Building a Decision Support System for Agricultural Land Use Planning and Sustainable Management at the District Level in Vietnam

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ABBREVIATIONS

AEZ	Agro-Ecological Zones
ARIS	Agricultural and Rural Information System
DSS	Decision Support System
ER	Entity Relationship
FAO	Food and Agriculture Organization
GSO	General Statistics Office
ILWIS	Integrated Land and Water Information System
IMGLP	Interactive Multiple Goals Linear Programming
IRRI	International Rice Research Institute
LMU	Land Mapping Unit
LUP	Land Use Planning
LUP/LA	Land Use Planning/Land Allocation
LUPAS	Land Use Planning and Analysis System
MARD	Ministry of Agriculture and Rural Development
MCDM	Multi-Criteria Decision Making
MCE	Multi-Criteria Evaluation
MoNRE	Ministry of Nature Resource and Environment
MOLP	Multi Objective Linear Programming
NIAPP	National Institute of Agricultural Planning and Projection
NISF	National Institute for Soils and Fertilizers
SDSS	Spatial Decision Support System
SEMLA	Strengthening Environmental Management and Land Administration
SFDP	Social Forestry Development Project
SQL	Structured Query Language

ABSTRACT

This research aims at developing a decision support system (DSS) to improve the decision-making capacity of administrators as well as other interested parties. The system will help develop their skills in land use planning and strategic management for agricultural resources to arrive at better decisions. The DSS will provide useful tools to improve policies on land use planning and implementation of other rural development and land resource management programs.

An agricultural database for Geographic Information System (GIS) and DSS in land use planning was built on the results from evaluating the suitability of major potential land use alternatives in the studied area. Informatics and mathematical modeling techniques are used in processing data, determining the optimal solution and providing information for the decision-making support. In determining the optimal solution for land use, mathematical modeling has been a widely used method and considered an important tool to quantify social-environmental indicators and criteria. However, most models using this method are single goal optimization ones which can increase economic efficiency but cannot simultaneously deal with other problems of land use, for example, social or environmental impacts. Thus, this research applies the latest model of multiple goal optimizations known as the Multi Objective Linear Programming (MOLP) Model to build up a systematic and coherent scheme of planting crops, which deals with other land use problems mentioned above.

This research is a multidisciplinary study which involves collecting data of crop production, analyzing and processing GIS data, designing databases for information system, and investigating multi-objective linear programming and group decision making models to achieve the consensus of experts and consultants to reach collective decisions. As a result, a DDS for agricultural land use planning was designed with the following functions: (i) System administration, (ii) Showing mapping data (iii) Database management (iv) Solution to the MOLP model and (v) Group decision making based on experts' opinions. The designed DDS is hoped to be a reference model for further application of information technology in land use planning towards sustainable development in the regional and global contexts.

CHAPTER 1

INTRODUCTION

1.1 Background to the Research

The Geographic Information System (GIS) was first introduced in the 1960s to meet the needs of state management in some developed countries such as the United States and Canada. At present, GIS applications are quite numerous in many aspects of planning and management as well as scientific research in almost all sectors. With the wide application and rapid development of information technology, technical GIS today has developed very rapidly and diversified.

GIS can provide a wealth of contextual information such as aerial photographs as part of the visualization which greatly aids the interpretation of the output from the planning tools. It is also possible via GIS interface to interrogate subcomponents of the allocation to query or override allocations (Keith, 2001).

It is evident to see how much information technology has contributed to global socio-economic development, especially in the field of agricultural development. Nevertheless, the use of information technology in agriculture poses a lot of problems to decision makers in both developed and developing countries since environmental protection must be included in planning and making policies towards sustainable development. Accordingly, consequences of agricultural land misuse such as issues of soil degradation should be dealt with an ecological approach in which we have to consider the impacts of natural elements such as climate, topography, soil, water and other natural resources in the local context with its concrete socio-economic conditions.

Scientists from the Netherlands and the International Rice Research Institute (IRRI) have succeeded in constructing and developing the software on Land Use Planning and Analysis System (LUPAS) with Multiple Goal Linear Programming Model (Van Ittersum et al., 2004.)

Effective land use has to not only achieve high productivity of crops but also conserve an ecologically balanced environment and maintain the fertility of soil. Thus, for each region and each specific area, we must study to find suitable land use types as well as proper crop rotation to obtain the highest yields.

Utilizing land's potential in a highly efficient way is very important and necessary to ensure the development of agricultural production as well as the economic development of each country. To figure out a rational method of utilizing land, we first need to study and evaluate factors affecting the efficiency of land use in each specific region.

Evaluating the effectiveness of land use by crop yield or in terms of economic aspect has been commonly discussed and studied by many scientists around the world in order to find out solutions to boosting agriculture and forestry. However, evaluating the effectiveness of land use in a more comprehensive, integrated, and ecology-oriented method as well as the conservation of fertile soil in order to determine the structure of plants and proper cultivation formulas for each locality is still an open issue. Therefore, developing a supporting tool for land management and evaluating other options for land use planning so as to ensure effective land use towards sustainability and environmental protection urgently requires a solution.

To find the optimal plan for land use, mathematical modeling method has been used widely and is considered an important tool to quantify social-environmental indicators and criteria, analysis and evaluation of land use planning solutions. However, most models are optimal in one goal, which only solves the requirement about the economic efficiency, but does not solve the other targets of the above-mentioned land use problem. Thus applying the latest achievements of the optimal model for multi-targets it is necessary, allowing the construction of suitable crop rotation in accordance with the overall targets.

Land use planning in Vietnam has been conducted but still insufficient for many years. In rural areas, it has been predominantly relying on assessing the suitability of soil for agricultural production. Besides, the planning has extensively incorporated statistics.

The current rapid economic growth of Vietnam during its economic transition has increased the pressure on land and water resources which leads to a necessity to adjust the approach to land use planning (LUP) in order to support the economic growth of the country, align its approach with globalization trends, and provide a framework to manage the development in a sustainable manner. This situation necessitates a change of land use planning from a ***static*** and descriptive approach to a ***dynamic***, analytical and strategic one. There is also a need to have a closer alignment between socio-economic development plans, the overall environmental strategy and the land use plans.

Besides taking environmental, socio-economic parameters into consideration, land use planning must involve different stakeholders who are affected by changes in land use. In fact, human resource in LUP and management in local areas has been weak in many aspects such as the number of personnel staffs and human capacity. Therefore, it is necessary to have a tool to support policy makers and planners in developing, appraising, and selecting planning scenarios, which collaborates different social, economic, and environmental development dimensions in order to gain sustainable development goals.

To address this problem, a Decision Support System (DSS) has been developed that interface with LUP tools. The research evaluates the options for representing the LUP problem within a DSS framework and explores the potential of applying DSS to multi-objective LUP.

1.2 Objectives of the Research

The overall objective is to develop a DSS for LUP and management and agricultural production in Vietnam. This system can integrate GIS data on Land Use Type and the data on the cultivation, cost, profit with calculation modules, experts' opinion and mapping to reach a rational decision of land use planning for agricultural production, adapt to the goal of sustainable agricultural development.

The aim of this research is also to further study the process of calculations to find optimization plans with Multiple Goal Linear Programming problem and group decision-making for processing expert's evaluation.

The specific objectives are:

- To analyze and evaluate land suitability of land use types in agricultural production and propose suitable land use types towards sustainable development.
- To assess the existing framework of land use planning and land information system of the region.
- To develop a method using experts' knowledge as a component of the DSS in regions with lack of data information in land use planning and management.
- To build a Decision Support System based model for upgrading capability in making decision of administrators at district level.

1.3 Methodology

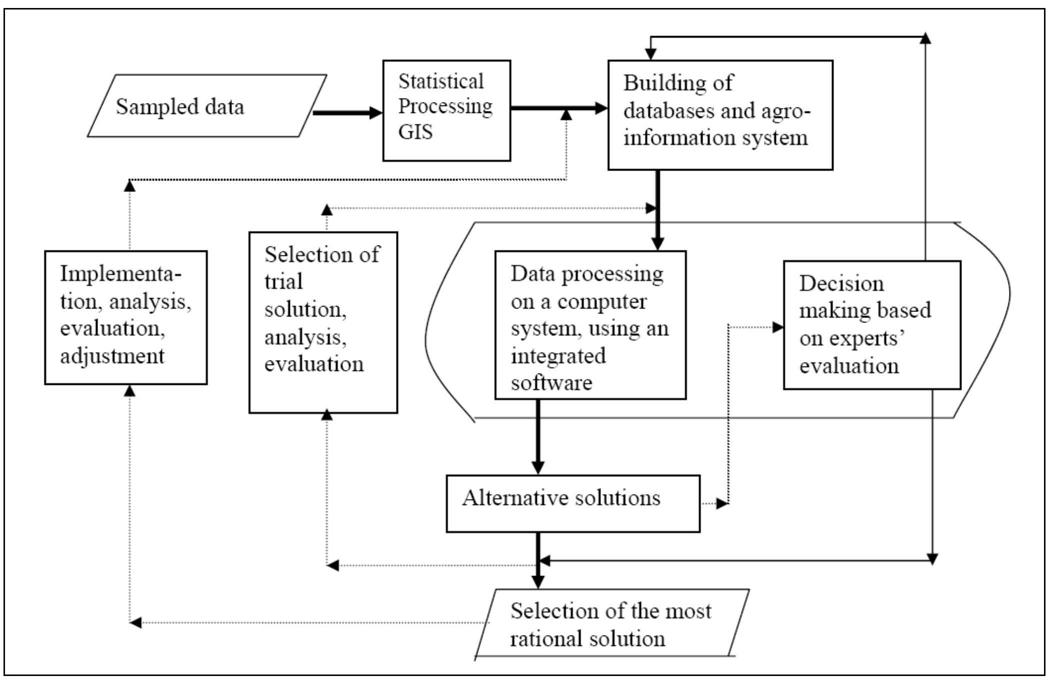
Informatics and mathematical modeling techniques were used in processing data, determining the optimal solutions and providing information to develop a DSS.

This research used land classification and land utilization types guided by the FAO framework for land evaluation to determine land suitability in studied areas. Based on the results of land suitability, an approach to improve land use can be proposed for land use planning with a focus on sustainable development and environmental protection.

The research then applied GIS techniques with a multi-criteria approach for analyzing land suitability for main crops in Tam Nong district. The data were also obtained through secondary data sources, results from interviews with farmers and personnel staffs. In doing so, it can be said that the suitability assessment in the studied area has been done on the ground of socio-economic and environmental suitability evaluation.

The above mentioned databases continued to be processed with DSS software to formulate alternative solutions which shall be consulted with experts' opinions to select the most rational one (Adapted from Thanh 2005). Based on the result, an approach to improve land use planning can be proposed with a focus on sustainable development and environmental protection

The research work on building Decision Support System can be described in the simplified diagram as follows:



1.4 Scope of the Research

The research only focuses on developing Decision Support System for land use planning and management at district level because planning at district level (from 1:25.000 to 1: 50.000) plays a key role in the system of land use planning in Vietnam, which lies between the overall planning at regional level (from 1:50.000 to 1:100.000 or more) and the detailed planning at local commune level (from 1: 5000 to 1:10.000).

The study also concerns agricultural land which has a direct influence on land use planning in Vietnam. In the research, Tam Nong was chosen as the studied area because Tam Nong is a region which characterizes Vietnam's agricultural features with diverse topography, varied kinds of plants and land use types. The total land area being studied in Tam Nong district is 11,273 ha, accounting for 72.37% of the total area of natural land. Other areas such as non-agricultural land and mountainous area without forest trees were not taken into consideration.

1.5 Structure of the Research

This thesis consists of seven chapters. **Chapter 1** introduces the research topic, the objectives of the study along with the background to the research. The following chapters will further develop the conceptual framework for this work with the aim at building a DSS system for Land Use Planning and Management.

Chapter 2 presents the conceptual framework of land use planning used by FAO as well as key steps in the FAO approaches. The second chapter then provides an overview of GIS, DSS and Multi-Criteria approach in LUP, followed by a review on application of Information Technology in this field and the situation of LUP in Vietnam.

Chapter 3 describes and analyzes selected methods to build the Soil Map and evaluate potential Land Suitability. Modeling the agricultural Land Use Planning process is realized with data for building standardized agriculture database at the district level and analysis on algorithms for the optimization model of determining the crop rotation for DSS program.

Chapter 4 examines country background and its natural conditions and resources. The chapter also analyzes socio-economic conditions, current status of land use, land management and agricultural production in the research area.

Chapter 5 presents an analysis and assessment on land mapping and land suitability evaluation in Tam Nong to build database for DSS program.

Chapter 6 focuses on analyzing system, designing database for building the DSS program, modeling problems of Land Use Planning, and designing a Delphi Algorithm to support decision making in order to select the optimal solution for LUP.

Finally in **Chapter 7**, the results of the study and main conclusions are discussed together with recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 The Conceptual Framework of Land Use Planning

2.1.1 Definition of Land Use Planning

The FAO Guidelines for Land Use Planning (FAO, 1993) defined land use planning as:

> *´´The systematic assessment of physical, social, and economical factors in such a way as to assist and encourage land users to select the land use options that increase the productivity, is sustainable and meets the needs of society''.*

Land use planning (LUP) is a systematic and iterative procedure carried out in order to create an enabling environment for sustainable development of land resources, which meets the needs, and demands of the people. It assesses the physical, socio-economic, institutional and legal potentials and constraints with respect to an optimal and sustainable use of land resources and empowers people to make decisions about how to allocate these resources (FAO, 1999).

LUP involves the selection of land use alternatives based on land evaluation (LE). LE is a physical land assessment involving matching land requirements with the land qualities to assess land suitability. Guidelines for LE have been set up for different land use types (FAO, 1991) but Anaman & Krishnamra (1994) consider some of these guidelines having a top-down approach. In the current trend in land use/ resource planning, emphasis is being put on the need for the active involvement and participation of stakeholders particularly the local level in decisions on land use and management (FAO, 1999). The argument is that LUP should be a mechanism of decision support for formulating policies, laying strategies and helping land users to reduce the current problems of land use rather than a technical evaluation procedure. Some methods and tools to improve LE for LUP have been suggested by Bronsveld *et al.* (1994) including the involvement of land users in the planning process, use of more flexible data processing methods, and better procedures for selecting and describing land use types.

Effective planning and management of land resources requires timely and accurate information on the different aspects of land such as the different land use systems, their suitability, sustainability, potential, and the consequences of implementing each one of them depending on the level/scale of planning. LUP is generally applied at three interactive levels: national, regional and local (FAO, 1993), where different priorities, planning strategies and decisions are made. At the national level, general land use planning policies, priorities and legislation are set. At the lower levels, the plans become more detailed such as putting in place water sources and infrastructure. Interaction, information flow and data sharing between the planning levels are important.

It results in broad consensus that stakeholders should be involved in research supporting sustainable development, since the interpretation of sustainability in terms of natural resource use systems managed by people is ambiguous, and hence its inclusion in research is not value-free (Parker et al., 2002)

2.1.2 FAO Approach to Land Use Planning

In the thesis we use certain terminologies drawn from FAO's guidelines on land evaluation. These definitions are synthesized and updated from those in FAO (1976; 1983; 1984; 1985) land evaluation can be defined as the process of predicting the use potential of land on the basis of its attributes. Although land evaluation provides the technical coefficients necessary for optimal land allocation, it does not include optimal land allocation.

2.1.2.1 Planning at Different Levels

FAO's Guidelines for Land-use Planning stating three different levels at which LUP can be applied are national, district and local. These different levels of LUP are relevant to "*the levels of government at which decisions about land use are taken*" (FAO, 1993). Each level of LUP also uses different map scales. Namely,

(i) *National-level land-use planning* is applied to planning at national government level which deals with the country's land, water or other resources as a whole. Small map scales are used. In large countries, planning of the major administrative divisions has some of the characteristics of national-level planning.

(ii) *District-level land-use planning* is a level of land-use planning between the national and local levels, typically but not necessarily that of the administrative district. Intermediate *map scales* such as 1:10000 to 1:50.000 are used. Land-use development projects are often at the district level.

(iii) *Local-level land-use planning* is a level of land-use planning based on a village or other local community. Large *map scales* are used, such as 1:10000. This level is also referred to as village level land-use planning.

The two-way links between the three levels of planning are shown in Figure 2.1. It is also noted that the degree of detail and the direct participation of the local people should increase at each successive level of planning. The framework of the thesis focuses on the district level through which decisions on national land-use priorities are translated into local plans. At this stage, a number of conflicts between national and local interests must be resolved (FAO, 1993) as follows:

- The setting of developments such as new settlements, forest plantations and irrigation schemes.
- The need for improved infrastructure such as water supply, roads and marketing facilities.
- The development of management guidelines for improved kinds of land use on each type of land.

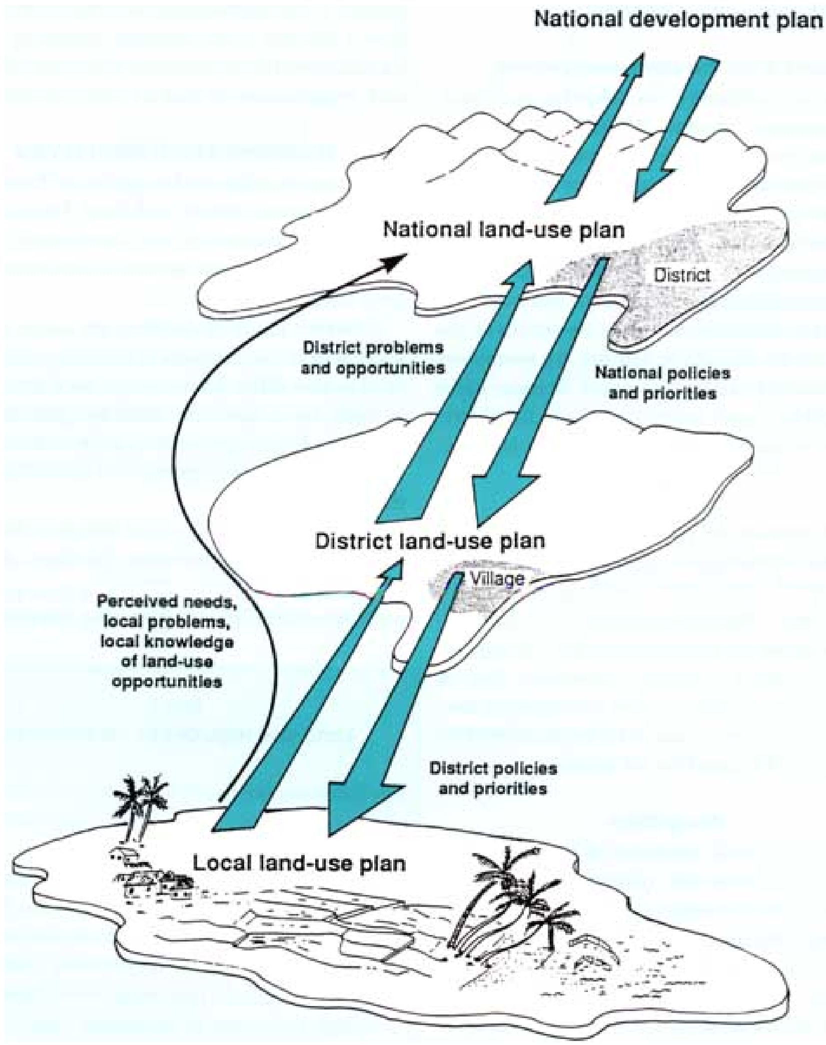


Fig. 2.1 *Two-way links between planning at different levels. Source: FAO, 1993*

2.1.2.2 People in planning

Concerning people in planning, it is necessary to clarify three groups of people directly involved in LUP (Fig. 2.2)

(i) ***Land users*** are "the people living in the planning area whose livelihood depends wholly or partly on the land" (FAO, 1993), for example, farmers, herders, foresters, and others who use the land directly as well as those who depend on these people's products such as operators in crop or meat processing, sawmills and furniture factories, or staffs in national parks. Land users play an important role in planning since they not only provide labor, capital and management (as well as produce goods and services) but also they implement the plan on the ground.

FAO also suggested that planners should involve the participation of local people in planning by providing them opportunities to contribute opinions and ideas through local discussions, mass media, and workshops. Public participation is the key factor leading to the success of any plans because local people will better involve in implementing plans in which they can help planning rather than are imposed to do so.

(ii) ***Decision-makers*** are "those responsible for land-use policy, action and allocation of resources" (FAO, 1993). They are either government ministers at national and district levels or members of the council or other authorities at the local level. After the planning team provides information and present plans, the decision-makers decide whether to implement plans and instruct planners based on key issues and goals. In addition, the decision-makers should regularly supervise planning activities, publicize their decisions and be open to public scrutiny.

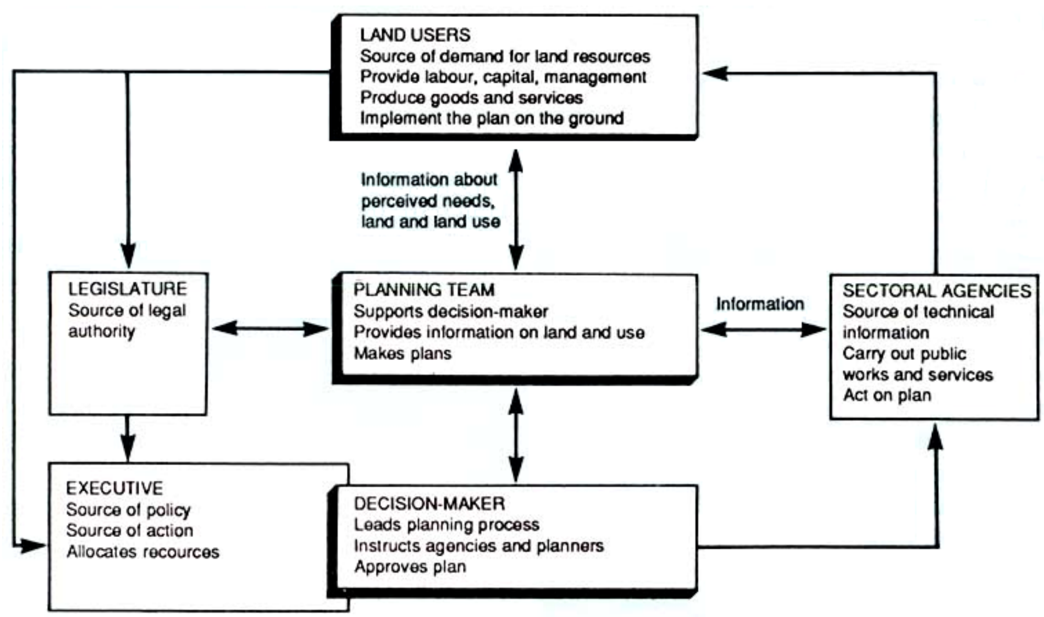


Fig. 2.2 *People in planning (FAO, 1993)*

(iii) ***The planning team or planners*** are those "responsible for the preparation of a land-use plan, working in close cooperation with the **land users** and the **decision-makers**" (FAO, 1993). In order to support decision-makers and provide sufficient information, a planning team usually consists of a wide range of experts such as a soil surveyor, a land evaluation specialist, an agronomist, a forester, a range and livestock specialist, an engineer, an economist and a sociologist because land-use planning requires expertise in multiple disciplines like natural resource, engineering, agricultural and social sciences. At smaller scales or local level, a land-use planner and one or two assistants are needed but each must take responsibilities for various tasks. In this case, the planning team needs specialist advice from government agencies and universities.

2.1.2.3 Need for Land Use Model to Guide Planning

Another important issue is the selection of a necessary tool for land use analysis that generates natural resource management options so that policy changes are guided and the scope of agricultural systems is assessed beyond the constraints of current policies.

The LUP procedure in the FAO guidelines (1993) contains ten steps which can be described as in Fig. 2.3

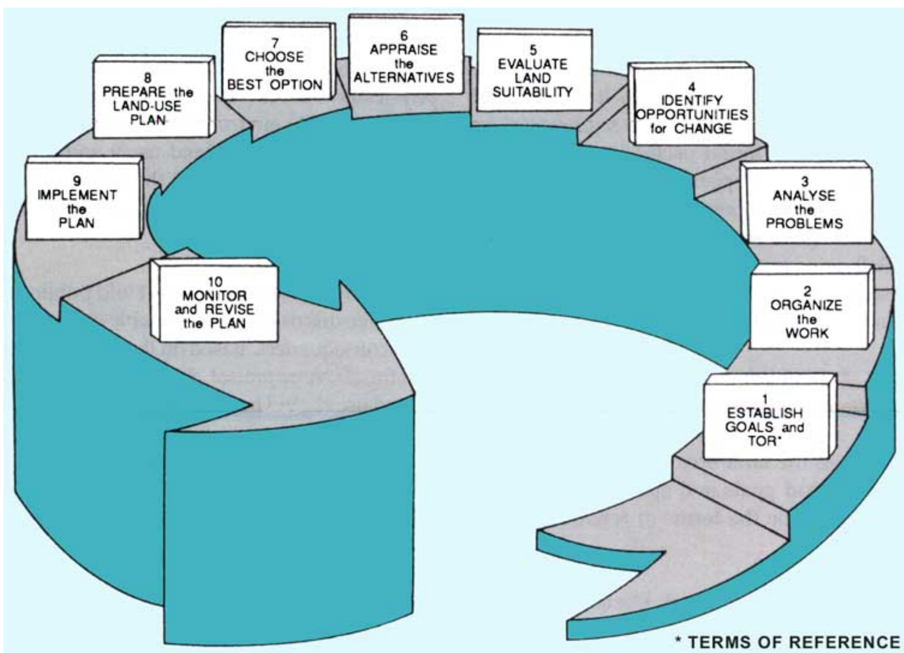


Fig. 2.3 *Steps in land-use planning FAO 1993*

With regard to the relation between LE and LUP, the principle of following FAO (1981) is applied. In fact, LE as part of LUP was originally defined as the assessment of the suitability of land for human use in agriculture, forestry or for other purposes (Van Diepen et al., 1991).

