16èmes Journées des Sciences de la Santé « Santé et Mutations Environnementales dans les Pays en Développement », Bobo-Dioulasso (Burkina Faso): du 07-11 mai 2012.

NB: Award-winning of the 1st prize of the best communication

According to the scientific journal PLoS, each paper devoted to research and control of NTD, and to increase their awareness is denominated (Hotez, 2009):

"A New Voice for the Poor".