2.1.2.4 Land Suitability Classification

The process of land suitability classification is the appraisal and grouping of specific land interims of their suitability for defined uses. Suitability can be scored based on factor rating or the degree of limitation of land use requirements when matched with the land qualities. In other words, land suitability evaluation is a comparison and matching of land utilization type requirements with land unit's characteristics. Land suitability classes reflect degrees of suitability. Land suitability assessment was founded in 1976 by FAO and afterwards, many researches have worked and are being working in land suitability evaluation for land utilization types (LUT) in different countries (FAO, 1984).

According to land evaluation by FAO (1984), the suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses. There are four categories recognized for land suitability classification:

a) Land Suitability Orders: reflecting kinds of suitability, indicating whether given types of land are suitable or not suitable, for the land utilization type concerned. Therefore, we use S for Suitable and N for Not suitable in assessing the land use.

b) Land Suitability Classes: reflecting degrees of suitability within suitable orders, three classes are normally recognized: Highly Suitable, Moderately Suitable and Marginally Suitable, indicated by symbols S1, S2 and S3 respectively. The classes are defined as follows:

- S1 (Highly Suitable): Land having no significant limitations to sustained application of a given land utilization type, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.

- S2 (Moderately Suitable): Land having limitations which in aggregate are moderately severe for a sustained application of a given land utilization type. The limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use will be appreciably inferior to that expected on class S1 land.

- S3 (Marginally Suitable): Land having limitations which in aggregate are severe for sustained application of a given land utilization type and will so reduce productivity or benefits, or increase required inputs, that this expenditure will only be marginally justified.

- N1 (Currently Not Suitable): Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost. The limitations are so severe as to preclude successful sustained application of the given land utilization type.

- N2 (Permanently Not Suitable): Land having limitations which appear as severe as to recluse any possibilities of successful sustained application of a given land utilization type.

c) Land Suitability Sub-classes: Subclasses reflect kinds of limitations or required improvements measures within classes.

d) Land Suitability Units: indicating differences in required management within subclasses.

Quantitative definition of these classes is normally unnecessary, since by definition both are uneconomic for the given use. The upper limit of Class N1 is already defined by the lower limit of the roast suitable class in Order S.

The boundary of class N2, Permanently Not Suitable, is normally physical and permanent. In contrast, the boundary between the two orders, Suitable and Not Suitable is likely to be variable over time through changes in the economic and social context.

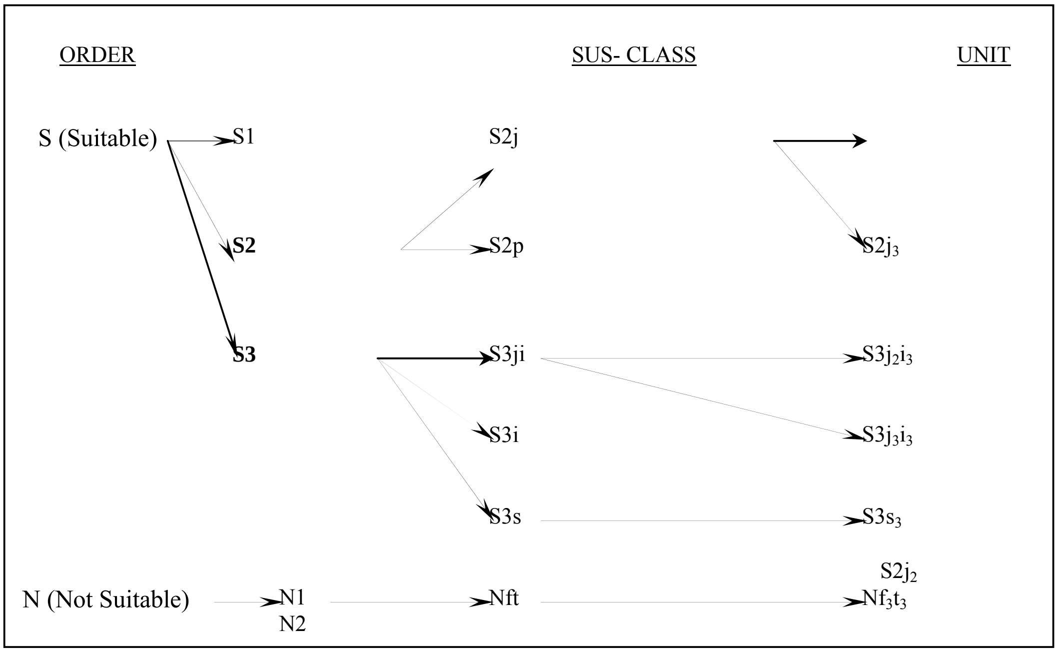


Fig. 2.4 *Structure of the Suitability Classification (FAO, 1984).*

Land Use Sustainability Assessment

In order to be meaningful, planning for the resources should be sustainable i.e. the land use option(s) selected for implementation should meet the needs of the present without compromising the ability of the future generations to meet their needs. After the spatial analysis of the suitability of the potential land use options in the previous section, this section looked at a thematic assessment of the sustainability of these options. Selected social and economic indicators of land use sustainability were combined into a Multi-Criteria Evaluation (MCE) by a Decision Support System to obtain a ranking of the alternatives based on their performance in the evaluation criteria. DSS is a management information system that supports decision makers such as planners, analysts, managers in the decision making process (Sharifi, 2001). They enable the decision maker to explore the problem environment by provision of data and models appropriate to the decision and also generate and evaluate alternative solutions.

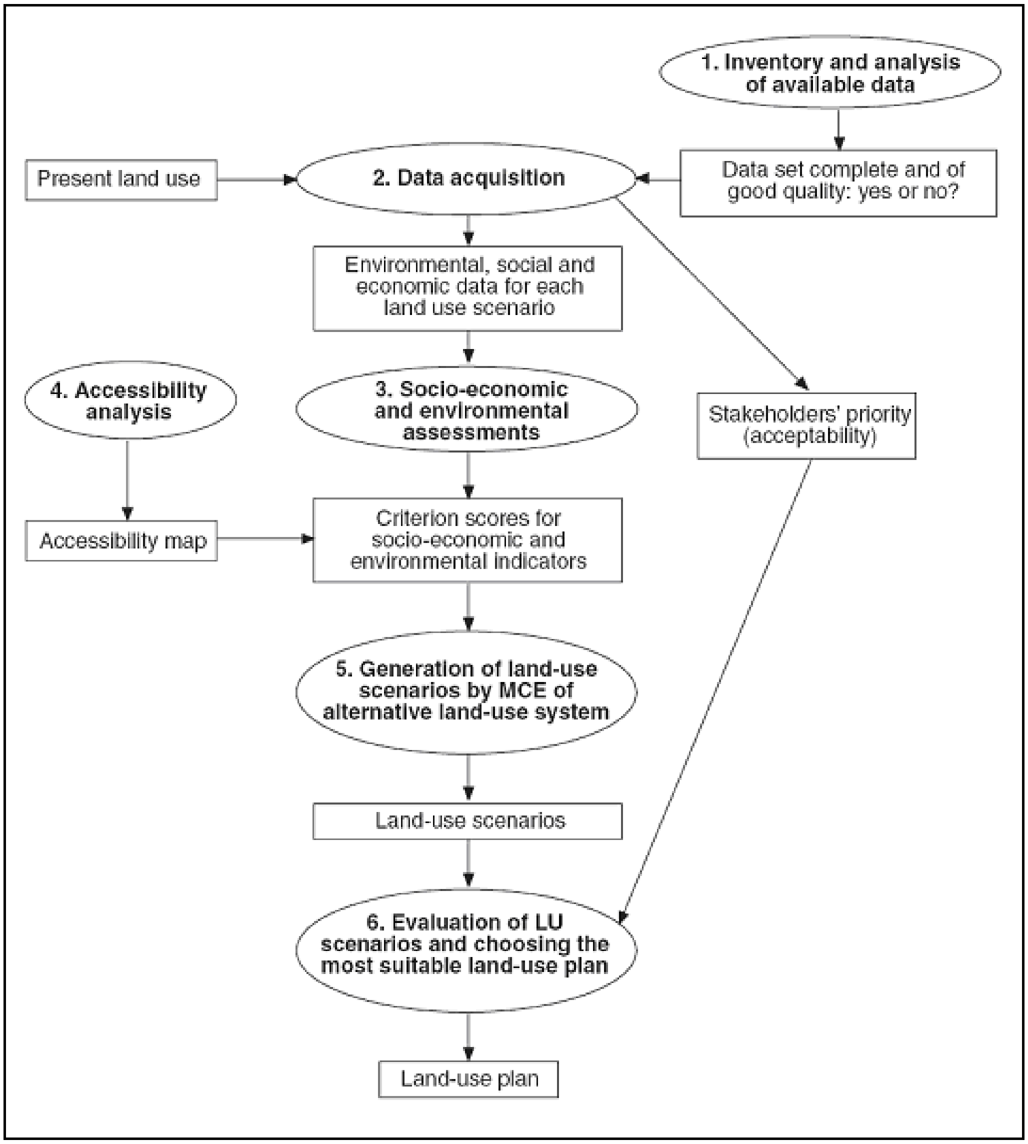


Fig. 2.5 *Integrating the FAO approach with MCE (adapted from Kempen, 2004)*

2.2 GIS and Decision Making in Planning

2.2.1 Overview of Geographic Information System (GIS)

A GIS also known as a geographical information system or geospatial information system is any system being used to store and process data referenced to the Earth's surface (Molenaar, 1998). These data contain both thematic and geometric (spatial) information which can be represented in raster or vector form. Huxbold (1991), Masser and Blackmore (1991) affirmed that "the thematic aspects of a terrain description are of prime importance" which means that "the data querying and processing will be organized and formulated primarily from a thematic perspective" whereas "the structuring and formulation of the geometric aspects of the data will be secondary" (as cited in Molenaar, 1998, p.4). In other words, the geometric problem formulation will depend on that of the thematic problem.

There are two principal structures for linking thematic and geometric data. The first structure is the field approach. In the field approach, terrain objects are represented in the form of attributes, the values of which depend on the position and the thematic information is directly linked to geometric data. In the terrain feature oriented or terrain object structured approach, terrain objects can be defined with a location or position, a shape and several geometric characteristics. The link between thematic and geometric data is an indirect one in the second structure because both data are linked to the object identifier.

2.2.2 GIS and Decision-Making in Planning

GIS is widely used in local and regional planning for managing, integrating, and visualizing spatial data sets. However, beyond basic levels of decision support, GIS remains largely external artifacts to the decision-making process. This suggests that despite increased analytic sophistication, most GIS software is more suited to providing limited outputs than as a tool for decision support. To improve the usefulness of GIS as a decision support tool, two needs should apparently be met. First, decision makers require methods that allow them easily to select alternatives most closely aligned with their priorities across a number of relevant criteria. Second, it is necessary to recognize explicitly that most decision-making processes involve multiple participants. (Robert D. Feick et. al., 1999)

Since problem solving is often characterized by multiple and conflicting objectives, methods that contribute toward consensus building are required. Feick and Hall (1999) described a Spatial Decision Support System (SDSS) that satisfies these needs through a tight-coupling of GIS functionality and Multiple Criteria Analysis (MCA) techniques. The potential benefits of adopting this approach and future extensions to the prototype are discussed in light of a land use-planning example.

The FAO Guidelines for Land-use Planning (FAO, 1993) defined **land-use planning** as: "*land-use planning is the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land-use options. Its purpose is to select and put into practice those land uses that will best meet the needs of the people while safeguarding resources for the future. The driving force in planning is the need for change, the need for improved management or the need for a quite different pattern of land use dictated by changing circumstances".*

Much of the use of GIS in planning assumes use of a rational mode of decision-making which entails a linear process initiated with the identification of a problem, followed by a comprehensive search for alternatives and concluded with the selection of the optimal alternative as indicated by the gathered information (Batty, 1993). This process is typically characterized by recursive feedback loops in the decision process where evaluation and selection criteria are refined and steps repeated as a result of refinements. However, these loops are generally non-systematic and informal. Under bounded rationality, uncertainties and resource constraints in the decision environment cause decision makers to adopt a satisfying mode of behavior such that the search for solutions concludes once an option which meets or exceeds their context-specific aspiration levels (Malczewski and Ogryczak, 1996).

Data Quality and Control

According to Longley P.A, et al., (1999), data quality can be differentiated in space, time and theme, of which several components of quality include accuracy, precision, consistence and completeness. Data and information have quality when they meet the needs and expectations of its users (Hawryszkiewycz, I.T 1998).

Good decision-making for resource planning in a research area requires good quality information. Data quality assessment in the proposed system will be undertaken in a process called "Data output and quality control" and is intended to improve the current data's quality. The assessment involves accuracy testing. In the process of land use mapping, the responsible staff selects a sample of point locations and compares the land use classes assigned to these locations by the classification procedure, with the classes observed on source at these locations.

Timeliness, reliability, consistence, correctness, completeness and the way of presentation of output products will be some of the indicators for the correctness of the procedures of data processing. These will be verified by getting feed back from the data/ information users in the region on their satisfaction regarding those aspects (Nabwire 2002).

2.3. Decision Support Systems

2.3.1 Overview of Decision Support Systems (DSS)

The history of DSS probably dated back to the late 1950s and early 1960s with studies on organizational decision making at the Carnegie Institute of Technology by Herbert Simon and Allen Newell and interactive computer systems at the Massachusetts Institute of Technology by Tom Gerrity (Power, 1999). Then Scott Morton in the early 1970s first expressed concepts involved in DSS under the term management decision system which was devised by Gorry and Scott Morton in 1971. Accordingly, the term 'DSS' was defined as an interactive computer based system that helps decision makers to utilize data and models to solve semi structured or unstructured problems (Gorry & Scott Morton, 1971).

Sprague and Watson (1986) defined DSS as a system that makes some contribution to decision making while Stuth and Lyons (1993) explained the term as contemporary jargon for an integrated approach to the age-old problem of helping people to make better decisions. Makowski (1994) proposed that DSS are computerized tools to analyze large amounts of data and complex relations for making rational decisions. Klosterman (1997) explains the term 'DSS' as a system or methodology that assists poorly or ill-structured decisions by facilitating interactive and participatory decision processes. Although the DSS developed significantly in the following decades, no single definition is widely accepted (Claire, 1997).

A DSS can be defined as an interactive computer-based system designed to support a decision-maker in a complex environment (Morton 1978). SDSS are different from the ordinary DSS in that they integrate GIS and model base management system capabilities. The common feature of GIS systems is their focus on the capture, storage, manipulation, analysis, and display of geographically referenced data (Jacek Malczewski, 2000**)**.

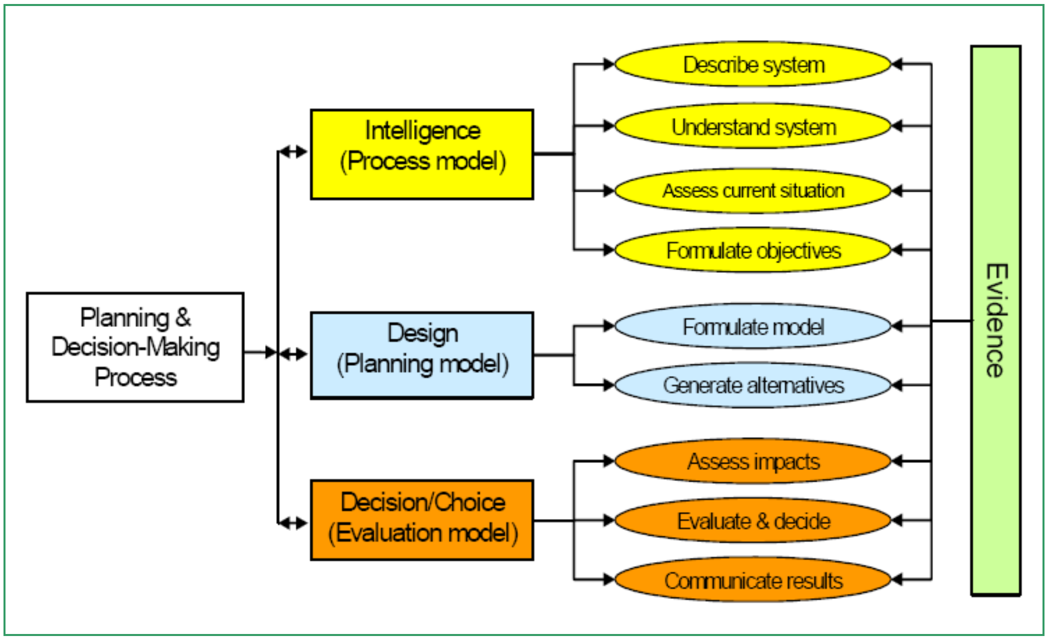


Fig. 2.6 *Planning and decision-making processes explained by Sharifi and Rodriguez (2002) based on Simon's model (1960)*

Jozefowska has developed a DSS for short-term production planning and scheduling. The system has two phases: In the first phase a rule-based expert system is used to reduce the space of feasible solutions in two ways. On one hand soft constraints are introduced in form of production rules. On the other hand, the expert experience can be used to formulate rules eliminating solutions, which are very likely to be dominated by other solutions. In the second phase, a multiple criteria genetic algorithm is applied to find a set of potentially Pareto-optimal solutions (Jozefowska et al. 2008).

2.3.2 Integrating GIS with the DSS.

Most of the agricultural data have geographic attributes while GIS is an important tool for agricultural analysis, so it is very important to include GIS into the DSS for regional agricultural management. Nevertheless, it does not mean that the system should be developed on professional GIS. The pure second-time development capacity of professional GIS makes it difficult to develop attractive interfaces for users. Besides, the difficulty of operating attribute data with professional GIS is not helpful in meeting the various demands of users. Considering the demand of the management and the improvement of the function of various GIS components, GIS components will be a good choice (Yongzheng, 2002).

The geographic information system provides all the biophysical information for the DSS; this includes climate, soils and topographic data and information on the farm infrastructure.

Understanding the relationship between planning theory and methods and geospatial technologies is crucial for building and implementing tools that are suitable to planning practice. Esnard and MacDougall (1997) maintained that there is a common ground for integrating planning theory and GIS in data creation, analysis, and presentation. They suggest this integration as part of an educational experience. Guhathakurta (1999) also found that urban modeling and decision support tools could be developed to serve the practice and to link to its theoretical underpinnings. The author referred to a new form of rationality that encompasses both positivist and interpretative epistemology and promised to provide a framework for the development of planning technologies and tools (Batty, 1993).

According to Basnet C. et al. (2006), any DSS needs to conform to the hierarchical nature of decision making. According to the research, compared to lower level decisions, the top level decisions are made with a longer planning horizon and the amount of detail is lesser at the higher echelons of decision making. As decisions are made further down the hierarchy, the lower level decisions are subservient to the higher level decisions.

2.4 Multi-Criteria Decision Making Approach

2.4.1 Overview of Multi-Criteria Decision Making

Selene M. (1982) and Pitel (1990) defined Multi-Criteria Decision Making (MCDM) as methodology chosen to assess countermeasure suitability within the SDSS. MCDM is a well-known branch of decision making techniques that logically structure and evaluate problems with multiple attributes and objectives.

Multi-objective planning, where one decision maker seeks, within a single plan, to achieve more than one objective, is dominated, in a land-use context, by methods collectively known as multi-criteria decision making or MCDM (El-Swaify & Yakowitz, 1998). MCDM recognizes that there are often multiple, convicting criteria underlying a land-use decision.

These connecting criteria are brought together using a variety of methods to derive a single recommended alternative, a reduced set of acceptable alternatives or a ranking of all possible alternatives (Jankowski, 1995).

2.4.2 Existing MCDM Approaches to Land-Use Planning.

Kheirkhah Zarkesh (2005) pointed out two classes of MCDM approach that may be usefully distinguished into compensatory and non-compensatory. Compensatory approaches are methods where high performance for one criterion may be traded-against poorer performance for another. These methods require the decision maker to identify the relative importance of criteria using weighting schemes. Non-compensatory approaches are order-based methods where alternatives are compared using single criterion in an order defined by the decision maker.

2.4.3 MCDM Applications in Land Use Planning

Land use planning applications of MCDM have typically been found in site selection and regional scale zoning problems. For site selection, the goal is to use the MCDM to provide a ranking of sites from which the decision maker may choose (Carver 1991). For land-use zoning applications the output from the MCDM analysis is one or more land-use suitability maps, with MCDM scores mapped as a grid for the area of interest (Eastman, Weigen, Kyem & Toledano, 1995), (Beedasy & Whyatt, 1999). While the suitability map(s) may be sufficient for some applications, the creation of an indicative land-use plan may need to take into account adjacency constraints or the desire to allocate zones with fixed minimum sizes. The process of arriving at a final allocation based on the suitability derived by MCDM may itself be a complex process of optimization. MCDM provides a useful method to support decision making where there are many factors and is helpful in structuring the decision making process. It is open to question how well the decision makers can define the relative importance of more than eight criteria, though consistency checking techniques are available.

Weights and orderings used in MCDM may be refined as part of the process and visualization of the results as maps signicantly aids the decision maker in this regard (Kheirkhah Zarkesh, 2005).

2.5 Application of the Technology in LUP and Management

2.5.1 The Role of Information Technology

To identify potential benefits and problems, land-use planners require sufficient information about the interaction of economic and ecosystem properties. Although much of this information is available in various forms, all of it must be in an integrated system to help in prioritizing and planning. Continuous improvements in the power and convenience of computer-based GIS are making an important contribution to LUP. Information from satellite imagery, as well as wider availability of satellite imagery, is essential for planning sustainable land use at all spatial scales (Michael Huston, 1997).

Land-use planners also need computer models for extrapolating information from areas that are well understood to those about which little information is available. Models of hydrology and soil erosion that are based on fundamental principles can be widely applied: planners can insert basic information on topography, soil properties, and vegetative cover, much of which can be obtained from satellite imagery (O'Loughlin, 1986; O'Loughlin et al. 1989; Beven and Moore, 1993). Similarly, planners can use models of crop growth (Keulen and Wolf, 1986; Wolf *et al*., 1991) to estimate crop production under different soil and climatic conditions and to extrapolate data from experimental plots to larger regions.

2.5.2 Computers and Software Programs Applied to Land Use Planning

Computers and software programs have been applied to land evaluation at different levels of detail. The first implementation of the FAO Framework was the land evaluation computer system (LECS) in Indonesia (Wood & Dent, 1983). This has recently been incorporated into the FAO's Agricultural Planning Toolkit (APT). A map-unit based, expert-systems approach is the ALES framework (Rossiter & Van

Wambeke, 1995). ALES has been used to implement several provincial, country, and regional land evaluations (Johnson & Cramb, 1991); (Mantel, 1994) and (van Lanen & Wopereis, 1992). Another computer program is Micro LEIS (De la Rosa *et al.*, 1992) for land evaluations in Mediterranean climates. Land evaluation by map analysis techniques may be accomplished with any geographical information system (Burrough, 1986; 1987). Conceptual design and component integration of Micro LEIS DSS land evaluation decision support system are shown in Fig. 2.7:

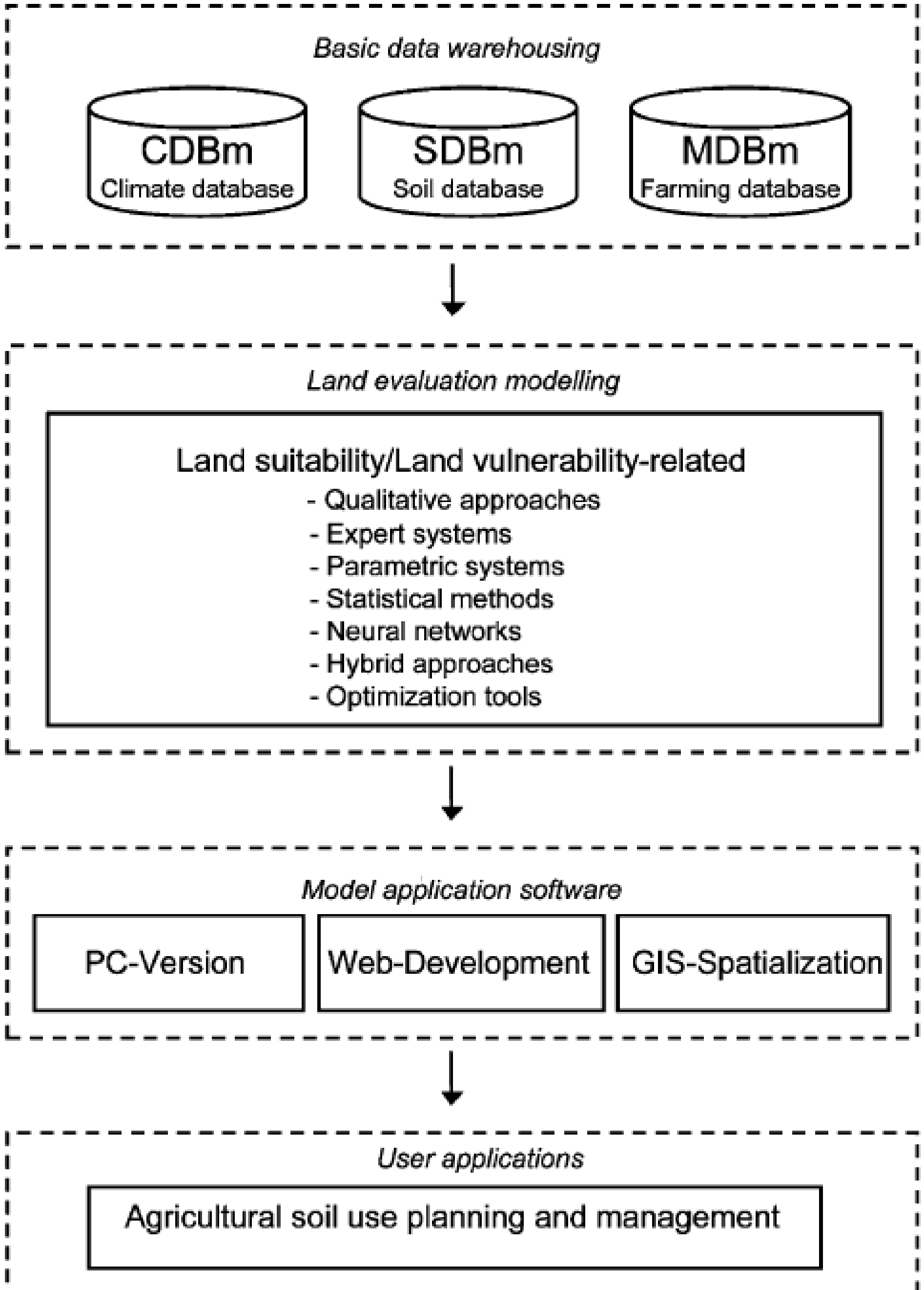


Fig. 2.7 *Conceptual designs and component integration of the current status of Micro LEIS DSS land evaluation decision support system. De la Rosa, D., F. Mayol, et al. (2004)*

The Land Use Planning and Analysis System (LUPAS) has three main methodology components: (i) land evaluation; (ii) scenario construction based on policy views; and (iii) multiple goal linear programming (MGLP) model (Hoanh *et al*., 1998).

The components of LUPAS are described in the following figure:

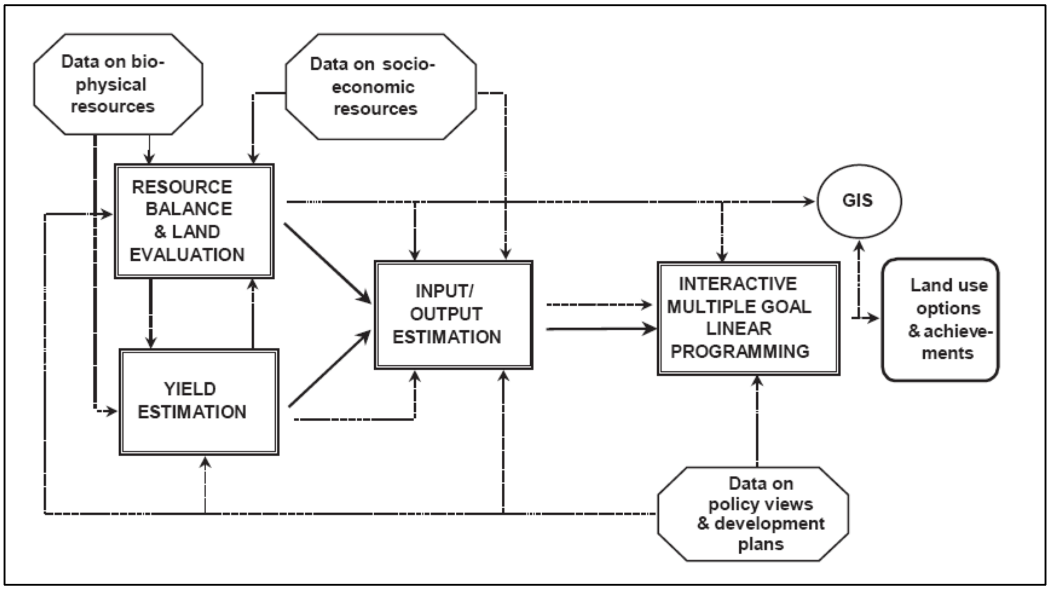


Fig. 2.8 *Components of LUPAS (van Ittersum, Roetter et al. 2004)*

LUPAS is used as a model to determine the amount of conflicting objectives or strategies developed by regional planning as well as offering solutions to land use in the most optimal conditions resources. LUPAS was built by Rice Research Institute World (IRRI) for specific areas of tropical East Asia. (Section 2.5.4 will further analyze LUPAS applied in LUP in Tropical Asia)

2.5.3 Application of GIS analysis and MCE in Land Use Planning

Decisions on a Finite call as DEFINITE (set of alternatives with multiple objectives develop by Institute for Environmental Studies Vrije Universiteit – Amsterdam) is a decision support software package that has been developed to improve the quality of environmental decision making. Types of methods are incorporated in DEFINITE including Toolbox of methods:

- Graphical methods to support representation,
- Methods for weight assessment,

- Multi-criteria methods,

- Cost-benefit analysis,

- Graphical evaluation methods,

- Methods for sensitivity analysis on the results of MCA and CBA.

Nabwire (2002) focused on the need to assess the suitability and sustainability of the potential land use alternatives in the region. Land use suitability and sustainability assessment is undertaken in the corresponding process of the proposed system. GIS Integrated Land and Water Information System (ILWIS) and Decision Support System (DSS- DEFINITE) software were used for the evaluation. The figure below is a schematic representation of how this was approached.

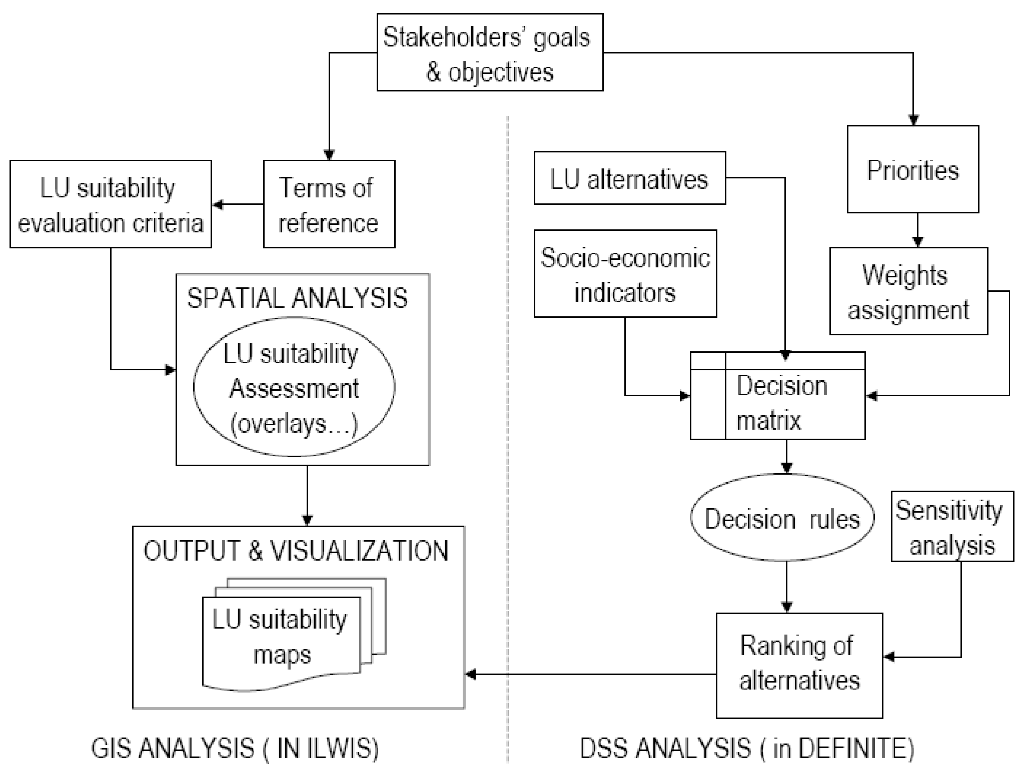


Fig. 2.9 *Schematic summaries of steps taken in land use suitability and sustainability assessment (Nabwire 2002)*

In data modeling, Nabwire designed Entity Relationship (ER) database modeling which was adapted for the proposed GIS database. The relational database tables allow both integration and updating of data, thereby increasing its quality and its use for resource/land use planning. With the data inserted into the various tables, queries can be performed using the Structured Query Language (SQL) to show how the various aspects of land resources relate, e.g., to assess relationships among biophysical, and socio-economic data in the region. However, ***Entity Relationship Diagrams too complicated*** with data were presented in form of tables corresponding to entities such as Agro-Ecological Zones (AEZ), constituency, farmer/land user.

2.5.4 Land Use Planning and Analysis System for Tropical Asia

In collaboration with `Systems Research Network for Eco-regional Land Use Planning in Support of Natural Resource Management in Tropical Asia' (SysNet), a user-friendly computer model called Land Use Planning and Analysis System (LUPAS) has been developed, assessed and tested in a localized regional setting. It was based on an exploratory land use study approach, and employed the Interactive Multiple Goals Linear Programming (IMGLP) optimization model. The following inputs such as objective functions, land units, land evaluation, resource balance (land, water and labor), promising land use types and production technology, agricultural inputs and outputs, and market demand for agricultural products are employed in the model. The model used optimization software with links to a spreadsheet where input data are retrieved and the results of optimizations are saved. It is also linked to GIS databases for spatial display of the results. Using user-friendly interface, the SysNet also had been built using a local web server to provide easy running of the model and retrieval of the results. The output is in the form of tables, charts and maps. The prototype also offers facilities for comparing results between model runs (MARDI, 2001). The table 2.1 shows characterization of LUPAS components and techniques applied in provincial land use scenario analysis.

Table 2.1 LUPAS components and techniques applied in provincial land use scenario analysis

Component	Main functions	Tools and techniques
Resource balance and land evaluation	To identify land units and their characteristics based on agro-ecological units and administrative units.	Overlay technique in GIS
	To estimate available resources (land, water, labour) for production-oriented land use (agriculture, fisheries, and production forestry).	Statistical analysis for population and labour projection Referring to policy reports and sectoral development plans Balance between supply of resources and demands for other than production-oriented land use (settlements, infrastructure, industry) GIS to identify resources available for agricultural land use in each land unit
	To identify promising land use types and possible technology levels applied in each land unit.	Statistical analysis of experimental and farm survey data; literature review, comparison by transfer and experimental research Consultation with national and international experts, including stakeholders and farmers Qualitative land evaluation including crop simulation modelling
	To formulate objective functions for various land use scenarios.	Referring to policy reports and sectoral development plans Consultation with stakeholders
	To identify demand for products (type and amount) and potential changes.	Projection of local demand Statistical analysis of market potential
Yield estimation	To estimate actual, potential and future attainable yield of main products and by-products from promising land use types at well-defined technology levels in each land unit.	Crop modelling, including complex models and simple parametric models Statistical analysis of farming survey data; consultation with national and international experts (including local farmers); interpolation or aggregation of environmental variables by GIS
	To estimate side-effects, in particular environmental impact promising land use types in each land unit.	Thematic modelling (as soil erosion model, methane emission model; leaching models) and links to GIS: statistical analysis of experimental and survey data Consultation with national and international experts
	To analyse spatial and temporal variations of yield and side-effects	GIS and statistical analysis
Input/output estimation	To estimate input-output relations for the various production activities.	Crop modelling Statistical analysis of experimental and survey data Using technical coefficient generators Expert judgement
	To estimate variations of input-output values due in dependence of selected land use options	Expert judgement Analysis of elasticities of supply and demand (not formalized in SysNet case studies) Multi-temporal analysis (not formalized)
	To analyse spatial and temporal variations of input-output	GIS and statistical analysis
Multiple goal linear programming	To generate land use options for each scenario by optimizing selected objective functions under explicit goal constraints.	Linear programming using commercial software packages
	To identify and analysis conflicts in land use objectives and land resources	Scenario analysis by using interactive multiple goal linear programming (IMGLP) technique
	To identify the effects of government policy	Sensitivity analysis of government policy parameters
	To analyse the risks associated with selected land use options	Statistical analysis of relevant factors of physical and economic environment Sensitivity analysis in IMGLP of relevant factors
	To analyse spatial and temporal distribution of resources to land use types	GIS and statistical analysis

The SysNet methodology aims at exploring alternatives for agricultural land use and development to assist strategic planning. In an interactive process with stakeholders, SysNet methods and tools are then tailored to local conditions. The aim of analyzing various scenarios is to finally come up with a feasible plan for agricultural production and associated land use for a given region. The four study regions of SysNet include: Haryana State, India; Kedah-Perlis Region, Malaysia; Ilocos Norte Province, Philippines; and Cantho Province, Vietnam (Roetter et al., 1998).

R. Roetter (1998) started that views within the SysNet methodology development can be observed from two different perspectives. It is a component of the methodology development itself and as input to the optimization model. From another perspective, the output from the exercise is also in some form of policy views - it provides sets of different options that are supposed to suggest policy changes to be considered by the stakeholders in relationship to their development goals and the available resources. In a situation where the policy views are very strong comprehensive, and formulated with the involvement of major stakeholders at the macro-planning level, as is the case in Malaysia, the policy views could be in the form of quantification of resource use and expected outputs. Hence, if these views are considered in totality, fully expressed in the form of objective functions and constraints, the primary goal of the methodology development itself, that is a tool for exploring land use options by opening up 'windows of opportunities', might not be fully realized. It is thus important that critical analysis is done on all possible policy views to ensure that a limited set of current views are not 'binding' the final outputs from the analysis, so that more future-oriented scenarios can be developed to support the decision-making process among the various stakeholders.

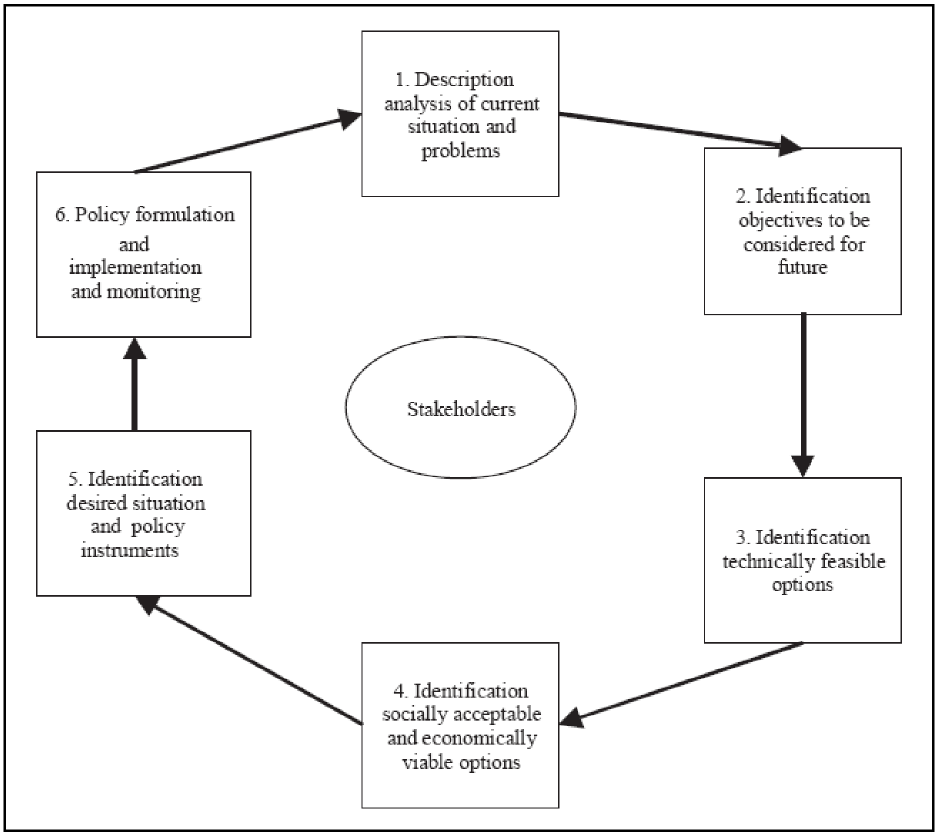


Fig. 2.10 *Development cycle of policies for natural resource management*
Van Ittersum, Roetter et al. (2004) ,Rauscher (1999)

2.6 Situation in Vietnam

2.6.1 Land Management System in Vietnam

Vietnam has a total land area of over 33 million hectares stretching along Latitude 15" (Northern Latitude 8'23"). It is situated in the northern hemisphere within the tropical zone. The country comprises of various terrain types and three-quarters of the land mass is mountainous.

The red-yellow soil which is suitable for agriculture and forestry comprises 50% of the total land area. Alluvial soils suitable for paddy and cash crop cultivation comprise only 9 per cent of the total area.

Vietnam is a country which has a large population but a small land area. The country ranks 15^{th} in the world in terms of largest population but 160^{th} in terms of average land area per capita. It also experiences one of the highest rates of population growth. From the beginning of this century, the world‘s population increased 3.8 times, but Vietnam’s population increased 5.8 times. Therefore, the pressure of population growth on land resources is becoming more critical every year.

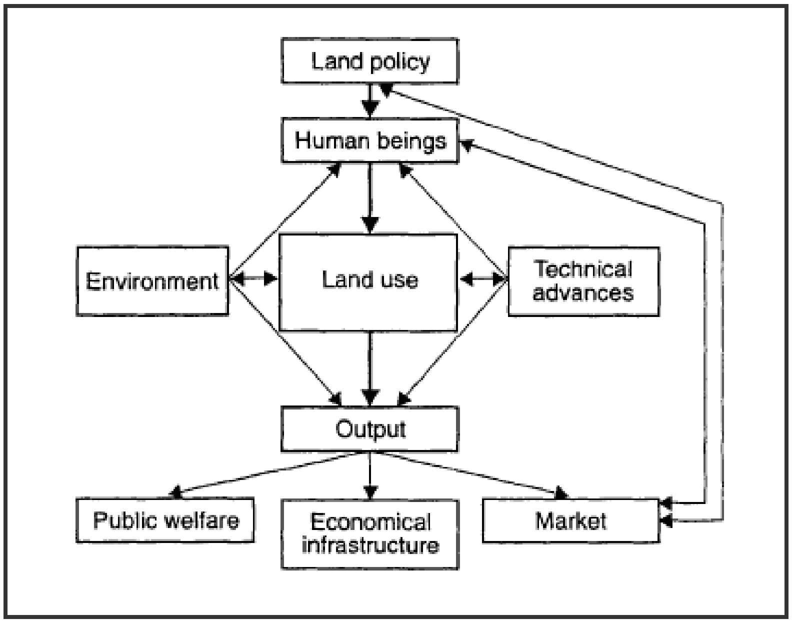


Fig. 2.11 *Key factors influencing LUP in Vietnam (Country Profile, 1993)*

The future of LUP strategies will have to consider the current distribution of the population which is heavily skewed towards particular areas. At present, the difference in density of population between the most populated and least populated areas is about 17 times. Therefore, future land use plans may have to seriously consider redistribution and resettlement of the population covering the entire country, not just selected areas. The following figure shows the key factors which influence LUP in Vietnam (SEMLA, 2005).

The situation of LUP in Vietnam has been assessed on a number of occasions throughout the past decade. The Strengthening Environmental Management and Land Administration in Vietnam (SEMLA) program has since 2005 supported the Ministry of Nature Resource and Environment (MoNRE) in improving land use planning, both at policy level and in the field (Jonas Novén, 2008). A thorough review of the LUP framework was done early in the program and the main issues identified were:

• Poorly integrated planning (with other sectors)

• Poor quality baseline data/mapping

• Complex instructions which are easily ignored (circular 30 and technical guidelines)

• Weakness of planning expertise (lack of capacity)

• Inflexibility of plans (difficult to change)

• Lack of unified LUP strategy

• Conflicting values and interests

• Weak environmental planning

• Lack of community consultation

Integration of land and environment has an objective scientific basis coming from a close relation between land and environment. Land is both a factor of environment (together with other factors such as water, air, etc) and an input factor of many processes of production; activities which are closely related to environment and can cause damages to environment (SEMLA, 2007).

2.6.2 Land Use Planning in Vietnam

In Vietnam, the planning system basically follows the same system as before when the government interfered arbitrarily in the production and distribution process (Quang, 2003; Rock, 2004). All "planning" is viewed as a top-down process of implementing the planned investment of state resources, rather than a means of guiding and controlling private development or investment for the public interest (Lawrie, 2000) .

Moreover, research studies on LUP only propose solutions without taking much consideration on the root causes of the problems while the state budget for research funding is rather limited.

Bringing LUP in line with local demands for socio-economic development and natural conditions is one of the first measures to ensure sound management and sustainable use of natural resources, as well as improvement of people's living standard. Land use rights need to be granted on a long-term basis to farmers to facilitate investments in production. LUP/Land Allocation (LUP/LA) which responds to people's wishes and local development trends provides an important basis for the implementation of regional economic development plans. (Tariful Islam et. al, 2007).

Social Forestry Development Project (SFDP) has implemented a participatory LUP/LA methodology in Son La and Lai Chau provinces with a view to achieve the following objectives:

- Direct and full participation of people in the whole process of LUP/LA.

- Feasibility within locally available financial, human and technical resources at district and communal levels.

- Acceleration of the LUP/LA process in an efficient and sustainable manner by applying PRA techniques (Wehr, 2003).

Table 2.2*: Overview of objectives and contents of each level regarding LUP/LA*

Planning Level	Implementing Offices	Responsibilities
Province	LUP/LA Provincial Steering Committee, headed by Deputy Chairman of Provincial People's Committee (PPC)	Advise PPC on land use policies; develop landuse plans and organize implementation; provide training for district level; appoint working group
	Department of Land Administration (DLA)	Administrative execution of cadastral mapping, land registration, issuing of land use certificates, allocation of agricultural areas
	Forest Protection Sub-Department (FPSD	Responsible for allocation and management of forest land
	Department of Agriculture and Rural Development (DARD)	Cooperation
	Department of Finance	Financial responsibilities
District	LUP/LA District Steering Committee headed by Vice Chairman of District People's Committee (DPC)	Assist DPC to implement landuse policies; develop district LUP/LA plans; guide/monitor/ facilitate LUP/LA implementation; Co-ordination; appoint working group; clarify admin. boundaries; resolve boundary disputes
	Agriculture and Cadastral Unit (ACO)	Co-ordination Mapping, land registration, issuing of land use certificates, allocation of agricultural areas
	Forest Protection Unit	Responsible for allocation and management of forest land
	Justice Section	Policy dissemination, legal supervision
	Planning Section	Cooperation between sectors
	Finance Section	Financial responsibilities, budget allocation
Commune	**Commune Land Registration and Allocation Council**, headed by Chairman of Commune People's Committee (CPC) Incl. Communal Cadastral Staff, Commune Forest Protection Staff, Accounting Staff, Agriculture Extension Staff, village heads, Youth Union, Farmer Union, Women Union, Fatherland Front	
	Communal Working Group District/Commune Forest Protection Staff, District/ Commune Cadastre Staff, Forest Inventory and Planning Institute (FIPI) Staff, Village Head	Assist CPC in implementing LUP/recording land declarations, preparing cadastral documents; organise villagers' meeting; instruct 3D model; receive applications for land use rights; organise and implement field allocation; finalise LUP/LA documents

There have been many investigations undertaken over the last decade that have examined the approach to LUP. Most concluded that in the past LUP in Vietnam focused more on establishing the soil types and determining the most suitable agricultural product for the soil than undertaking a LUP process that examines land use demands, resolves conflicting land use purposes and develops a sustainable plan for utilizations of the land resource (SEMLA, 2006).

2.6.3 Planning Policies and Directions

SEMLA (2006) reports that at present, the planning system in Vietnam comprises a hierarchy of planning levels in which the upper levels identify 'targets' or 'orientations' to be achieved by lower levels within the plan period. This hierarchy is reflected in the administrative hierarchy, from national, through provincial and district levels, to communes. The various plans derive from, and must be consistent with, the long-term visions and strategies for the country that are developed by the Party, and approved by the National Assembly. The recent 10th Party Congress held in June 2006 defined the strategic orientation for Vietnam and established specific Socio-economic and Environmental Targets to be achieved in the next 10 years. This provides the overall framework upon which the specific land use demands are forecast by the various sectors. The LUP regulatory framework that was established by the 2003 Land Law, Decree 181 and Circular 30 embodies the overall policies of the Government in respect to LUP.

According to Trung (2006), in the period 1975 – 1986 Vietnam had a centrally planned economy decreed by five year plans with production targets. In the southern part of the country most agriculture was still done by small households or private farming but at that time the agricultural services of every province were also operated by a number of large-scale communal state farms. These farms produced not only industrial crops such as sugar cane and pineapples but also rice or, in the coastal zone, shrimp. Private farmers and state farms had to sell pre-determined quantities of rice with fixed prices to the government. Land use was planned by local and provincial authorities, guided by the Ministry of Planning and supported by the National Institute for the Agricultural Planning and Projection (NIAPP).

2.6.4 GIS Applied Land Use Planning in Vietnam

In Vietnam, GIS has been used as a tool for land evaluation and LUP in several projects. For example, a project was undertaken by the National Institute for Soils and Fertilizers (NISF) in Doan Hung, Phu Tho Province, during the period 1995-1997. Soil maps, using a mapping exercise based on the FAO soil classification system, were compiled. Using the land use maps of 1995, as well as satellite images and aerial photos, district-level land use maps were compiled, as well as land unit maps and land suitability maps. In 2002 and 2003, a participatory land-use planning approach was undertaken in two villages of the Mekong Delta coastal area. GIS was utilized for analyzing land-use changes, realization of farmers' expectations, changes in expectations, and the conflicts between aquaculture and agriculture farmers' groups based on differing expectations.

GIS was applied for land-use planning and land allocation in the Social Forestry Development Project in Song Da. This was the first step undertaken to identify measures for sustainable land use and improving the conditions of the people living in the Song Da watershed area. The use of GIS allowed uniform measurements and 1:10,000 maps that accelerated the planning process.

Khang, N. *et al.* (2004) has developed The Agricultural and Rural Information System (ARIS). ARIS was built to provide the necessary information for those from the decision makers, scientist to the producers. Such information system consists of database and tools which help access, analyze, and support in making decisions on agricultural and rural management and planning at the provincial levels. ARIS system is based on the geographic information database. ARIS was experimentally implemented in the representative provinces of seven agro-economic zones in Vietnam. The system was most completely developed for Dak Lak province. The ARIS had been built on GIS application. The database is united, gathering almost full information in map and tabular formats on agricultural and forestry land use, crop diseases, rural labors in order to satisfy the demand in building information analyzed model and supporting decision making in the management of agriculture and rural development.

CHAPTER 3

METHODOLOGIES

3.1 Methods of Evaluating Potential Land Suitability

The study relies on a number of documents such as the Guide of FAO's Land Evaluation (1986), Guide of Soil Examination and Classification by the Soil Science Association of Vietnam (1999), a research on assessing land use for agriculture by Ministry of Agriculture and Rural Development (MARD) and other documents of the Ministry of Natural Resources and Environment (MoNRE) regarding formulation, adjustment and evaluation of LUP.

Specific Methods:

- Collecting data and analyzing the collected data, also utilizing previous research on land and other related contents.

- Surveying, analyzing physical and chemical soil and creating a soil map in accordance with the Vietnam Protocol and FAO’s guidelines.

- Applying digital technology to build maps of soil, maps of current status of land use, maps of land units, and maps of land adaptability classification and proposing appropriate land use and other thematic maps.

All maps were first built on the base map at the base coordinates system in VN 2000, at the ratio of 1/25,000; meridian axis is $104^0$45’, projectors 3^0; from results of outside survey map in the district’s current status of land use in 2000 and 2005 with the rate of 1/25,000. In the next step, some adjustments were made, and compiled with drawings on the background map of the entire district.

Analyzing some limitations of identifying the factors and classifying criteria of selection, that serves to evaluate the adaptability and proposing some proper manners of land use with weight method.

Utilizing software programs provided by Automatic Land Evaluation System to assess, analyze economical and environmental impacts, social benefits, land suitability classification and make proposals for land use.

Combined approaches/methods: surveying, interviewing farmers, experts, workshops and other professional approaches from different fields.

3.2 Building the Soil Map

The soil map was built on the base map at the base coordinates system VN2000. The original map was built by manual crafting methods after receiving the final results of classification combined with results of the survey, adjusting the boundaries outside the contour of the field-based map according to the base coordinates system, the ratio of 1/25,000 maps and current status of land use in 2005; followed by digitizing original maps and editing with MapInfo software; the results are final soil maps;

The total land area being studied in the Tam Nong district is 11,273 ha, accounting for 72.37% of the total area of natural land. Other areas of land comprising aquaculture land, non-agricultural land and mountain area without forests tree were not studied.

Social data are more difficult to quantify, as they often attempt to measure human distributions that are influenced by decisions or attitudes for which no common metrics or mathematical relationships are known.

3.3 Data for Building Standardized agriculture Database at the District Level.

Secondary Data Collection

Secondary data were used, from previous studies, census from the statistical offices and department of agriculture and rural development at district, provincial and national levels, as well as from other sources such as national and international projects implemented in the study areas.

Spatial Data Source

The main spatial data sources necessary for this study including:

- Digital soil map with a scale of 1:25,000
- Digital topography map with a scale of 1:25,000;
- Current land use maps in year 2005 with a scale of 1:25,000;
- Existing LUP maps for period of 2000-2010;
- Other existing spatial databases;

Attribute Data Source

The main attribute data sources necessary for this study including the data accompanying with spatial data above and the non spatial data:

- The data of location, climate;
- The census of physical, social-economic,
- The census of agricultural production and main crops production sector
- Ecological requirements of selected main crops.

Data collection methods: analyzing available information and database sources; inventory and gathering the needed attribute data; interviewing, discussion and seminar; field work and up-to-date the existing maps; overlaying the thematic maps by GIS.

Framework of land suitability evaluation for selected main crops in the study area: The criteria selection and development for suitability assessment in the study area have been divided into two ways: physical land suitability evaluation and then social-economic, environmental suitability evaluation.

The following physical factors: soil unit type, soil texture, soil effective depth and soil slope degree were used for considering and calculating to address the physical land suitability.

3.4 Selecting methods of Evaluating Potential Land Suitability

In Vietnam's current land evaluation practice, several methods of evaluation are being applied:

- The method of land evaluation of Russia and Eastern Europe.
- The method of land evaluation of the USA, France, UK, Canada.
- The method of land evaluation of the FAO.

The process of land evaluation was launched by the Vietnamese National Institute of Agricultural Planning and Projection (NIAPP) under the MARD (Code 10TCN 343 - 98).

The various methods of land evaluation mentioned above have their own pros and cons. Therefore, the selected method of assessment depends on the practical conditions of the region and the inputs for the land evaluation.

Land evaluation method of the FAO has gained its popularity among the scientists thanks to its advantages. This method can be applied to many different regions and many different countries in the world.

However, one limitation of the method is that it has not given the detailed land evaluation for region levels equivalent to districts and communes in Vietnam. Besides, this approach requires pedagogical documents built on the basis of classification by the FAO that almost all provinces in Vietnam have not provided yet.

The procedure of land evaluation with Code Number 10 TCN 343-98 introduced by NIAPP under MARD relies on the basic method of land evaluation of FAO with some adjustments and improvements that are applicable to existing conditions in Vietnam.

This procedure can be used for the land evaluation on both detailed and general levels.

Based on the selected method of land assessment, we conducted land evaluation according to natural, economic and social characteristics, organized discussions among experts (by ministries and sectors related to the purpose of land use) and conducted inside surveys and outside surveys to supply and clarify additional information.

In addition, thematic maps were built as a basis to overlay the map of land mapping units. Types of land use were specified to analyze and assess economic, social and environmental benefits of land use types according to the criteria on the quantity and quality of soil.

The requirements of land uses for each type of land use were determined in order to assess land suitability. The final goal of land evaluation process is to determine the appropriate level of topological specifics for each land use type. Results of land suitability assessment play a role as important scientific bases for making proposals on land use for the future. The mapping of evaluation on land suitability of each land plot was also done.

3.5 Modeling the Agricultural Land Use Planning Process

When building the LUP model we should focus on the suitability, feasibility, practicality and sustainability. Land use on a sustainable basis should satisfy three requirements: economically sustainable in terms of plants that achieve high economic efficiency and are accepted by the market; environmentally sustainable in terms of being able to prevent degeneration of land and protect the natural environment; socially sustainable in terms of attracting workers and ensuring that social life develops. The modeling below adapted from the proposal modeling method by Nguyen H. T. *et al* (2006).

To choose the appropriate formula for cultivation in accordance with the land's conditions and also to reach the desired efficiency, a multi objective optimization model needs to be addressed while considering the three following objectives:

- Economic Efficiency
- Land Suitability
- Sustainable Environment

The entire area of cultivated land is divided into M types. Also from results of the research on allowed cultivation on that land, N different formulas of rotation cultivation are assessed at L levels of suitability. For the sake of simplicity, L can be set equal to 2: the level of suitability is 1 if the cultivation flow is appropriate, otherwise 2 if the cultivation flow is less suitable.

Consider decision variables x_{ijk} denoting the area under cultivation formula i (i = 1, 2... N) With the suitability level j (j = 1, 2) and the land type k (k = 1, 2… M).

Also, consider coefficients a_{ijk} related to decision variables x_{ijk} in type k land area. The value of aijk can be determined as: a_{ijk} =0 if the cultivation formula i is not applied to land type k and a_{ijk} =1 otherwise. Besides, let b_k be the total area of land type k with k = 1, 2… M.

Therefore, the binding conditions or the constraints of the LUP multi objective optimization model can be stated as follows:

$$\begin{cases} \sum_{i=1}^{N} \sum_{j=1}^{2} a_{ijk} \, x_{ijk} = b_k \quad (k = 1, 2, ..., M) \\ x_{ijk} \geq 0 \qquad \forall i, \forall j, \forall k \end{cases}$$

Consider c_{ijk} the profitability multiplier on an area unit of land type k under cultivation formula i with the suitability level j, the objective set on economic efficiency is written as follows:

$$\sum_{k=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{2} c_{ijk} \, a_{ijk} \, x_{ijk} \rightarrow Max$$

To maximize the general suitability level, it is needed to maximize the total area of the rotation cultivation with the suitability level 1. Therefore, the following objective on the total level of suitability is stated:

$$\sum_{k=1}^{M} \sum_{i=1}^{N} a_{ijk} \, x_{ijk} \rightarrow Max$$

One more objective to be considered is the objective set for optimizing the total environmental effect of the crop rotation and land use. It is needless to mention that this is a practical problem of great importance. However, environmental effects are always difficult to quantify.

The environment related multiplier for different rotation cultivation formula is determined by analyzing experts' opinions. Each expert will give his/her assessment of the environmental effect for cultivation formula i using the ranking system: Excellent, Good, Fairly Good, and Poor. These rankings are then quantitatively evaluated as 100, 75, 50 and 25 points, correspondingly. Percentages of the opinions for each evaluation level will be considered as experimental probabilities. Therefore, each rotation cultivation formula will correspond to a pair of numbers (m_i, σ_i) in which m_i is expected value and σ_i is the standard deviation of the experimental probability distribution obtained for the environmental-related multiplier. This multiplier can be considered as a random variable with normal distribution N (m_i, σ_i).

For the sake of computational simplicity, the random variable with normal distribution N (m_i, σ_i) as obtained above will be converted into triangular fuzzy number $\tilde{m}_i = (m_i - 3\sigma_i, m_i, m_i + 3\sigma_i)$.

The objective for optimizing the total environmental effect can now be represented as the following objective with fuzzy coefficients $\tilde{m}_i$:

$$\sum_{k=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{2} \tilde{m}_i \, a_{ijk} \, x_{ijk} \rightarrow Max$$

This objective with fuzzy coefficients can be treated as a pair of a crisp objective and an additional binding condition as follows:

$$\sum_{k=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{2} m_i \, a_{ijk} \, x_{ijk} \rightarrow Max$$

$$\sum_{k=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{2} (m_i - \varepsilon_i) \, a_{ijk} \, x_{ijk} \geq e$$

Here, ε_i can be any value that satisfies the conditions: $0 < \varepsilon_i < 3\sigma_i$, usually we set ε_i = 90% $\times 3\sigma_i$ or $\varepsilon_i = 2.7\ \sigma_i$. The value for the parameter e can be selected by the decision maker using appropriate information derived from the above model (such as information derived from the pay-off table); e is often called the minimum acceptable threshold.

In summary, the LUP model is stated as the following multi objective optimization model with three objectives:

$$Z_1 = \sum_{k=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{2} c_{ijk}\, a_{ijk}\, x_{ijk} \rightarrow Max$$

$$Z_2 = \sum_{k=1}^{M} \sum_{i=1}^{N} a_{ijk}\, x_{ijk} \rightarrow Max$$

$$Z_3 = \sum_{k=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{2} m_i\, a_{ijk}\, x_{ijk} \rightarrow Max$$

Subject to the constraints:

$$\begin{cases} \sum_{i=1}^{N} \sum_{j=1}^{2} a_{ijk}\, x_{ijk} = b_k \quad (k = 1, 2, ..., M) \\ \sum_{k=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{2} (m_i - \varepsilon_i)\, a_{ijk}\, x_{ijk} \geq e \\ x_{ijk} \geq 0 \qquad \forall i, \forall j, \forall k \end{cases}$$

The above multi objective optimization model with 3 objectives can be solved by the decision maker - computer interaction method to help the decision maker gradually learn and adapt to the information provided by computer in response to the decision maker adjustment in each iterative interaction steps in order to eventually arrive at the most satisfying solution.

The working of the interaction method for the multi objective optimization model with n objectives can be described in more details as follows:

First, the objectives of the model are converted to the fuzzy goals that reflect the aspiration level of the decision maker. This is a very reasonable approach because the different goals which are quantified using different measurement units can now be quantified by a common unit measurement system that evaluates the satisfaction level of the decision maker. It is a special advantageous feature of fuzzy optimization among many other advantageous features.

Second, when considering each goal with the common binding conditions as mentioned above, the model will provide an optimal solution. However, if we simultaneously consider many goals, a solution that is optimal for one goal may not be certainly optimal for the remaining goals. Therefore, the decision-maker should determine an appropriate utility function for each goal. Based on the utility functions thus determined, an aggregation utility function will then be constructed in an appropriate way depending on the decision maker preference. Thus, each iterative interaction step has its aggregation utility function to be optimized to provide an optimal solution. The information of the obtained optimal solution provided by computer can be used by the decision maker to make adjustment in the next iterative interaction step.

The utility function for each goal (say, i^{th} goal) may be determined as follows:

$$\mu_i(Z_i) = \frac{Z_i - Z_i^w}{Z_i^B - Z_i^w} \rightarrow Max$$

Where, Z_i^B is the best value of Z_i and Z_i^W is the worst value of Z_i (i = 1, 2... n).

Based on the utility functions determined as above, an aggregation utility function is to be constructed using the weighted function approach:

$$Z = \sum_{i=1}^{n} w_i \mu_i(Z_i) \rightarrow Max$$

Where w_i, i = 1, 2… n, satisfy condition: $0 \le w_i \le 1$ and $\sum_{i=1}^{n} w_i = 1$.

The multiplier w_i is called the weight that reflects the importance of i^{th} utility function in the aggregation function. Now, instead of the multi objective optimization model (in our LUP model there are three objectives with a set of constraints as stated above), we have a single objective optimization model subject to the same set of constraints, which can be solved by a suitable optimization technique (in case the model is linear programming model it can be solved by the well-known simplex method).

By changing in each iterative interaction step the values of weights, different alternate optimal solutions can be obtained to replace each other. Changing the weights depends on the decision-maker, or a group of experts. This solution process enables the decision maker to finally arrive at an optimal solution that is the most desirable land use and crop rotation decision in LUP for sustainable development.

3.6 Algorithms for the Optimization Model of Determining the Crop rotation Initial Step

Enter data for the objective function Z_i (i = 1, 2, 3) and M binding conditions.

Solve the linear programming problem obtained for each objective function with the M initial binding conditions (without the additional binding condition) to get the alternative optimal solutions X_1, X_2, X_3.

Calculate the value of the objective function at the alternatives solutions X_1, X_2, X_3 and form the pay-off table to determine the value of Z_i^B and Z_i^W for i[th] goal, i = 1, 2 and 3.

Set the additional binding conditions:

$$\sum_{k=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{2} (m_i - \varepsilon_i) a_{ijk} x_{ijk} \geq e$$

With $e = Z_3^w + \varepsilon(Z_3^B - Z_3^W)$

Identify utility function for each objective based on the information derived from the pay-off table:

$$\mu_i(Z_i) = \frac{(Z_i - Z_i^w)}{Z_i^B - Z_i^w}$$

$i = 1, 2, 3.$

Based on the above utility functions, build an aggregation utility function Z to be maximized:

$$Z = w_1\mu_1(Z_1) + w_2\mu_2(Z_2) + w_3\mu_3(Z_3) \rightarrow \text{Max}$$

Where w_1, w_2, w_3 are the weights reflecting the importance of the corresponding utility function in the obtained aggregation utility function.

Iterative Interaction Step

(Consider the k^{th} iterative interaction step)

Sub step 1

Enter the weights w_1, w_2, w_3 that satisfy conditions:

$$w_1 + w_2 + w_3 = 1 \text{ and } 0 \leq w_1, w_2, w_3 \leq 1.$$

Sub step 2

Solve the linear programming problem

$$Z = w_1\mu_1(Z_1) + w_2\mu_2(Z_2) + w_3\mu_3(Z_3) \rightarrow \text{Max}$$

Subject to M initial binding conditions and the additional binding condition, the optimal solution obtained is denoted by X (k).

Calculate the value of the objective functions Z_i as well as that of the utility function μ_i (Z_i), i = 1, 2, 3 and provide the obtained information to the decision maker. If the decision-maker is not satisfied with some of these values, X (k) is not the satisfying solution, go back to sub step 1.

Otherwise, if the decision maker is satisfied, the optimal solution X (k) is selected as the most desirable solution

Sub step 3

Stop.

The above algorithm can be extended to solve the LUP optimization model with n objectives. As for the objectives with fuzzy coefficients, the above approach for determining the minimum acceptable threshold may be applied.

Instead of the replacement process as described above when X(k-1) is replaced by X(k), another approach may be considered: All optimal solutions obtained in iterative interaction steps are retained for a group of experts to conduct a group decision making process in order to select a most desirable solution. For reference, it is meaningful to read about similar algorithms for multi-objective optimization in Mohan and Nguyen Hai Thanh (2001) and Nguyen Hai Thanh et al (2006).

COUNTRY BACKGROUND AND STUDY AREA

4.1 Country Background

4.1.1 Vietnam Geographical Overview

Vietnam is located in the centre of Southeast Asia, comprising the eastern boundary of the Indochinese Peninsula, with a natural area of about 330,000 km. The country borders China to the north and Lao PDR (Laos) and Cambodia to the West. Vietnam lies competently within the tropical belt of the Northern Hemisphere, extending over 15^0 of latitude. On one end it is approximately 8^0 from the equator, and on the other it is close to the Northern Tropic. The country stretches from its furthest point north at $23^0$22 N on the Dong Van Plateau, to its furthest point South on Ca Mau cape, at $8^0$30 N, while its westernmost point is $102^0$10 E at Khoang La Xan mountain Muong Te district in Lai Chau province, and the easternmost point at $117^0$21 E on the Truong Sa archipelago. In the east and the South Vietnam faces the Eastern Sea, the Gulf of Bac Bo, and Thailand. The coastal zone from Mong Cai at the border with China to Ha Tien is 3,260 km long. The country measures 50 km at its narrowest point in the Quang Binh province and 600 km at its widest point between Mong Ca and the Vietnam-Laos border.

Vietnam is at the crossroads of several natural systems. It possesses great diversity in geology, terrain, climate, hydrology, soil types and fauna. The territories are criss-crossed with mountain ranges and high hills, presenting substantive obstacles to human access and thus constraining economic development. The mountainous areas are also characterized by low population density and high rates of poverty. However, they are often rich in minerals and hydroelectric potent as well as forest products.

In the past several years, Vietnam's socio-economic situation has improved tremendously. However, environmental degradation and pollution associated with economic growth have grown at an equally rapid pace. In particular, environmental problems related to forest degradation are among those that have had the most adverse impacts on the largest scale.

Table 4.1 Land status in Vietnam

No.	Land Classification	Area (ha)
1	**Agricultural land**	**22,948,700**
1.1.	Agricultural production land	9,037,800
	- Paddy land	4,039,400
1.2.	Forested land	13,889,500
	- Land for newly planted forests:	1,356,400
	- Land for forests delimited for regeneration	1,070,900
1.3.	Land for salt production	21,400
2	**Non-agricultural land**	**3,606,000**
2.1.	Residential land	1,014,900
	- Rural residential land:	931,200
	- Urban residential land:	83,700
2.2.	Land for special use	1,846,500
3	**Unused land**	**6,369,400**

Sources*: Resolution 29/2004/QH11 on LUP to 2005 and 2010 – National level.*

Three-quarters of the country consists of mountains and hills. Lying between the mountainous highlands are midlands regions which make up about one-third of the country. The remaining areas (one-quarter) include the fertile plains formed by 15 major rivers. Amongst the major rivers are the Mekong with a drainage basin of

72,300 km^2, and the Red River which has a drainage basin of 60,960 km^2 within Vietnam. The plain areas of the Mekong River Delta (MRD) in the south and the Red River Delta (RRD) in the north, separated by 1,300 km, are the major agricultural areas and centers of population (Linh, 2001).

The population of Vietnam is about 79.7 million and the annual growth rate was 1.35% in 2002. The majority of the population belongs to the Kinh ethnic group. Minority groups which make up approximately 10% of the total population are mainly located in the highland areas. Approximately 75% of the total population lives in rural areas, and about 74% of the total labor force is engaged in agriculture (GSO, 2002). Rural population densities average at 194 persons per km^2, but vary greatly according to region. In the Red River Delta, they range in different provinces from 893 to 1,092 persons per km^2. Nearly one-third of the population of the country lives in these two deltas. In the central highlands and the northern mountainous provinces, population densities are lower, with fewer than 100 persons per km^2.

The administrative structure of the country consists of cities and provinces. The provinces are subdivided into districts which are further subdivided into communes with each commune consisting of many villages.

4.1.2 Economy and Agriculture

Vietnam can be rated among the poorest countries in the world with an average income of US$240 in 1998, or US$370 per capita (it ranked 167 out of 206 countries according to the World Development Report 2000/2001: Attacking Poverty). In the last ten years, the annual growth rates of GDP have surged to an average of 7- 8%; in 1995, the economy grew by 9.5% (Linh, 2001).

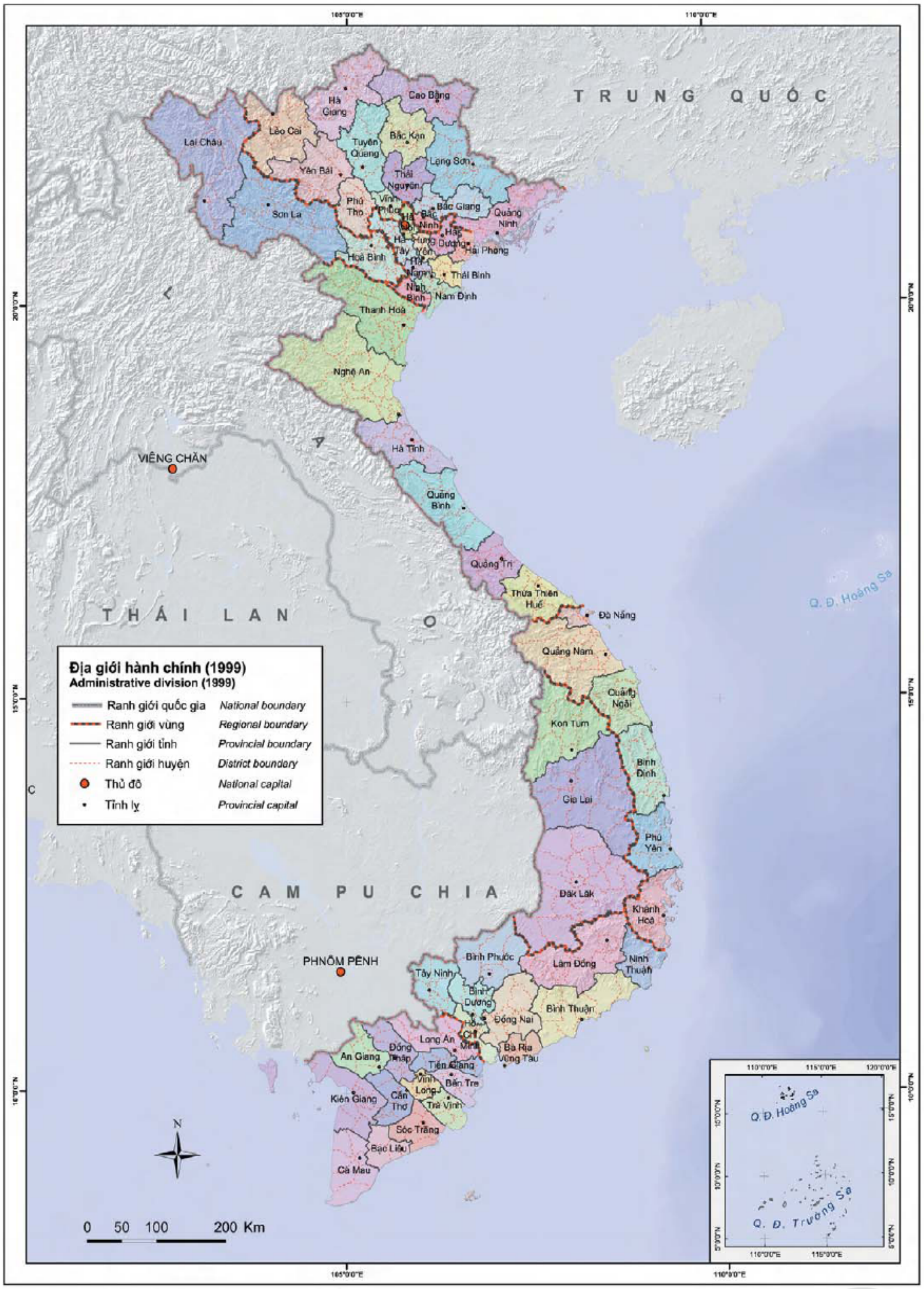


Fig. 4.1 *Vietnam Administrative divisions, Atlas Cartographic Publishing House (1999)*

In the years during which the reforms were enacted, Vietnam’s economic structure has changed due to an increase in the diversification of industries and plants, and the development of businesses. These changes have contributed to a transition in the national economic structure whereby the contributions of industry and services to the GDP have increased, whereas, on the other hand, those of agriculture have declined (Cuong, 2005).

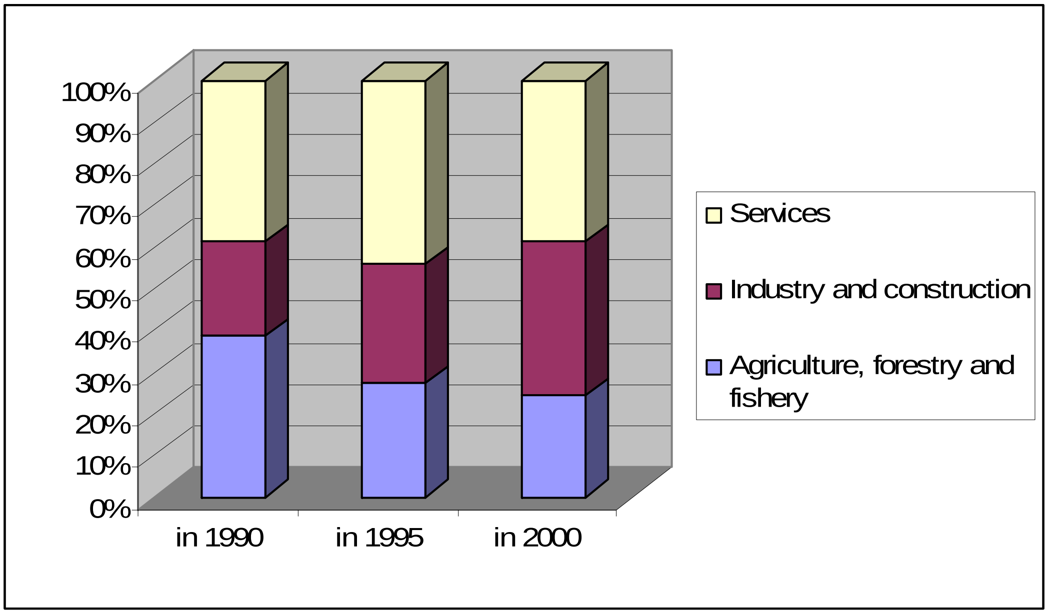


Fig. 4.2 *GDP of the economy structure Data. Source: GSO (2003)*

4.1.3 Rural Poverty

Agricultural output and productivity have risen significantly, and food security has been achieved at the aggregate level. More people in Vietnam now have access to basic social services including clean water, health services and education. Rural incomes have increased, poverty has declined, and the overall well-being in rural areas has seen considerable improvements. Indeed, in just six years, from 1992 to 1998, the number of poor people in rural areas dropped by one third (Trung, 2001). However, poverty remains primarily a rural problem; too many rural people still live in poverty due to a lack of resources or the absence of remunerative employment. As the recently completed Vietnam Living Standard Survey for 1997/1998 has indicated, a majority of the rural population has been excluded from the development process and the benefits of economic growth. The pace of rural poverty reduction has been considerably slower than the pace in urban areas, and poverty is still about five times higher in rural areas than in urban areas.

4.2 Natural Condition and Resources in the Research Area

4.2.1 Geographical Location

Tam Nong district, Phu Tho province, a rural agricultural based area located 90 km northwest of Hanoi, Vietnam, locating at 105°08'E-105°24'E and 21°13'N-21°15'N. Total Square of this district is 15,577.69 ha, containing 4.43% of province's square. Tam Nong includes 19 communes and a town (Hung Hoa)

Fig. 4.3

Tam Nong Administrative Map

Source Tam Nong Natural Resource Department

4.2.2 Terrain

Tam Nong district locates in midland region, sloping down from Northwest to Southeast. Tam Nong's terrain is divided into two main types:

Plain alluvium terrain, a fairly even and flat strip of land, is left by Hong River, Da River and Bua River. The slope normally lowers than 3^0, other part with slope from 3^0 to 5^0

Hill and mountain terrain: terrain here is mostly hills and mountains, the slope is from 15^0 to 25^0 and over 25^0.

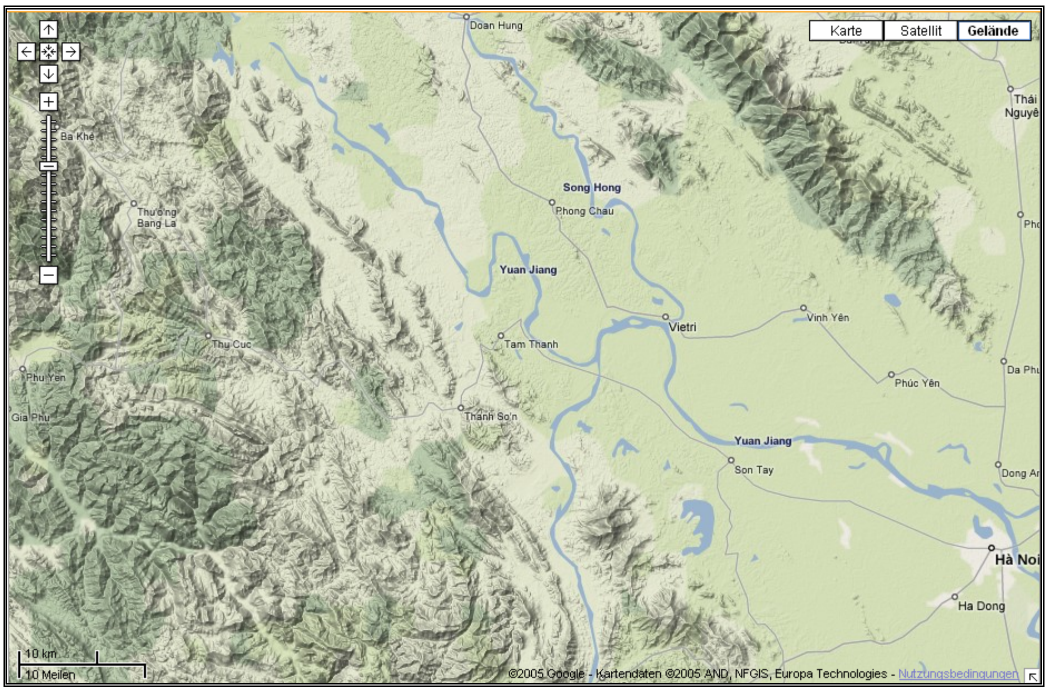


Fig. 4.4 *Tam Nong Terrain Image from Google Earth accessed on 16/04/2008*

4.2.3. Climate

Considering the climate in the Phu Tho Province, Tam Nong district located in the centre of sub-region of midland hill climate.

Total annual average rainfall was from 1,450 to 1,500mm. The frequency of local drought and flood causes a lot of damages.

Average relative humidity is 84%. Average temperature ranges from 23^{0}C to 24^{0}C. Frost and hoarfrost rarely happen. There are two kinds of wind: southeast monsoon and northeast monsoon.

Table 4.2 *Climate Tam Nong District, Phu Tho*

	Average temperature (*^{0}C*)	Rain fall (*mm*)	Total Rainfall (*day*)	Humidity averaged (*%*)	Total evaporation (*mm*)	Total sunny hours
Jan.	15.9	8.3	11	86	23.0	18.0
Feb.	21.6	24.9	4	87	31.0	26.0
Mar.	20.8	58.8	17	93	15.0	26.2
Apr.	22.6	120.1	13	89	23.0	25.0
May.	26.2	197.3	12	82	11.0	160.6
Jun.	29.1	171.2	15	83	104.5	195.1
Jul.	29.2	124.7	14	85	110.7	187.0
Aug.	28.7	206.9	18	87	87.6	177.3
Sep.	26.3	232.6	13	87	77.4	142.7
Oct.	24.5	50.9	6	87	67.8	117.7
Nov.	19.7	10.2	3	79	91.6	181.7
Dec.	19.1	9.5	8	82	18.0	50.8
Year	**23.8**	**1205.2**	**134**	**85.6**	**660.6**	**1308.1**

Source: Meteorological - Hydro North Vietnamese in Phu tho, 2007

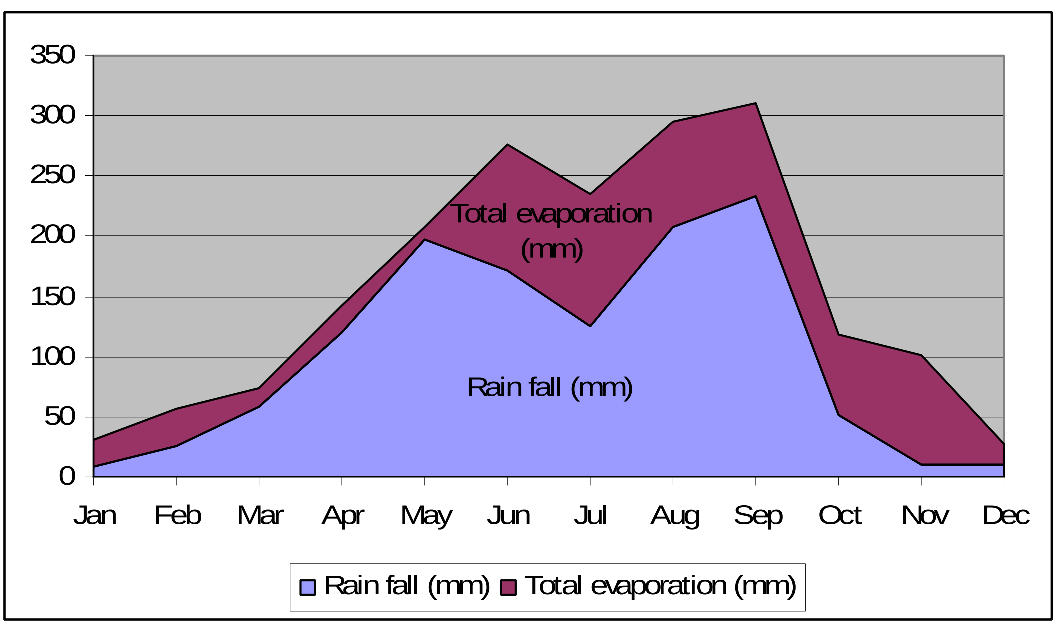


Fig. 4.5a *Climatic diagram of Tam Nong in Rain fall and Total evaporation factor*

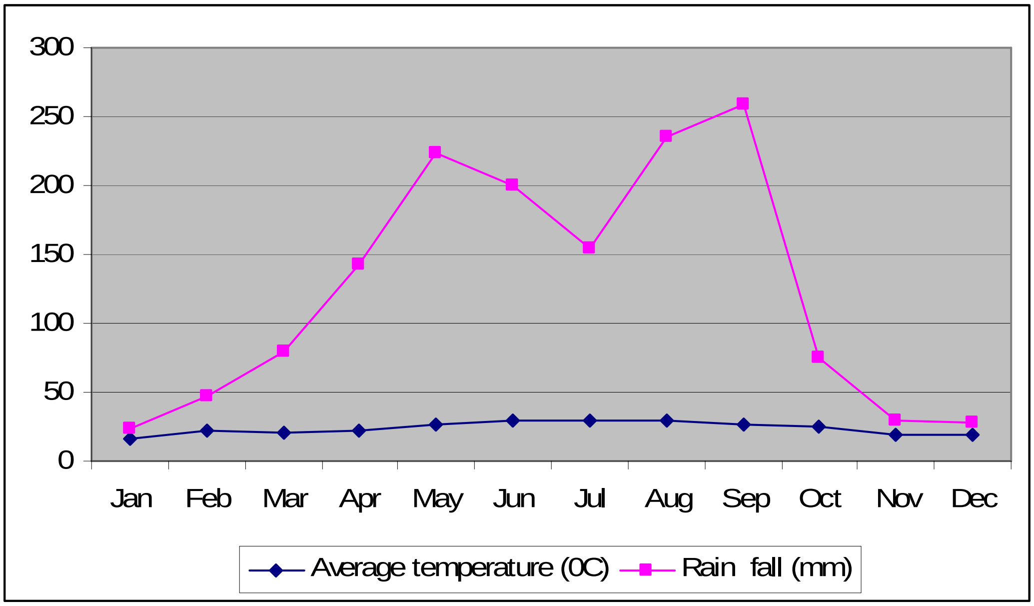


Fig. 4.5b *The average temperature and rail fall changes recorded in Tam Nong*

4.2.4 Plants

In the area of hills and mountain of districts: natural vegetation of the district is 220 hectares of natural forest protection; the rest forest trees are mainly Eucalyptus, long industrial plants such as Wax plant *(Rhus succedanea L, Anacardiaceae),* tea and fruit trees.

In the plain areas and the land alternatives between hills and mountains, vegetation is entirely short-term crops such as rice, maize, potato, peanut and vegetables

Fig. 4.6 *Wax plant (Rhus succedanea L, Anacardiaceae) - the native tree with high economic value in Tam Nong*

4.2.5. Agriculture

In the process of agricultural production, people have a positive impact on land by introducing high system cultivation and sustainable structure of production to ensure the social life, which has contributed to increasing of land cover.

Fig. 4.7 *Non- irrigated agricultural cultivation systems in Tam Nong.*

Irrigation systems from Red River and Bua River have provided a number of alluviums to the field, contributing to improving the fertile soil.

However, the dike protecting crops and people leads to the compensated alluvium, which created rough areas causing interference problems for the construction of irrigation systems. Deforestation, random forest exploitation, and any work on the hill slopes cause the land to erode rapidly.

4.2.6 Hydrology and Water Resources

The district has three passing-through rivers: the Red River, Da River and Bua River. The rivers play a role as drainage system, water supply and alluvium soil accretion for the field. However, because the river flows through the narrow and hilly mountain terrain with high slope, large floods often occur in monsoon.

Besides, the ponds and canals also contribute actively to the production and supplying more water in the district into the rainy season. Underground water is quite abundant and is now being exploited through digging or drilling.

4.2.7 Landscape and Environment

The environment in the district is quite clean because it is less affected by industrial waste. Land area is not utilized thoroughly to produce farm forestry and contribute to covering the barren hills and mountains. Forest areas are rehabilitated; the coverage of the forest is 23.23% in 2005, up 4.37% compared to 2000 and increased 7.31% compared to 1995. In agricultural production, alternate cultivation methods are used to enhance and strengthen the soil. Chemical fertilizers and pesticides that have a bad effect on the environment are used limitedly.

4.3 Socio - Economic Conditions

4.3.1 Population and Labor

The population of the district was 81,525 people in 2005, of which 73,430 people or 90.07% of the total population were engaged in agriculture and 8,095 people or 9.93% of the total population were in the non-agricultural sector. Average population density of the district was 521 people per square kilomete. The rate of population growth in 2005 was 0.80%.

The district has 42,202 employees, accounting for 51.77% of the population with 30,950 people in agriculture accounting for 73.33% total employees and 6,209 people in industrial construction services accounting for 14.71% (TSO, 2005).

4.3.2 Status of Economic Development Society

Economic growth on average in the period of 2000-2005 reached 9.4% per year (GSO, 2005)[7]. In 2005, total production value of the district reached 322,043 mil.VND (fixed price in 1994), increasing 24.53% compared with 2004, and average production value is 3,950,000 VND per person per year.

Value of agriculture, forestry and fishing reached 158, 866 mil.VND, increasing 12.11% (compared with 2004). Industrial production and construction reached 61.274 mil.VND, increasing 14.53%. Trade services reached 101,903 mil.VND, increasing 23.67%.

In terms of economic structure, agriculture and forestry account for 49.33. Industry and construction account for 19.03%. Trade and services account for 31.64%. Compared with 2004, economic structure has shifted to the right direction, reducing the proportion of the agricultural sector by 5.47%, increasing the proportion of industry and small industry sector by 5.73%, decreasing service by 0.26%. The rate of poverty is 7.91%, decreasing by 1.1% compared to 2004.

4.4 Land Use and Management

4.4.1 Land Management Background

In general, land management in the district has been implemented in accordance with the law of the government. According to the report from Tam Nong Resources and Environment department, each specific area is presented as follows:

- Issuing legal documents on land use and implementation of the documents: Department of Natural Resources and Environment succeeded in directing the People's Committee of the district to publish the regulations on land use and implementation.

- Defining border, and creating records administrative border, establishing administrative mapping: Up to date from the district to all communes and towns, administrative records are set up for management and use.

- Managing and LUP: the District People's Committee has directed and managed the land use plan well in the district and communes level on a regular basis, ensuring proper land regulations.

- Managing, leasing, receiving land, and changing the purpose of land use: the District People's Committee has successfully directed, managed the land closely, leased land to all the interested parties in the district, and transferred of land use purposes.

- The registration of land use rights and management of local records, certificates of land use rights: Presently, the district has issued certificates of land use rights for agricultural production to 15,951 households reached 96.9% of households. Land forestry reached 40.77%; and urban land reached 98%.

- Statistics and inventory of land: The land inventory is examined periodically every 5 years and annual district land statistics are supervised to ensure objectivity and proper status use.

- Financial management of land, monitoring the implementation of rights and obligations of land use, inspection, and dispute resolution are performed well by the district People's Committee to both commune and town level.

- Management and market development of land use right in real estate market and services on land: This is the new field; the non-regulated real estate market will create many problems.

- Survey measurement, land evaluation, assessment, industry map, current land use status map and map of land use plans: After building the map details, the District Committee has implemented the classification of agricultural land (mainly based on crop productivity on the land) for the agricultural tax purposes. The mapping of the land use and planning the land use was under the Committee’s guidance. Collaboration with the technicians is needed to complete the construction of maps from district to commune in accordance with the documents and the articles in Vietnam’s Land Regulations.

4.4.2 Current Status of Land Use

Table 4.3 *Areas and Proportion of Land Use in Tam Nong in 2005*

Items	VN Code	In 2005	
		(ha)	Proportion (%)
1.Agricultural land	**NNP**	**11,460.68**	**73.57**
Agricultural production	SXN	7,267.34	46.65
Annual crops	CHN	5,074.48	32.58
Paddy	LUA	3,759.87	24.14
Wet Rice	LUC	1,462.03	9.39
Rice and crops	LUK	2,297.84	14.75
Other annual crops	HNC	1,314.61	8.44
Perennial industrial trees	CLN	2,192.86	14.08
Forest Land	LNP	3,619.34	23.23
Production forest	RSX	2,881.09	18.49
Protective forest	RPH	738.25	4.74
Water surface land for fish farming	NTS	573.27	3.68
Other Agricultural Lands	NKH	0.73	0.01
2. Non Agricultural Lands	**PNN**	**3,726.78**	**23.92**
3. Unused land	**CSD**	**390.23**	**2.51**
Total		**15,577.69**	**100.00**

Source*: Phu Tho Natural Resource and Environment Department*

Tam Nong district has a natural area of 15,577.69 hectares, accounting for 4.43% of the province's natural area. Current status of the land use is presented below.

1. **Agricultural land** is occupied 73.57% of natural area, including:

- Land for agricultural production is 7,267.34 hectares, accounting for 63.41% of agricultural land. On average, one demographic unit is 998m2.

- Land for annual crop is 5,074.48 hectares or 69.83% of agricultural land, on average, one demographic unit is 697m2, in which land for wet rice growth is 3,759.87 hectares or 516m2 over one demographic unit on average.
- Perennial Plant Land is 2,192.86 hectares, accounting for 30.17% of the agricultural land area.
- Land Forestry's 3,619.34 hectares, accounting for 31.58% of the agricultural land. Forest land for production is 2,881.09 hectares, accounting for 79.6% of the forest land. Forest land for conservation is 738.25 hectares, accounting for 20.4% of the forest land.
- Aquaculture land is 573.27 hectares, accounting for 5.00% of the agricultural land.
- Other agricultural land is 0,73hectare, accounting for 0.01% of the agricultural land

2. **Non-agricultural land**: the area has 3,726.78 hectares, accounting for 23.92% of the natural land.

- Land for residence is 503.48 hectares, accounting for 13.51% of the non-agricultural land. Urban area is 26.56 hectares, accounting for 94.72% of the land area. Rural area is 476.92 hectares, accounting for 5.28% of the land area.

3. **Unused land**: the area has 390.23 hectares occupied 2.51% natural area, including:

- Unused land in flat terrain is 223.82 hectares, accounting for 57.35% of land not used.
- Unused land in hills and mountains is 162.48 hectares, accounting for 41.64% of land not in use.
- Land Stone Mountain without forests tree is 3.93 hectares, accounting for 1.01% unused land.

Table 4.4 *Area, Productivity and Crop Yield of Main Crops in Tam Nong*

Crops	Unit	2005	2006	2007
1. Rice				
- Area	ha	4,661.5	4,375.4	4,437.9
- Productivity	100kg/ha	48.8	47.9	44.0
- Crop yield	ton	22,758.2	20,946.9	19,545.0
2. Maize				
- Area	ha	1.572.6	1,429.0	1,587.5
- Productivity	100kg/ha	45.9	46.4	47.1
- Crop yield	ton	7,224.3	6,633.1	7,477.9
3. Soybean				
- Area	ha	174.6	151.7	110.9
- Productivity	100kg/ha	12.6	11.6	12.7
- Crop yield	Ton	219.4	175.3	140.6
4. Peanut				
- Area	ha	783.7	753.4	778.2
- Productivity	100kg/ha	13.6	11.9	15.5
- Crop yield	Ton	1,067.4	896.9	1,203.2
5. Cassava				
- Area	ha	590.7	552.4	515.9
- Productivity	100kg/ha	104.3	106.1	113.6
- Crop yield	ton	6,161.4	5,859.8	5,859.0
6. Vegetable				
- Area	ha	515.0	502.2	451.0
- Productivity	100kg/ha	128.2	113.3	118.5
- Crop yield	ton	6,602.3	5,690.0	5,344.6

Source: Tam Nong Statistical Office, 2007

CHAPTER 5

LAND MAPPING AND LAND SUITABILITY EVALUATION

Soil classification for land suitability evaluation in Tam Nong has been carried out by the cooperation between Phu Tho's Department of Natural Resources & Environment and Hanoi Agricultural University. These results were used as an input for secondary data source to analyze soil types. We also conducted some specific methods, the results land mapping units and land suitability classification for land evaluation following FAO guideline. These data will be collected into agricultural database in Tam Nong for testing and assessing DSS program.

5.1 Soil Classification

Soil classification of Tam Nong district was based on the diagnostic level, diagnostic material and natural characteristics of each soil type. Besides, the table of soil classification and Phu Tho soil map published in 1965 with legend were referred to be in accordance with the soil classification of FAO.Based on the description of image of soil profile, results of the chemical and physical characteristics of soil profile were analyzed. Each soil profile was compared with the standards and principles of soil distribution and sub-classification to determine the soil name for each soil profile. After that, all the maps were combined to build a comprehensive table of soil classification of the district.

Detailed Soil Classification of Tam Nong based on the classification of FAO in Appendix A.

Sample of Soil Profile Descriptions ID - Tam Nong TN 08

Location: Ho truong, Vuc Truong commune, Tam Nong district. Flat terrain Spécimens: Alluvial Soil; Plants: 2 Rice + 1 Crop.

Description of soil layers horizons

0-22cm: brown grey (7.5YR 5/2), wet, Soil Texture Limon, blog structure, including root of rice, clarity change layer

22-50cm: brown (7.5YR 5/3), wet, Soil Texture Limon and sand, blog adherence structure, including root of rice, clarity change layer

50-85cm: brown red color (7.5YR 4.5/3), wet, soil Texture Limon and sand, adherence structure

85-125cm: brown red color (5YR 4.5/4), brown red color (7.5YR 4.5/3), wet, soil Texture Limon and sand, adherence structure.

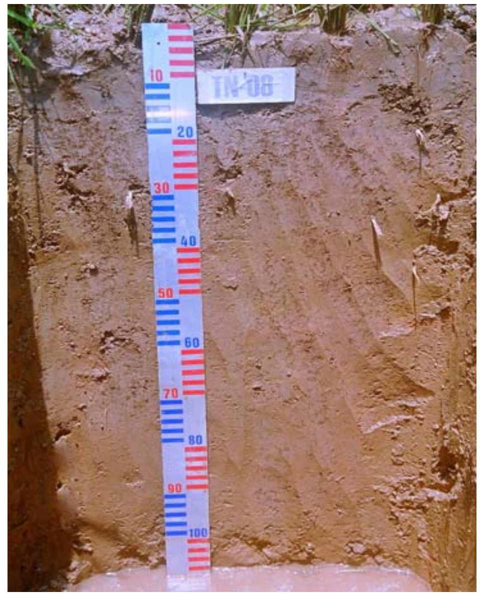


Fig. 5.1 *Soil Profile Descriptions*

Table 5.1 The results of Soil Analysis on chemical-physical properties *(TN-08)*

Horizon (cm)	pH_{H2O}	pH_{KCL}	Total concentration (%)				Available concentration $P_2O_5K_2O$ (mg/100g soil)		Exchange cation (mg/100g soil)				Fe^{2+}-Fe (mg/100gđ)	Soil Texture (%)		
			OC	N	P_2O_5	K_2O	P_2O_5	K_2O	Ca^{++}	Mg^{++}	Na^{+}	CEC		Clay	Limon	Sandy
0 - 22	8,32	7,91	1,30	0,12	0,160	1,67	40,0	7,99	8,91	2,27	0,35	11,73	77,4	16,0	42,9	41,1
22-50	8,48	8,22	0,37	0,04	0,092	1,81	30,0	5,64	4,50	1,57	0,30	6,54	53,7	6,9	27,1	66,0
50-85	8,54	8,16	0,37	0,04	0,083	2,10	15,0	5,64	4,60	1,50	0,26	6,51	33,1	10,3	30,8	58,9
85-125	8,63	8,24	0,34	0,03	0,075	1,20	15,0	5,64	5,00	1,81	0,34	7,46	40,0	11,6	53,8	34,6

Source: Analysis at Center for Soil Analysis, Hanoi University of Agriculture

Table 5.2 *Soil Types in Tam Nong*

Soil Types Name	Symbol	Area (ha)	Proportion (%)
1. Fluvisols	P	3,724.85	23.88
1.1. Eutric Fluvisols	P	3,539.08	22.69
1.2. Dystric Fluvisols	Pc	185.77	1.19
2. Gleysols	GL	672.41	4.31
3. Acrisols	X	6,796.62	43.58
3.1. Hapli Acarisols	X	248.17	1.59
3.2. Gleyic Acrisols	Xg	646,.31	4.14
3.3. Feralit Acrisols	Xf	5,336.33	34.21
3.4. Hapli Ferric Acrisols	Xfe	565.81	3.63
4. Leptosols	E	79.83	0.51
Total		15,596.92	100

Source*: Phu Tho Natural Resource and Environment Department*

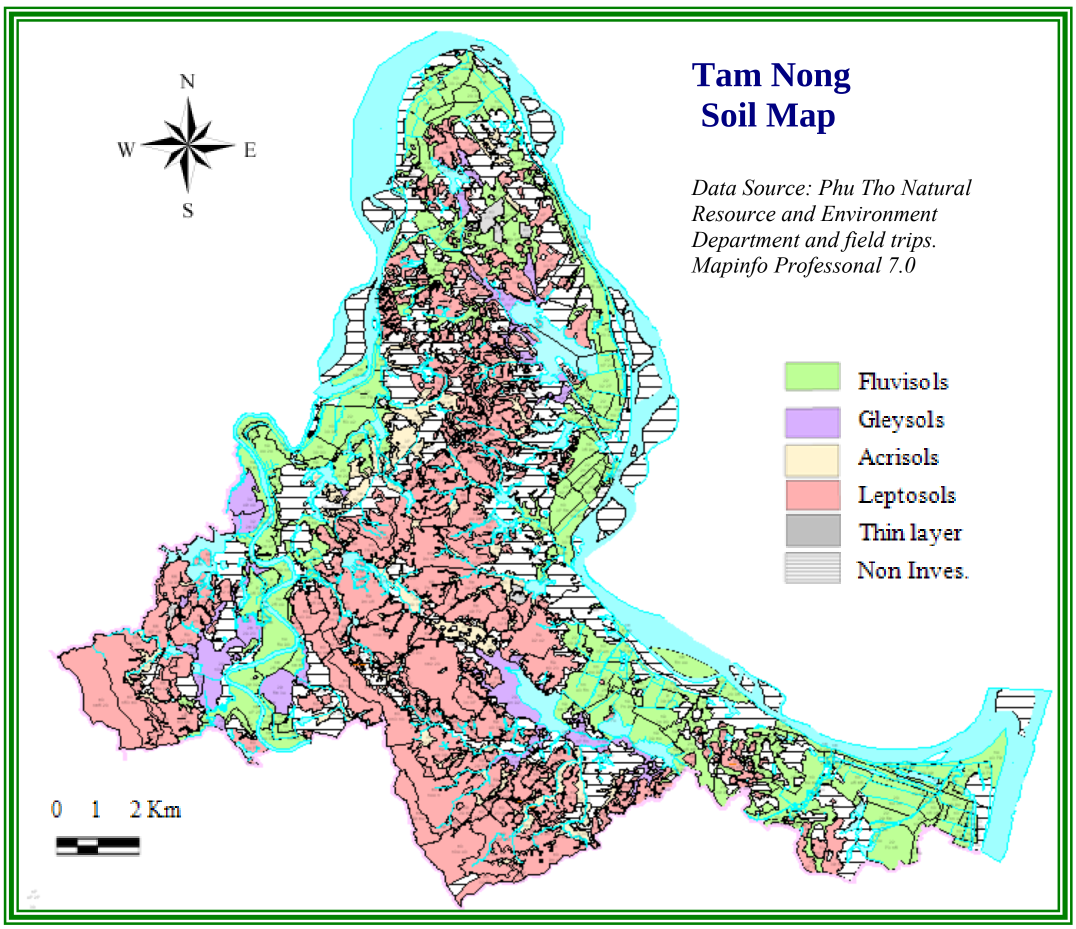


Fig. 5.2 *Soil Map of Tamnong District with main soil types*

5.2 Building Land Mapping Unit

5.2.1 Principles to Build Land Mapping Unit

Land Mapping Unit (LMU) is an area of land identified specifically on the land unit map with the characteristics and nature of land suitable to different kind of land use that have the same management conditions and same ability to produce and enrich land quality. Based on FAO, building LMU needs to comply with the following principles:

- LMU is required to ensure the ultimate consistency or classification criteria are to be identified clearly.
- LMU needs to be presented on the map.
- LMUs are to be defined simply based on characteristics observed directly on the field.
- Characteristics and nature of LMUs must be relatively stable and reliable and they demand using land appropriately for different land use and land evaluation.

5.2.2 Determining Factors and Classification Criteria of Building LMU

Fundamentals to Select Factors and Classification Criteria:

- Based on the nature of province and the district
- Existing land use type and results of analyzing investment, profits of different land use types.
- Impacts of natural conditions on productivity and requirements for land use towards development goals.
- Based on available documents and updated regulations
- Based on the ratio maps used in land evaluation

Principles to identify Factors and Classification Criteria

- Units of land map are required to be consistent on basic factors.
- Grouping LMUs must be practical in relation with land use.

- Units of land map are defined by the nature of soil that can be measurable, analyzed or estimated less affected by other factors.

5.2.3 Land Suitability Classification in Tam Nong

To put the best land use options into practice, it is necessary to underline biophysical land suitability for classifying key existing LUT. Suitability levels are expressed in qualitative terms, namely highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and unsuitable (N) (FAO, 1976). The spatial dataset used for this assessment include:

- Soil map 2005 (1:25,000)
- Land-use map 2005 (1:25,000)
- Topographic map 2005 (1:25,000)
- Climatic data and Census and Administrative Units

These data models were developed to provide a common design framework for key layers of geographic information in order to promote openness and interoperability of GIS data.

5.2.4 Select Elements and Hierarchical Criteria

The classification of soils in Tam Nong was based on the result of soil profile analysis with reference to soil table classification of Phu Tho soil mapping and in accordance with new classification of FAO modified for Vietnamese conditions.

Based on the status in Tam Nong and the result of land classification, the following elements and hierarchical criteria were selected: Soils type name (G), Topographic position (E), Slope (SL), Irrigational conditions (I), Flooding hazard (F), Effective soil depth (L), Soil depth (D), and Soil Texture (C).

Following land suitability classification, Tam Nong has four major soil groups and hierarchical criteria classified according to FAO.

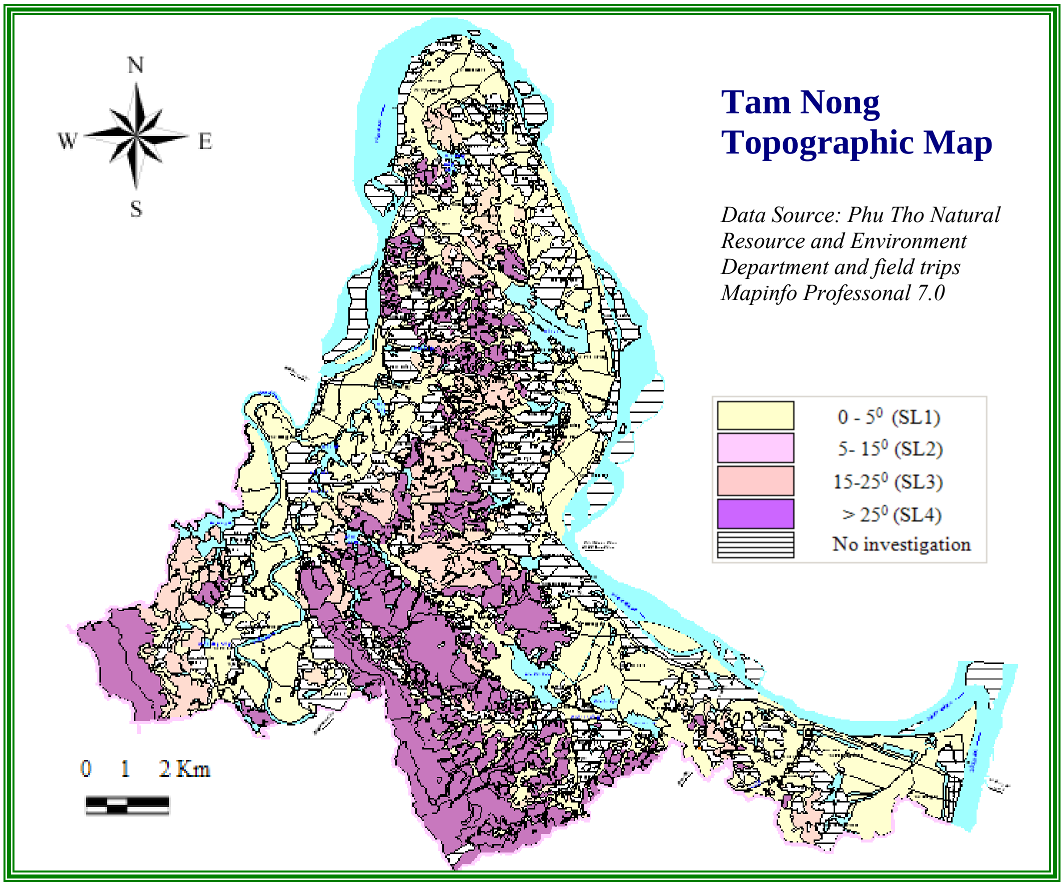


Fig. 5.3 *Tam Nong Topographic Map*

__Table 5.3__ Factors and Classification Criteria

No.	Factors	Classification	Criteria	Symbol
1	Soil types	1	Fluvisols	G_1
		2	Greysols	G_2
		3	Haplic Acrisols – Gleyic Acrisols	G_3
		4	Ferralic Acrisols – Ferric Acrisols	G_4
		5	Leptosols	G_5
2	Slope	1	From 0 to less than 5^0	SL_1
		2	From 5 to less than 15^0	SL_2
		3	From 15 to less than25^0	SL_3
		4	More than 25^0	SL_4
3	Topographic feature	1	Under mid slope	E_1
		2	Medium mid slope	E_2
		3	Lower mid slope	E_3
4	Irrigation régulations	1	Controlled irrigation	I_1
		2	Uncontrolled irrigation	I_2
		3	Non irrigated agriculture	I_3
5	Water flooding	1	Flooding under 3 months	F_1
		2	Flooding from 3 to 6 months	F_2
		3	Flooding more than 6 months	F_3
6	Thickness layer cultivation	1	More than 20 cm	L_1
		2	From 15 to 20 cm	L_2
		3	Under 15 cm	L_3
7	Soil depth	1	Over 100 cm	D_1
		2	From 50 to 100 cm	D_2
		3	Under 50 cm	D_3
8	Soil Texture	1	Sandy	C_1
		2	Limon	C_2
		3	Clay	C_3

5.2.5 Results of Building Land Mapping Units.

The district has 64 LMUs that consist of 790 plots, with an area of 11,273.71 hectares. Each plot has an area is 14.31 hectares on average. LMU No.1 has an area of 3.88 hectares, the smallest and No. 60 LMU has the largest area of 2,263.86 hectares (including 63 plots).

Table 5.4 Classification of LMU by Topographic Area

Topographic Area	Number of LMU	LMU	Total Area (ha)	Propottion (%)
		Flat-land area	**5,291.74**	**100**
High	10	1, 2, 3, 4, 5, 6, 24, 33, 34, 35	316.76	6.00
Average	20	7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 25, 36, 37, 38, 39, 40, 41, 42, 43	2,905.44	54.90
Lower	15	18, 19, 20, 21, 22, 23, 26, 27, 28, 29, 30, 31, 32, 44, 45	2,069.54	39.10
		Upland area	**5,981.97**	**100**
Level 1	3	46, 47, 48	388.62	6.50
Level 2	4	49, 50, 51, 63	499.94	8.36
Level 3	6	52, 53, 54, 55, 56, 64	1,393.44	23.29
Level 4	6	57, 58, 59, 60, 61, 62	3,699.97	61.85

The detailed and descriptive characteristics of LMU in Tam Nong were shown in table 5.6a and 5.5b

__Table 5.5a__ Characteristics of Land Mapping Units in Tam Nong

LMU	Characteristics								Total No.of plots	Area (ha)
	G	E	SL	I	F	L	D	C		
1	1	1		2		2		1	1	3.88
2	1	1		3		1		1	1	20.16
3	1	1		3		1		2	1	5.68
4	1	1		3		2		1	3	12.65
5	1	1		3		2		2	7	50.42
6	1	1		3		2		3	1	13.30
7	1	2		1		1		1	1	29.48
8	1	2		1		1		2	9	218.49
9	1	2		1		2		1	4	56.24
10	1	2		1		2		2	45	677.82
11	1	2		2		1		2	6	123.72
12	1	2		2		2		1	1	25.84
13	1	2		2		2		2	15	293.29
14	1	2		3		1		1	20	301.05
15	1	2		3		1		2	11	94.00
16	1	2		3		2		1	36	411.13
17	1	2		3		2		2	11	73.89
18	1	3			1	2		2	4	49.96
19	1	3			2	1		2	15	287.03
20	1	3			2	2		2	15	185.32
21	1	3			3	1		2	14	230.05
22	1	3			3	2		2	30	527.08
23	1	3			3	2		3	4	34.37
24	2	1		3		1		3	3	7.29
25	2	2		3		1		2	2	11.93
26	2	3			2	1		2	8	79.11
27	2	3			2	1		3	5	50.25
28	2	3			2	2		2	11	115.15
29	2	3			2	2		3	9	251.26
30	2	3			3	1		2	8	35.41
31	2	3			3	2		1	6	46.53
32	2	3			3	2		2	2	75.48

Table 5.5b *Characteristics of Land Mapping Units in Tam Nong (to be continued)*

LMU	Characteristics								Total No. of plots	Area (ha)
	G	E	SL	I	F	L	D	C		
33	3	1		3		1		1	15	74.90
34	3	1		3		2		1	33	114.08
35	3	1		3		2		2	7	14.40
36	3	2		1		1		1	3	43.30
37	3	2		1		2		1	10	101.38
38	3	2		2		1		1	4	13.68
39	3	2		2		2		1	12	78.03
40	3	2		3		1		1	6	49.42
41	3	2		3		1		2	11	98.78
42	3	2		3		1		3	1	11.39
43	3	2		3		2		1	33	192.58
44	3	3			3	1		1	11	33.83
45	3	3			3	2		1	18	68.71
46	4		1	3			1	1	27	91.07
47	4		1	3			2	1	31	226.01
48	4		1	3			2	2	3	71.54
49	4		2	3			1	2	14	59.36
50	4		2	3			2	1	24	323.56
51	4		2	3			3	2	8	71.58
52	4		3	3			1	1	1	84.40
53	4		3	3			1	2	27	332.14
54	4		3	3			2	1	2	118.45
55	4		3	3			2	2	30	560.20
56	4		3	3			3	2	5	263.86
57	4		4	3			1	1	1	88.18
58	4		4	3			1	2	61	844.70
59	4		4	3			2	1	3	308.52
60	4		4	3			2	2	63	2263.86
61	4		4	3			3	1	7	107.96
62	4		4	3			3	2	3	86.75
63	5		2	3			3	2	3	45.44
64	5		3	3			3	2	4	34.39

5.3 Determination of Land Use Types in Tam Nong

Following Land Suitability Classification and LMU in Tam Nong, LUT were detailed determining below:

5.3.1 Determination of Land Use Types

The terms “land unit” (LU), “land utilization type” (LUT) and “land use system” (LUS) have been widely accepted since their introduction by FAO in the 1970s (FAO 1976). When applied in the context of land evaluation, they have been effective in illustrating that the same type of soil can function in different ways depending on land use. The functioning of soil is considered often in a broader context than solely the production of crops. In many countries, environmental laws have been enacted calling for sustainable forms of land management, implying the realization of economically and socially acceptable production levels in production systems that are in harmony with nature and the environment (FAO, 1993).

Land use type is a special type of land use described by unique characteristics. In agricultural production, land type use is defined as a form of using land to produce one or a group of plants or animals in the cycle for one year or multiple years.

Such type of land use can be known broadly as the region for agriculture as follows:

- Delta areas: those focus on growing rice and rice with dry plants,
- Hills and mountainous areas: those are suitable to grow annual crops and perennial industrial trees.

Bases to determining LUTs are as follows:

- Current situations of land use, production results, and available research results.
- Nature conditions suitable with requirements of generating and developing plants.
- Land use types are required to be suitable with economic, political, and social developments of research areas.

5.3.2 Result of Determining LUTs in Tam Nong

Based on results investigated by farmer households of land use conditions to define a number of land use type on Tam nong district as shown in Table 5.6:

Table 5.6 *Status of Land Use Type in Tam Nong*

No	Land Use Type	LUTs (Land Utilization Types)
1	2 Rice + 1 Crop	Spring Rice + Winter Rice + Winter Maize
		Spring Rice + Winter Rice + Winter Potato
		Spring Rice + Winter Rice + Spring Tomato
		Spring Rice + Winter Rice +Soybean
		Spring Rice + Winter Rice + Winter Vegetable
2	1 Rice + 2 Crops	Spring Peanut + Winter Rice + Winter Maize
		Spring Soybean + Winter Rice + Winter Maize
		Spring Vegetable +Winter Rice +W. Vegatable
3	2 Rice	Spring Rice + Winter Rice
4	1 Rice + 1 Crop	Spring Peanut + Winter Rice
		Spring Soybean + Winter Rice
5	1 Rice + 1 Fish	Spring Rice +Fish
6	Vegetable	Varied Vegetables
7	Crops	Spring Maize + Summer Soybean + Winter Maize
		Spring Peanut +Summer Soybean+ Winter Maize
		Spring Maize + Winter Maize
		Spring Soybean+ Winter Maize
		Cassava
8	Perennial industrial trees	Waxplant*
		Tea
9	Fruit crops	Mango, Litchi,
10	Agro–Forest trees	Fruits + Planted Forest
11	Forest trees	Planted Forest
		Natural Forest

** Rhus succedanea L, Anacardiaceae tree.*

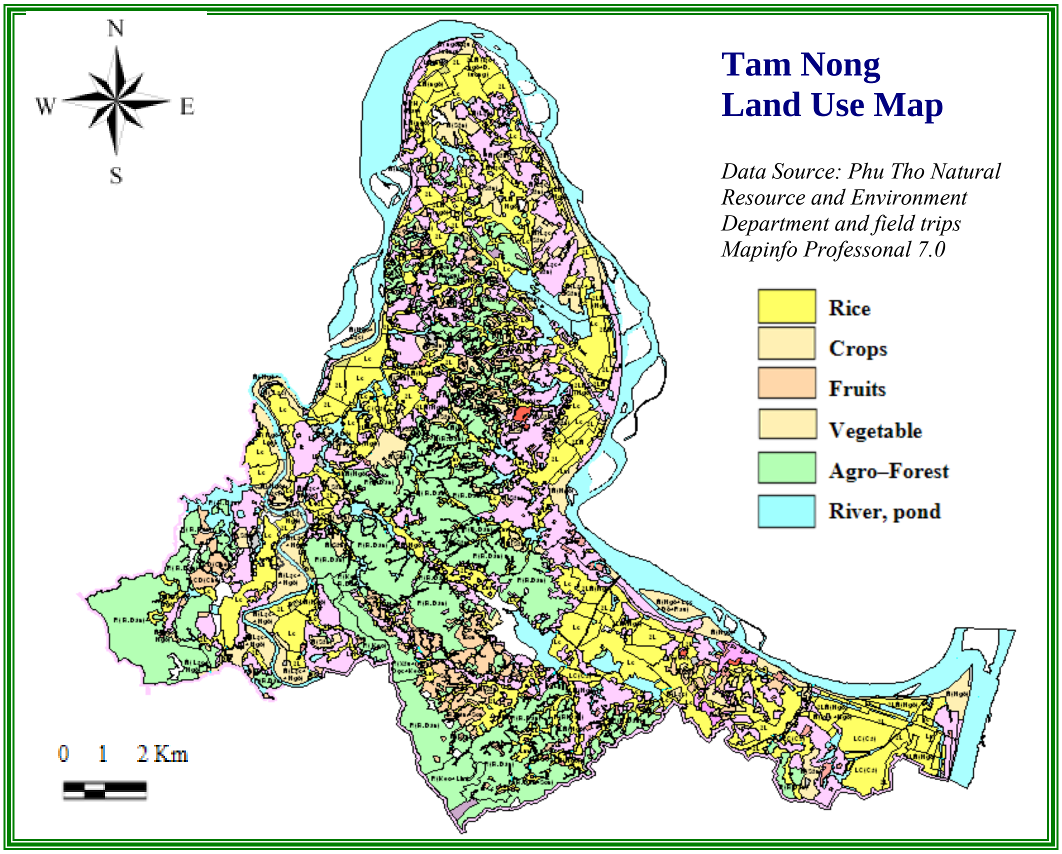


Fig. 5.4 *Present Land Use Type Mapping in Tam Nong*

5.3.3 Analyzing Economic Efficiency of Land Use Types

Based on LUT, a survey on analyzing economic efficiency of LUT models on soils and LMU was conducted relying on the criteria including productivity, material costs, production costs, total revenue, net income, and efficiency of capital. The criteria are based on per hectare, in which:

- Total value of product (total revenue): This is the value obtained per year and calculated by the product of the crop production and the selling price at the calculating time.
- Cost of material: It includes the cost of seed, fertilizer, pesticide, etc.; this criterion only reflects the requirements of money invested by one unit area per year.

- Production costs: It includes costs of irrigation fees, agricultural services, grubbing land costs, transportation costs when harvesting and other costs.
- Total cost: It includes all costs (material and production costs) per one unit area.
- Net income: also known as actual income, calculated by subtracting the total value of product from the total cost excluding the cost of labor.
- Efficiency of capital: It is calculated by net income divided by total costs.

The criteria of analyzing economic efficiency to assess and select the types of land use are divided into five levels: very high, high, medium, low, very low. They are explained in Table 5.7:

Table 5.7*: Division of Criteria on Assessing the Economic Efficiency of Land Use Types*

The level of assessment	Symbol	Total cost (Mil. VND)	Total income (Mil. VND)	Net income (Mil. VND)	Efficiency of capital (times)
Very High	VH	> 20	> 30	> 20	1,5
High	H	15-20	25-30	15-20	1,2-1,5
Medium	M	10-15	20-25	10-15	1,0-1,2
Low	L	5-10	15-20	5-10	0,8-1,0
Very Low	VL	< 5	< 15	< 5	< 0,8

(The fixed prices in 2005)

The types of land use in Tam Nong district require different levels of investment costs, total income, working day value or efficiency of capital.

The types of land use with the product value from High to Very High are the land use types cultivated 3 times per year, the type specializing in vegetable cultivation and type of land use of 1rice +1fish; the types of land use for planting wax plant, tea, fruit trees giving average income, but very high working day value. Three types of LUTs are often integrated with the LUTs of forestry into an agro-forestry model aiming at high level land protection, land erosion resistance and ecological environment protection. Such LUTs are constantly used by farmers.

However, for some LUTs with low efficiency such as planting cassava in hills with high slope, or the LUTs for one rice crop only, it is necessary to recommend farmers that they shift plant schemes of highly effective and more sustainable land use types.

At the same time, the evaluation on economic efficiency of land use types shows that the costs of agricultural materials in 2005 increased significantly while the prices of agricultural products decreased considerably. As a result, the effectiveness of capital in agro-forestry production was not very high, which caused many difficulties for farmers.

Table 5.8 *Economic effectiveness for LUTs* *(S: spring; W:winter; unit 1000 VND)*

No	Land Use Types	Total Value product	Cost			Net income	Eff. of capital (times)
			Total cost	Material cost	Produc_ tion cost		
	1	2	3=4+5	4	5	6=2-3	8=6/3
1	S. Rice + W. Rice + W. Maize	41696	21802	13537	8265	19894	0.91
2	S. Rice + W. Rice + Vegetable	40909	20390	12283	8107	20519	1.01
3	S. Rice + W. Rice + S. Tomato	37714	19988	11863	8124	17726	0.89
4	S. Rice + W. Rice + W. Vegetable	50351	21497	12846	8651	28854	1.34
5	S. Rice + W. Rice +Soybean	37222	19489	11755	7734	17733	0.91
6	S. Peanut + W. Rice + W. Maize	34583	18495	12203	6292	16088	0.87
7	S. Soybean + W. Rice + W. Maize	33682	18255	11012	7243	15427	0.85
8	S. Vegetable +W. Rice +W. Vegatable	48384	22502	15029	7473	25882	1.15
9	S. Rice + W. Rice	29109	16072	9520	6552	13037	0.81
10	S. Peanut + W. Rice	21995	12768	8187	4581	9227	0.72
11	S. Soybean + W. Rice	21094	11454	6996	4458	9640	0.84
12	S. Rice +Fish	50744	17771	9230	8541	32972	1.86
13	S. Rice	15341	6278	3236	3042	9063	1.44
14	W. Rice	11801	8037	4761	3276	3765	0.47
15	Vegetables	39829	21697	15402	6295	18131	0.84
16	S. Maize + Summer Soybean + W. Maize	33289	14875	10268	4606	18414	1.24
17	S. Peanut +Summer Soybean+ W. Maize	29716	13877	9679	4198	15839	1.14
18	S. Maize + W. Maize	25175	11458	8033	3425	13718	1.20
19	S. Soybean+ W. Maize	20701	9146	6252	2893	11555	1.26
20	Cassava	6475	2627	1943	684	3847	1.46
21	Wax plant	20488	2022	548	1474	18467	9.13
22	Tea	17111	8120	6938	1182	8992	1.11
23	Fruit crops	22328	10012	7204	2808	12316	1.23
24	Forest Trees	33984	6696	5011	1685	27288	4.08

Note: Combined and calculated from the field survey results.

Effective social indicator is difficult to be quantified. Thus, within our research topic we use a number of comparative results from surveys in the research area including:

- The ability to attract workers and provide jobs.
- The ability to coordinate with the market demands of the types of land use at the present and in the future.

5.3.4 Analyzing Environmental Impacts of Land Use Types

5.3.4.1. Erosion Hazard

Tam Nong, a mountainous district in Phu Tho province, is a transitional region between plains and mountainous areas. The terrain is characterized by low mountains and high hills with high slope level that are currently exploited under the project of reforestation and agricultural production. However, eucalyptuses and acacia are mostly planted in the area of planted forest and cassava is grown in low and gently sloping areas. Consequently, erosion still happens, which decreases soil fertility and causes the gradual erosion of soil leading to a reduction in agricultural land.

5.3.4.2. Flooding Hazard

As Tam Nong district is located in the transitional area between the delta and the region of hills and mountains, some low lands are often waterlogged. During the rainy season, this area is flooded with the water flowing from the Red River and Bua River, which has affected agricultural production. Currently, a part of this area is utilized for fish farming or rice- fish rotation.

5.3.4.3. Pesticides and Diseases

In recent years, the local people have been aware that using some pesticides in the production has harmful effects, which not only degrades the product quality but also contaminates water, soil and air. Thus, they are gradually using pesticides more properly and tend to use biological products instead because those substances are friendly to the environment.

5.3.4.4 Conditions for Fertilizing

Currently, the majority of farmers often abuse these chemical fertilizers in agricultural production, which results in a decrease in soil fertility. Therefore, we need to encourage them to further apply the scheme of legume rotation and use more organic fertilizers and microorganism fertilizers to grow plants.

5.3.4.5 Soil Toxicities by Industry

Although environmental impacts of industrial and small-scaled industrial production and services are not drastic as those of large-scaled factories in the district, some areas are suffering from the exhaust gas released from Lam Thao Fertilizers and Chemicals Company. Several small-scaled industrial units such as machine repair and maintenance, food milling and processing, brick and tile production were established in residential areas. In addition, domestic waste is considered as an agent that has a direct impact on the environment. Thus, it is important to make an appropriate land planning for the construction and distribution of industrial parks, small-scaled industrial units and to introduce waste treatment systems for sewage disposal.

5.3.5 Analyzing Social-Economic Factor Impacts of Land Use Types.

Tam Nong is a mountainous district where the three rivers, Red River, Da River and Bua River pass through. This region is endowed with fertile soil and rich human resources. These characteristics create favorable conditions for the development of agriculture sustainability and food security. The region provides crops for agricultural product processing. Currently, a number of models with different types of land use are applied to bring out high economic efficiency and generate more job opportunities for the majority of idle labor force.

5.3.6 Selecting Land Use Types

The selection of Land use types in Tam Nong could be based on the analysis on economic efficiency, social and environmental impacts as well as other specific conditions in Tam Nong district.

- Economic efficiency of land use types: Economic profits of households are measured on the system of economic indexes of land use types such as total costs, total income, net income, the effectiveness of capital. The land use types selected must have at least three quarters of the above-mentioned indexes attained at an average level.
- The suitability of land use types to environment: Selected land use types must create a proper land use system in which soil fertility can be improved and maintained, erosion and land degradation or negative impacts on ecological environment can be avoided.
- The land use types selected must be approved by farmers, which means they are suitable to the economic condition and production level.
- The land use types selected must be easy for applying scientific and technological advances into production.
- The land use types selected must coincide with the district's planning and socio-economic development objectives and simultaneously must be in accordance with socio-economic and environmental development planning of Phu Tho province in the period of 2000-2010 and the 2020 vision. Choosing land use types have to develop the potential of land use types in order to speed up their economic development towards sustainability with an emphasis on the development of industries and services to convert Tam Nong district into a developed area of the region and Phu Tho province.

5.4 Assessment, Classification of Land Sustainability.

5.4.1 Determining land use requirements of land use types.

Requirements of land use are determined by characteristics and qualities of different types of land. Each type of land is only suitable for one or several types of land use. Therefore, it is essential to determine the land use requirements of each land use type. Land use requirements of land use types are divided into three groups of criteria as follows:

5.4.1.1 Land use Requirements of Plant Growth

Each plant has its specific requirements to ensure enough nutrition to grow including soil type, relatively slope of terrain, irrigation, and soil quality. To determine the exactly requirements of land use for each type of plant, it is necessary to make a thorough study of the collected research material consulting specialists the agronomists and local people.

In general, the soil in Tam Nong (based on the research results of soil classification) includes many different types of soil, which creates favorable conditions for the development of various types of plants. In the future, it is essential to pay more attention to the application of measures that help strengthen and maintain the soil fertility by using organic fertilizer, alluvium irrigation as well as to the rotation of legumes and proper plant arrangement.

5.4.1.2 Land Use Requirements of Farming Management

Each type of land use requires a specific method of management, administration, investment and expected output. These requirements have to be adapted for all types of land use but are required to conform to economic conditions as well as the ability to apply science and technology into the production by local people.

5.4.1.3 Land Use Requirements for Sustainable Development

The selection of land use types must satisfy requirements of stability as well as ecological balance:

- In terms of economic sustainability, the selection of land use types should result in high economic efficiency and meet the requirements of the market
- In terms of environmental sustainability: Land use types must protect land, prevent it from erosion and soil degradation, and preserve the ecological environment
- In terms of social sustainability, land use types are expected to attract relatively stable labor resource, to utilize other available resources and on-site local production facilities to ensure the workers' life and social development

Land suitability class reflects degrees of suitability. The classes are numbered consecutively in sequence of descending degrees of suitability. Four classes are probably the most commonly used. The following names and definitions of factor ratings would be appropriate in a qualitative classification applied in Tam Nong:

- Class S1 - Highly Suitable is defined as land with no significant limitations to sustained application of a given use or with only minor limitations that will not significantly reduce productivity benefits and will not raise inputs above an acceptable level.
- Class S2 - Moderately Suitable is defined as land having limitations, which in aggregate are moderately severe for sustained application of a given use. The limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on class S1 land.
- Class S3 - Marginally Suitable is defined as land having limitations, which in aggregate are moderately severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.
- Class N - Not Suitable is defined as land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.

Results of Ratings of Diagnostic Factors for LUTs

Among various kinds of crops grown in Tam Nong, rice is the most important kind in agriculture, so results of ratings of diagnostic factors for LUTs will be divided into two groups - with Rice and without Rice.

***Table 5.9** Ratings of diagnostic factors for LUTs with Rice*

LUTs	Land Use Requirements-Diagnostic Factors	Factor Ratings			
		S_1	S_2	S_3	N
2 Rice + 1 Crop	Soils type name (G)	G_1	G_3	G_2, G_4	G_5
	Topographic position (E)	E_2		E_1	E_3
	Slope (SL)			SL_1	SL_2, SL_3, SL_4
	Irrigational conditions (I)	I_1	I_2	I_3	
	Flooding hazard (F)				F_1, F_2, F_3
	Effective soil depth (L)	L_2	L_1	L_3	
	Soil Texture (C)	C_2	C_1	C_3	
1 Rice + 2 Crops	Soils type name (G)	G_1	G_3	G_2, G_4	G_5
	Topographic position (E)	E_2	E_1		E_3
	Slope (SL)			Sl_1	SL_2, SL_3, SL_4
	Irrigational conditions(I)	I_1, I_2	I_3		
	Flooding hazard (F)				F_1, F_2, F_3
	Effective soil depth (L)	L_1	L_2	L_3	
	Soil Texture (C)	C_1	C_2	C_3	
2 Rice	Soils type name (G)	G_1	G_2, G_3	G_4	G_5
	Topographic position (E)	E_2	E_3	E_1	
	Slope (SL)			Sl_1	SL_2, SL_3, SL_4
	Irrigational conditions(I)	I_1	I_2	I_3	
	Flooding hazard (F)			F_1	F_2, F_3
	Effective soil depth (L)	L_2	L_1	L_3	
	Soil Texture (C)	C_2	C_1, C_3		
1 Rice + 1 Crop	Soils type name (G)	G_1	G_3	G_2, G_4	G_5
	Topographic position (E)	E_2	E_1		E_3
	Slope (SL)			Sl_1	SL_2, SL_3, SL_4
	Irrigational conditions(I)	I_1, I_2	I_3		
	Flooding hazard (F)			F_1	F_2, F_3
	Effective soil depth (L)	L_1	L_2	L_3	
	Soil Texture (C)	C_1	C_2	C_3	
1 Rice + 1 Fish	Soils type name (G)	G_2	G_1, G_3	G_4	G_5
	Topographic position (E)	E_3		E_2	E_1
	Slope (SL)			SL_1	SL_2, SL_3, SL_4
	Irrigational conditions(I)				
	Flooding hazard (F)	F_3	F_2	F_1	
	Effective soil depth (L)	L_1	L_2	L_3	
	Soil Texture (C)	C_2	C_3	C_1	

Table 5.9a *Ratings of diagnostic factors for LUT 2Rice +1 Crop*

LUTs	Land Use Requirements-Diagnostic Factors	Factor Ratings			
		S_1	S_2	S_3	N
2 Rice + 1 Crop	Soils type name (G)	G_1	G_3	G_2, G_4	G_5
	Topographic position (E)	E_2		E_1	E_3
	Slope (SL)			SL_1	SL_2, SL_3, SL_4
	Irrigational conditions (I)	I_1	I_2	I_3	
	Flooding hazard (F)				F_1, F_2, F_3
	Effective soil depth (L)	L_2	L_1	L_3	
	Soil Texture (C)	C_2	C_1	C_3	

Detailed description of the suitability level of LUT: 2 Rice and 1 Crop

High Suitable with Fluvisols soil types, Topographic medium mid slope, cultivation layer thickness from 15 to 20 cm, and the average Soil Texture.

Moderately Suitable with Haplic Acrisols – Gleyic Acrisols soil types, limited (uncontrolled) irrigation regulations, cultivation layer thickness more than 20 cm, and the Limon Soil Texture.

Marginally Suitable with Greysols and Ferralic Acrisols – Ferric Acrisols soil types, slope from 0 to less than 5^0 , Non irrigated agriculture, soil layer thickness under 15 cm and the clay Soil Texture .

Not Suitable with Leptosols soil type, lower mid slope, flooding area.

Fig. 5.5 *Landscape of LUT 2 Rice + Crop (Maize) in Tam Nong (photo by Nguyen H.)*

Table 5.9b *Ratings of diagnostic factors for LUT: 2Rice*

LUTs	Land Use Requirements-Diagnostic Factors	Factor Ratings			
		S_1	**S_2**	**S_3**	**N**
2 Rice	Soils type name (G)	G_1	G_2, G_3	G_4	G_5
	Topographic position (E)	E_2	E_3	E_1	
	Slope (SL)			Sl_1	SL_2, SL_3, SL_4
	Irrigational conditions(I)	I_1	I_2	I_3	
	Flooding hazard (F)			F_1	F_2, F_3
	Effective soil depth (L)	L_2	L_1	L_3	
	Soil Texture (C)	C_2	C_1, C_3		

Detailed description of the suitability level of LUT: 2 Rice

High Suitable with Fluvisols soil types, topographic medium mid slope, cultivation layer thickness from 15 to 20 cm, and the average Soil Texture.

Moderately Suitable with Greysols and Haplic Acrisols – Gleyic Acrisols soil types, Lower mid slope, cultivation layer thickness more than 20 cm, and the sandy and clay Soil Texture.

Marginally Suitable with Ferralic Acrisols – Ferric Acrisols soil type, under mid slope, None irrigated agriculture, soil layer thickness under 15 cm, flooding under 3 months.

Not Suitable with Leptosols soil type, slope more than 5^0, floods more than 3 months.

Fig. 5.6 *Landscape of LUT 2 Rice in Tam Nong (photo by Nguyen H.)*

__Table 5.9c__ Ratings of diagnostic factors for LUT Rice +1Fish

LUTs	Land Use Requirements- Diagnostic Factors	Factor Ratings			
		S_1	**S_2**	**S_3**	**N**
1 Rice + 1 Fish	Soils type name (G)	G_2	G_1, G_3	G_4	G_5
	Topographic position (E)	E_3		E_2	E_1
	Slope (SL)			SL_1	SL_2, SL_3, SL_4
	Irrigational conditions(I)				
	Flooding hazard (F)	F_3	F_2	F_1	
	Effective soil depth (L)	L_1	L_2	L_3	
	Soil Texture (C)	C_2	C_3	C_1	

Detailed description of the suitability level of LUT: 2 Rice and 1 Fish

High Suitable with Greysols soil types, topographic lower mid slope, flooding more than 6 months, cultivation layer thickness more than 20 cm and the average Soil Texture.

Moderately Suitable with Fluvisols and Haplic Acrisols – Gleyic Acrisols soil types, flooding from 3 to 6 months, cultivation layer thickness from 15 to 20 cm, and the clay Soil Texture.

Marginally Suitable with Ferralic Acrisols – Ferric Acrisols soil type, topographic medium mid slope, flooding under 3 months, soil layer thickness under 15 cm, and the limon Soil Texture .

Not Suitable with Leptosols soil type, under mid slope, slope more than 5^0.

***Fig. 5.7** Landscapes of LUT Rice + Fish in Tam Nong (photo by Nguyen H.)*

__Table 5.10__ Ratings of diagnostic factors for LUTs without rice

LUTs	Land use requirements- Diagnostic factors	Factor Ratings			
		S_1	S_2	S_3	N
Vegetable	Soils type name (G)	G_1	G_3	G_2, G_4	G_5
	Topographic position (E)	E_2	E_1	E_3	
	Slope (SL)			SL_1	SL_2, SL_3, SL_4
	Irrigational conditions(I)	I_1	I_2, I_3		
	Flooding hazard (F)			F_1	F_2, F_3
	Effective soil depth (L)	L_1	L_2	L_3	
	Soil Texture (C)	C_1	C_2	C_3	
Crops	Soils type name (G)	G_1	G_3G_4	G_2	G_5
	Topographic position (E)	E_1	E_2	E_3	
	Slope (SL)		SL_1	Sl_2	SL_3, SL_4
	Irrigational conditions(I)	I_1	I_2, I_3		
	Flooding hazard (F)			F_1	F_2, F_3
	Effective soil depth (L)	L_1	L_2	L_3	
	Soil Texture (C)	C_1	C_2	C_3	
Perennial industrial trees	Soils type name (G)	G_4		G_3, G_5	G_1, G_2
	Topographic position (E)			E_1	E_1, E_2, E_3
	Slope (SL)	SL_1, SL_2	SL_3	SL_4	
	Irrigational conditions(I)	I_1	I_2, I_3		
	Flooding hazard (F)				F_1, F_2, F_3
	Effective soil depth (L)	D_1	D_2	D_3	
	Soil Texture (C)	C_2	C_1	C_3	
Fruit crops	Soils type name (G)	G_1, G_4		G_3, G_5	G_2
	Topographic position (E)	E_1	E_2		E_3
	Slope (SL)	SL_1, SL_2	SL_3	SL_4	
	Irrigational conditions(I)	I_1	I_2, I_3		
	Flooding hazard (F)				F_1, F_2, F_3
	Effective soil depth (L)	D_1	D_2	D_3	
	Soil Texture (C)	C_2	C_1	C_3	
Agro-forest trees	Soils type name (G)	G_4	G_1	G_3, G_5	G_2
	Topographic position (E)		E_1	E_2	E_3
	Slope (SL)	SL_1, SL_2	SL_3	SL_4	
	Irrigational conditions(I)	I_1	I_2, I_3		
	Flooding hazard (F)				F_1, F_2, F_3
	Effective soil depth (L)	D_1	D_2	D_3	
	Soil Texture (C)	C_2	C_1	C_3	
Forest trees	Soils type name (G)	G_4	G_1	G_3, G_5	G_2
	Topographic position (E)		E_1	E_2	E_3
	Slope (SL)	SL_1, SL_2	SL_3	SL_4	
	Irrigational conditions(I)	I_1	I_2, I_3		
	Flooding hazard (F)				F_1, F_2, F_3
	Effective soil depth (L)	D_1	D_2	D_3	
	Soil Texture (C)	C_2	C_1	C_3	

Table 5.10a Ratings of diagnostic factors for LUT Perennial industrial trees

LUT	Land Use Requirements-Diagnostic Factors	Factor Ratings			
		S_1	S_2	S_3	N
Perennial industrial trees	Soils type name (G)	G_4		G_3, G_5	G_1, G_2
	Topographic position (E)			E_1	E_1, E_2, E_3
	Slope (SL)	SL_1, SL_2	SL_3	SL_4	
	Irrigational conditions(I)	I_1	I_2, I_3		
	Flooding hazard (F)				F_1, F_2, F_3
	Effective soil depth (L)	D_1	D_2	D_3	
	Soil Texture (C)	C_2	C_1	C_3	

Detailed description of the suitability level of LUT Perennial industrial trees

High Suitable with Greysols soil types, Topographic lower mid slope, flooding more than 6 months, cultivation layer thickness more than 20 cm and the average Soil Texture.

Moderately Suitable with Fluvisols and Haplic Acrisols – Gleyic Acrisols soil types, flooding from 3 to 6 months, cultivation layer thickness from 15 to 20 cm, and the clay Soil Texture.

Marginally Suitable with Ferralic Acrisols – Ferric Acrisols soil type, topographic medium mid slope, flooding under 3 months, soil layer thickness under 15 cm, and the limon Soil Texture .

Not Suitable with Leptosols soil type, under mid slope, slope more than 5^0

***Fig. 5.8** Landscape of LUT Perennial industrial trees(Tee+ Wax) in Tam Nong (photo by Nguyen H.)*

Table 5.10b Ratings of diagnostic factors for LUT Fruit Crops

LUT	Land Use Requirements-Diagnostic Factors	Factor Ratings			
		S_1	S_2	S_3	N
Fruit crops	Soils type name (G)	G_1, G_4		G_3, G_5	G_2
	Topographic position (E)	E_1	E_2		E_3
	Slope (SL)	SL_1, SL_2	SL_3	SL_4	
	Irrigational conditions(I)	I_1	I_2, I_3		
	Flooding hazard (F)				F_1, F_2, F_3
	Effective soil depth (L)	D_1	D_2	D_3	
	Soil Texture (C)	C_2	C_1	C_3	

Detailed description of the suitability level of LUT Fruit Crops

High Suitable with Fluvisols and Greysols soil types, topographic medium mid slope, flooding more than 6 months, cultivation layer thickness more than 20 cm and the average Soil Texture.

Moderately Suitable with Fluvisols and Haplic Acrisols – Gleyic Acrisols soil types, flooding from 3 to 6 months, cultivation layer thickness from 15 to 20 cm, and the clay Soil Texture.

Marginally Suitable with Ferralic Acrisols – Ferric Acrisols soil type, topographic medium mid slope, flooding under 3 months, soil layer thickness under 15 cm, and the limon Soil Texture .

Not suitable with Leptosols soil type, under mid slope, slope more than 5^0

Fig. 5.9 *Landscapes of LUT Fruit Crops in Tam Nong (photo by Nguyen H.)*

Table 5.10c *Ratings of diagnostic factors for LUT Forest tree*

LUT	**Land Use Requirements- Diagnostic Factors**	**Factor Ratings**			
		S_1	**S_2**	**S_3**	**N**
Forest trees	Soils type name (G)	G_4	G_1	G_3, G_5	G_2
	Topographic position (E)		E_1	E_2	E_3
	Slope (SL)	SL_1, SL_2	SL_3	SL_4	
	Irrigational conditions(I)	I_1	I_2, I_3		
	Flooding hazard (F)				F_1, F_2, F_3
	Effective soil depth (L)	D_1	D_2	D_3	
	Soil Texture (C)	C_2	C_1	C_3	

Detailed description of the suitability level of LUT Forest tree

High Suitable with Ferralic Acrisols – Ferric Acrisols soil types, slope level 1 to level 2 From 0 to less than 15^0, Controlled Irrigation regulations, soil layer thickness more than 100 cm and the average Soil Texture .

Moderately Suitable with Fluvisols soil type, slope from 15 to less than25^0 uncontrolled irrigation regulations, soil layer thickness from 50 to 100 cm and the sandy Soil Texture.

Marginally Suitable with Haplic Acrisols – Gleyic Acrisols and Leptosols soil types, slope from 15 to less than25^0, soil layer thickness less than 50cm and the clay Soil Texture.

Not suitable with Greysols soil type, lower mid slope, flooding area.

Fig. 5.10 *Landscape of LUT Forest trees in Tam Nong (photo by Nguyen H.).*

5.4.2 Land Suitability Classification for Land Evaluation

Land suitability classification for land evaluation is reflected in the level appropriate for each type of land use on the LMU. Based on requirements of LUT compared with the characteristics on the land-mapping unit for the appropriate ratings for each land unit map of each land use type in future classifying appropriate (see Appendix A)

5.5. Proposed Land Use Types

5.5.1. Basis of Proposed Land Use Types

The socio-economic development goals of the district in agricultural production are to promote the development of cultivation models and animal husbandry which is capable of improving and enriching the soil and protecting the ecological environment to improve the performance of land use.

Types of land use are proposed to ensure the development in the immediate and long term and to take advantage of the resources, facilities and labor resources of the region. Selected types of land use are required to meet the criteria of sustainable development, forming the specific-scaled production zones.

The proposed land use must be consistent with the market mechanism, which results in effective land use, ensuring the development of various economic sectors, service industries, and processing industries.

5.5.2 Proposal for Land Use Types in the Tam Nong District

Based on natural and socio-economic conditions as well as the above fundamental bases, our recommendations for the land use in the Tam Nong district are shown in Table 5.11

Thus to achieve the proposed area of land use, the district has to implement of soil protection and soil fertility enrichment which balance economic efficiency, environmental protection and ecological suitability.

Table 5.11 *Proposal for land use types in Tam Nong*

No	Land Use types	Factor ratings	Area (ha)	Land Mapping Units
1	2 Rice + 1 Crop	S_1	837,95	8, 10
		S_2	144,68	36, 37
2	1 Rice + 2 Crops	S_1	25,84	12
		S_2	185,07	1, 6, 15 ,17
3	2 Rice	S_2	457,43	11, 13, 38, 39
		S_3	11,93	25
4	1 Rice + 1 Crop	S_2	160,59	5, 41, 42
		S_3	7,29	24
5	1 Rice + 1 Fish	S_1	110,89	30, 32
		S_2	1651,0	19, 20, 21, 22, 23, 26, 27, 28, 29, 31,
		S_3	36,05	18
6	Specialized Vegetable	S_1	85,72	7, 9
		S_2	31,15	16, 17
7	Crops	S_2	1070,6	2,3,4,14, 16, 33, 34, 35, 40, 43
8	Perennial Indus. trees	S_2	1224,0	47, 50, 52, 54, 55
9	Fruit crops	S_2	221,97	46, 48, 49
10	Agri + Forest Trees	S_2	577,10	53, 56
		S_3	1589,8	57, 58, 60
11	Forest Trees	S_3	2171,0	51, 59, 61, 62, 63, 64

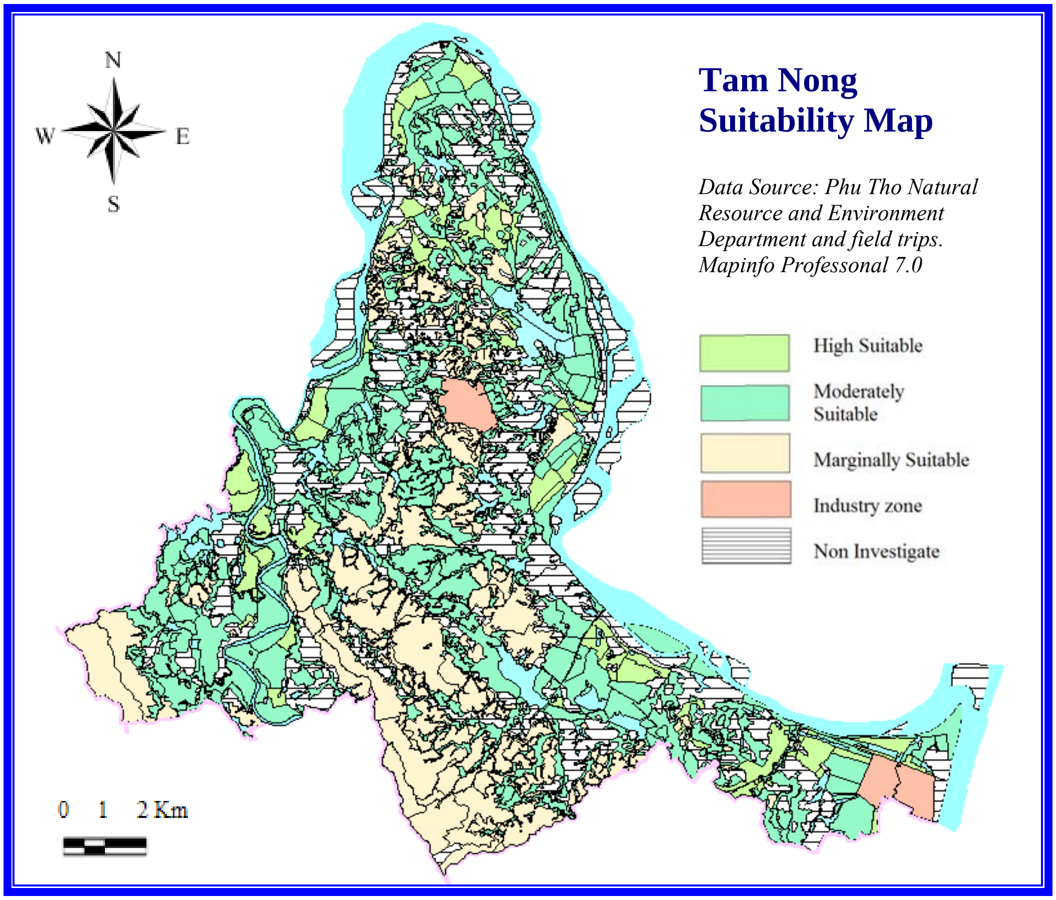


Fig. 5.11 *Tam Nong Suitability classification Map*

Table 5.12 *Compare between LUTs in 2005 and proposed LUTs in TamNong in terms of area*

Items	Code	In 2005		In Proposal		Compare (+/-)	
		Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(%)
Total Area		**15,577.69**	**100.00**	15577.69	**100.0**	0	**0.00**
Agricultural Land	NNP	11,460.68	73.57	10892.88	69.93	-567.8	4.95
Production Agricultural land	SXN	7,267.34	46.65	6771.83	43.47	-495.51	6.82
Annual crops land	CHN	5,074.48	32.58	4623.78	29.68	-450.7	8.88
Paddy land	LUA	3,759.87	24.14	3759.87	24.14		
Rice	LUC	1,462.03	9.39	1293.57	8.30	-168.46	11.52
Rice and others	LUK	2,297.84	14.75	2297.84	14.75		
Others annual crops land	HNC	1,314.61	8.44	1314.61	8.44		
Perennial industrial trees	CLN	2,192.86	14.08	2138.74	13.73	-54.12	2.47
Forest Land	LNP	3,619.34	23.23	3495.38	22.44	-123.96	3.42
Production forest land	RSX	2,881.09	18.49	2744.48	17.62	-136.61	4.74
Protective forest land	RPH	738.25	4.74	750.9	4.82	12.65	1.71
Water surface land for fishing	NTS	573.27	3.68	639.21	4.10	65.94	11.50
Others Agricultural Land	NKH	0.73	0.00	0.73	0.00		
None Agricultural Land	PNN	3,726.78	23.92	4316.85	27.71	590.07	15.83

5.5.3 Agricultural Database in Tam Nong

Based on the above-mentioned objective and the facts of the study area, the research puts forward the criteria to set up thematic maps and for evaluated land unit maps include: soil classification, soil sloping, soil layer depth, soil texture, soil fertility and current land use.

In addition to these criteria, in order to establish a more detailed thematic map, the study also pays attention to other criteria. These data are generalized and analyzed for the whole area without being separated for evaluated land units.

In Tam Nong district, there are 11 LUTs; each LUT has some cropping system with totally 24 cropping systems.

The LMU was based on combinations of soil units, soil slope, soil depth, and soil texture layers. LMUs which were identified in the Tam Nong district map and attributed information were recorded in MapInfo software.

There are four major soil groups with 64 LMUs of 11.273, 71 ha in the research area Tam Nong after overlaying the thematic maps: Soils type name (G), Topographic position (E), Slope (SL), Irrigational conditions (I), Flooding hazard (F), Effective soil depth (L), Soil depth (D) and Soil Texture (C).

Based on the survey and analysis of agricultural lands in Tam Nong, three classes are recognized within the suitable order as can often be recommended. The following names and definitions may be appropriate in a qualitative classification: S1, S2, S3 and N.

CHAPTER 6

BUIDING THE DECISION SUPPORT SYSTEM

6.1 Analyzing System

6.1.1 Requirement Analysis

LUP requires a decision-making support system that meets the following criteria:

- Support the model by creating linear programming problems.

- Support the development of options by solving problems and produce solutions of linear programming problems.

- Support the analysis of options and update the results for decision-making processes.

6.1.2 Model Description

Based on the factual data, we developed the decision-making support model including the following components:

- Problem supporting component: this component supports the builder of the problem and the digital data entry.

- Optimal solving problem component: this component helps the decision-maker solve the optimal problem by using the cut method.

- Combining experts' opinion component: this component helps the decision maker to set up the necessary requirements and expert data and to combine the experts' opinions by using Delphi method which developed by Arnold Kaufmann and Madan M. Gupta(1988) and modified by Thanh (2008).

- Reporting and implementing component: this component helps to report the final selected option on the planning map.

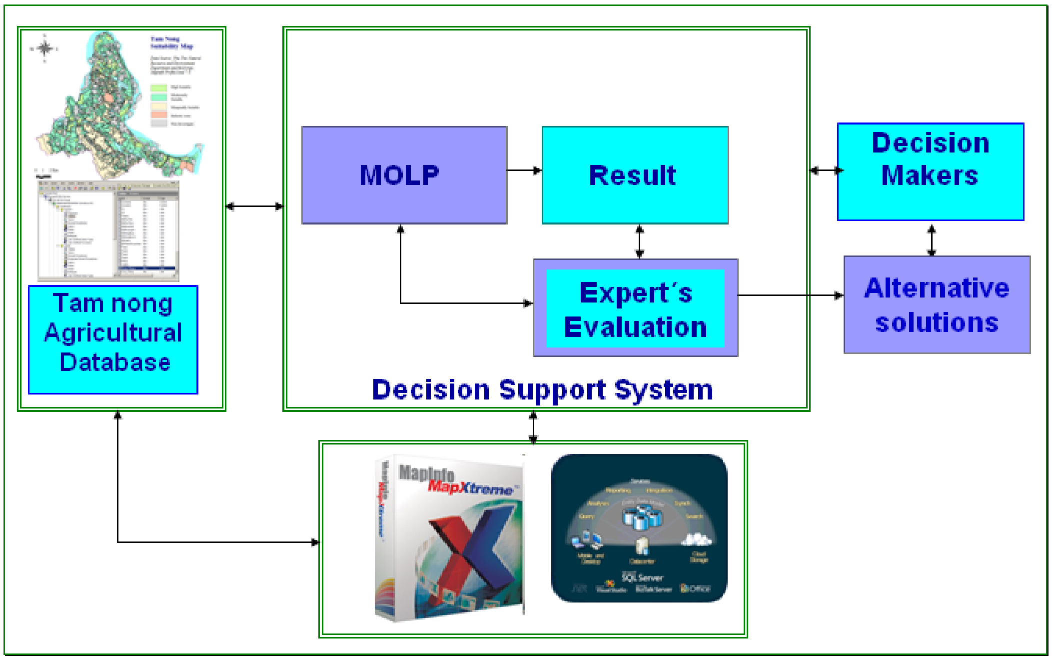


Fig. 6.1 *DSS Data processing on a computer system using integrated software.*

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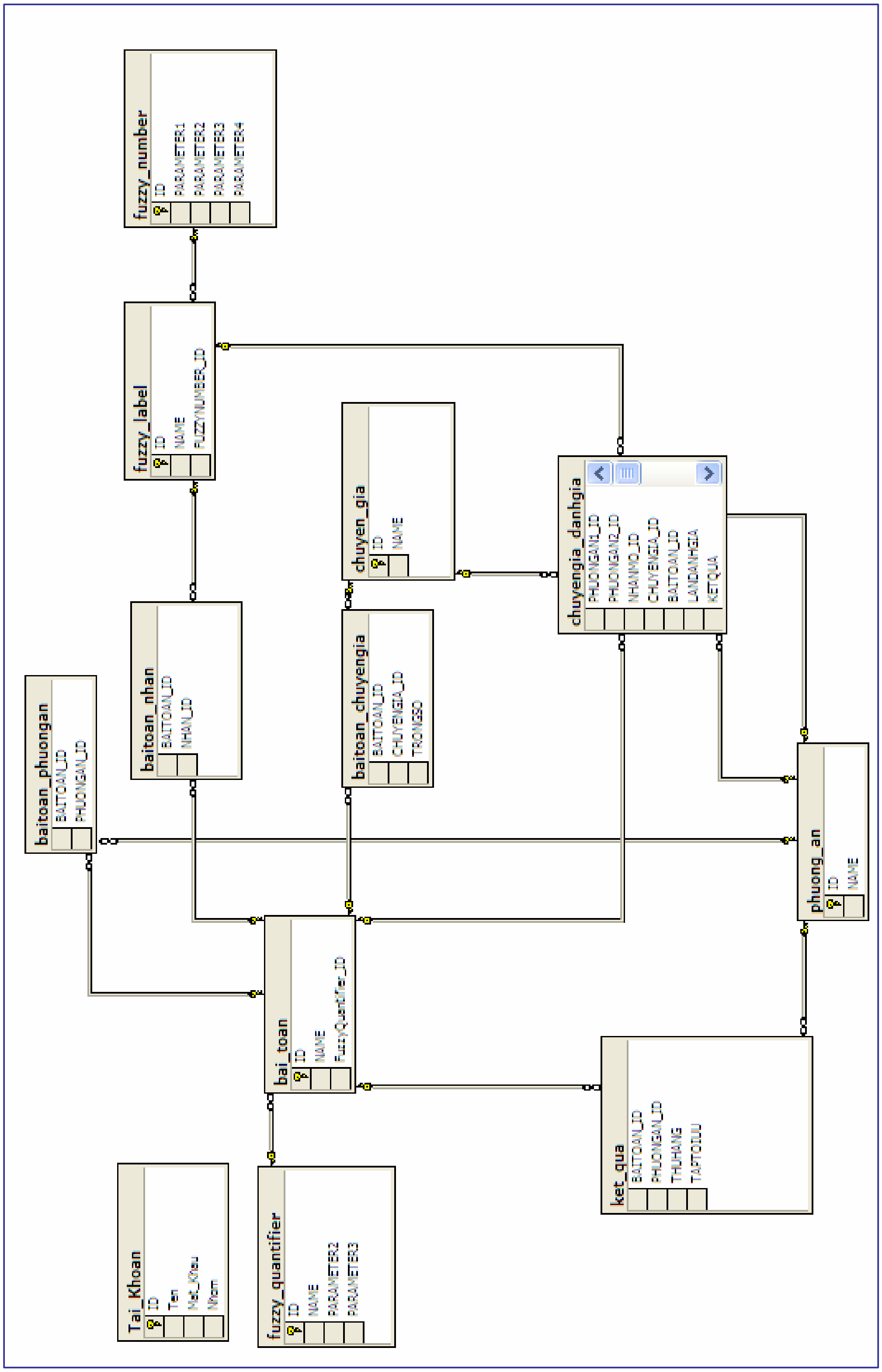

***Fig. 6.2** Modeling of Data Entity Relationship of the collective decision making problem adapted from Quan (2006)*

6.2 Building the Decision Support System

6.2.1 Designing the System´s Interface and Main Menu.

In the research, Microsoft Visual Studio together with MapInfo MapXtreme software are used to develop the DSS. Microsoft Visual Studio is an Integrated Development Environment (IDE) from Microsoft which can be used to develop console and graphical user interface applications along with Windows Forms. Map Xtreme is a major release of MapInfo's industry leading location-based development environment which enables the creation of custom mapping applications or map enablement of applications and solutions in Microsoft Windows desktop and web environments.

Main Menu

The system's interface is designed in a user-friendly manner. The system shares certain rights to users.

The system's interface is designed with the view on being user-friendly. The system shares certain rights to users.

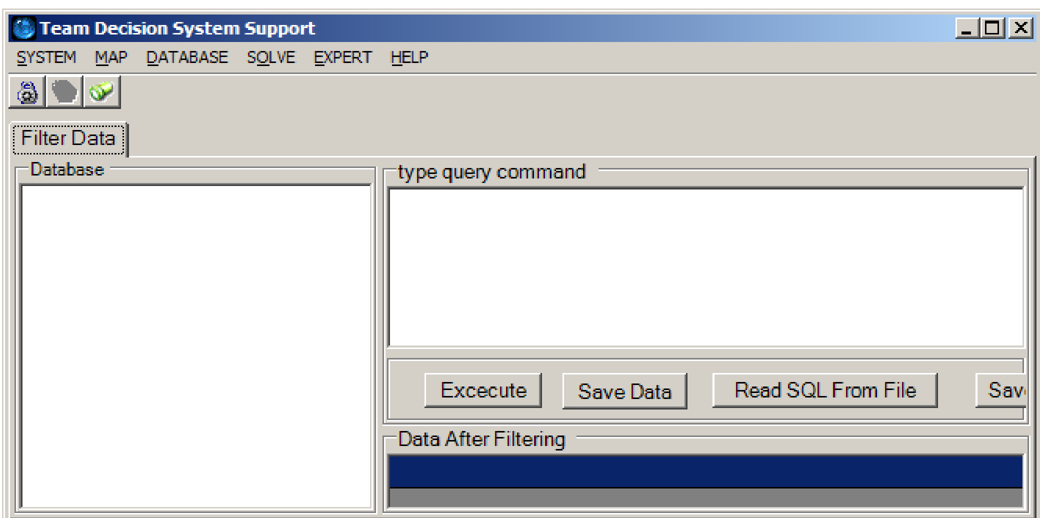

Fig. 6.3a *Main Menu in DSS Program*

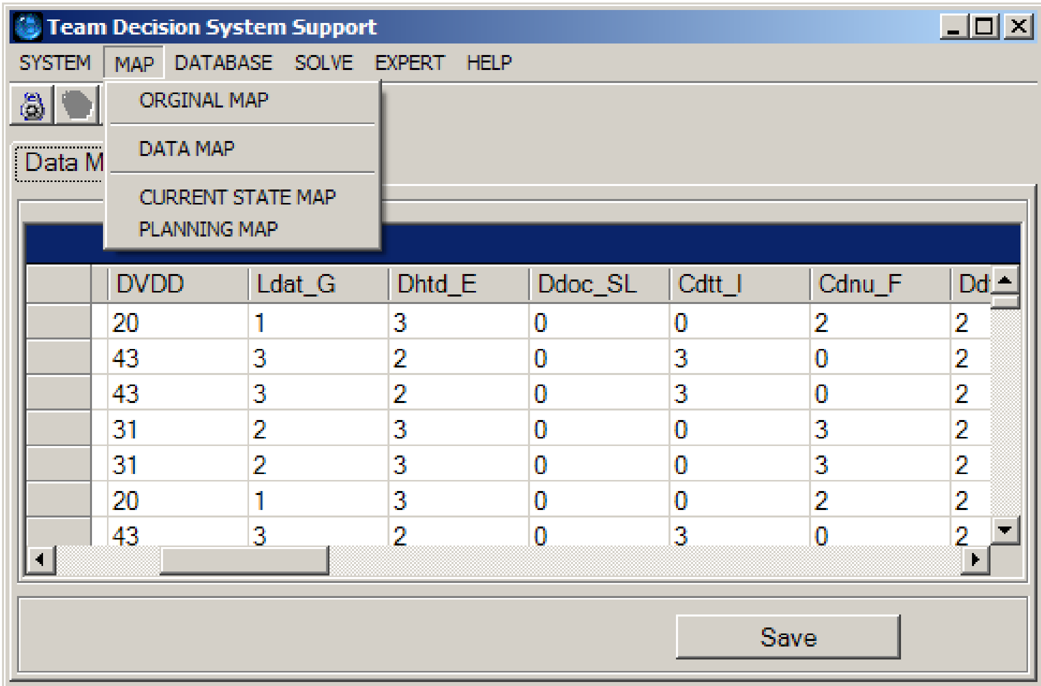

__Fig. 6.3b__ Manage attributed data in DSS Program

Manage Use

The administrator has the highest authority to set up the data and the problem. Users with less power can solve the established problems and obtain the corresponding result.

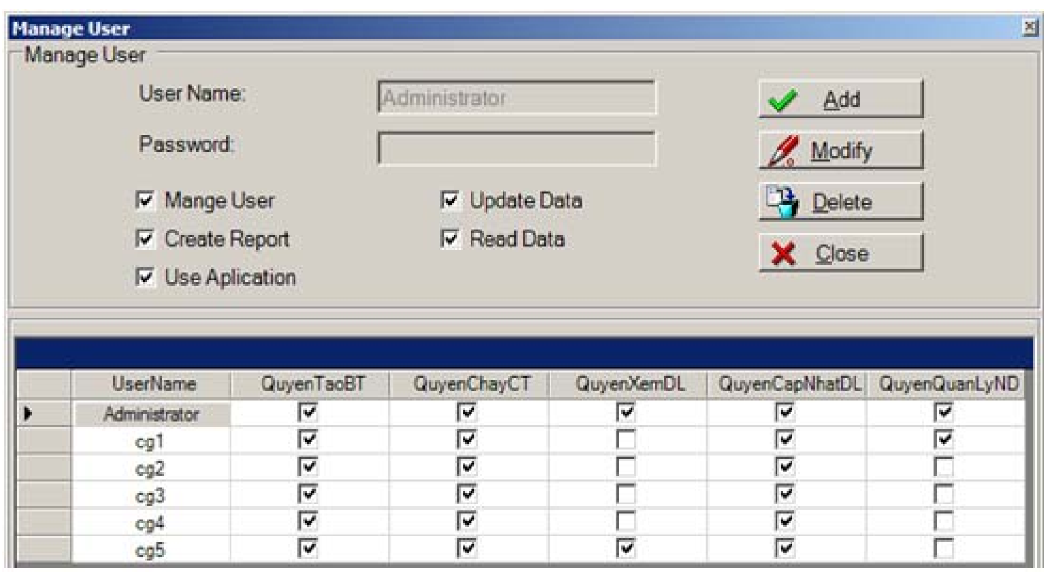

__Fig. 6.4__ Manage User in DSS Program

6.2.2 Designing Database

Data are stored in database **SQL Server**. The Database name is configured in file ***App.Config*** which includes parameters as follows: ***Server name, Database, User, Password***. Data for the MOLP problem in LUP map data have been built by MapInfo software together with other collected data in the district to build the decision-making problems.

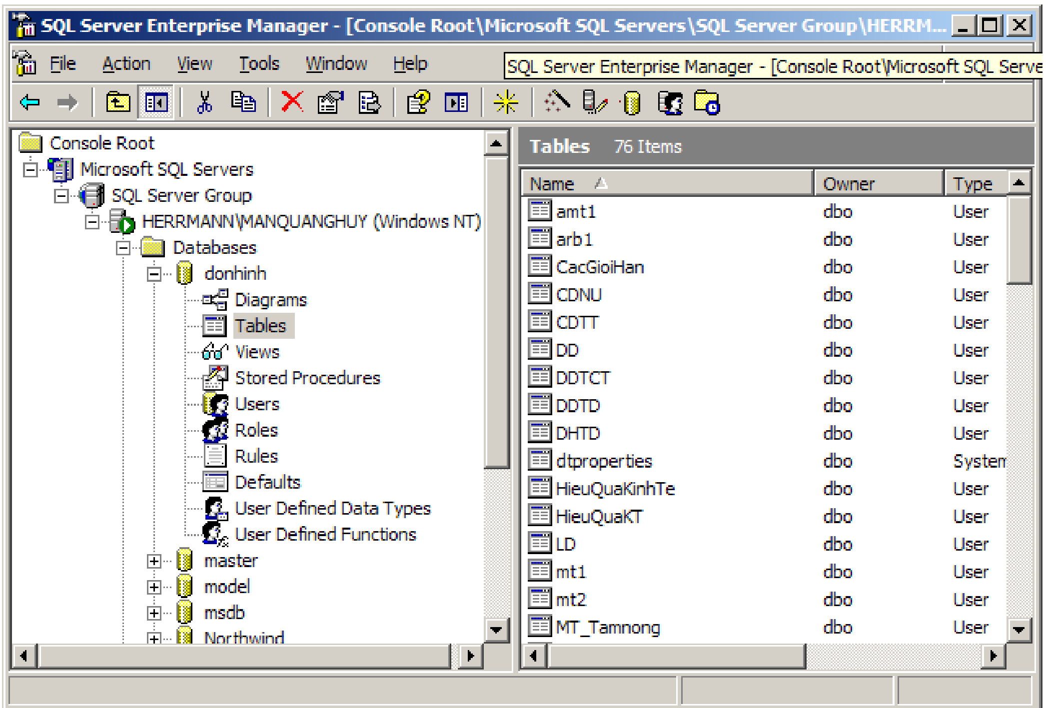

***Fig. 6.5** List of table in Databases in SQL Server Enterprise Manager*

The MapInfo data and data collected are dynamic, which means they do not follow a standard data field, since designing a standard database is a difficult task. As a result, a dynamic database is designed in this study.

Administrator users can create other necessary database tables within their application. Only the administrator is able to create tables and data query command to support the MOLP problem. Other users involved only in solving problems to select an appropriate decision.

The main data tables are described as follows; other data tables can be created to support data processing and decision making.

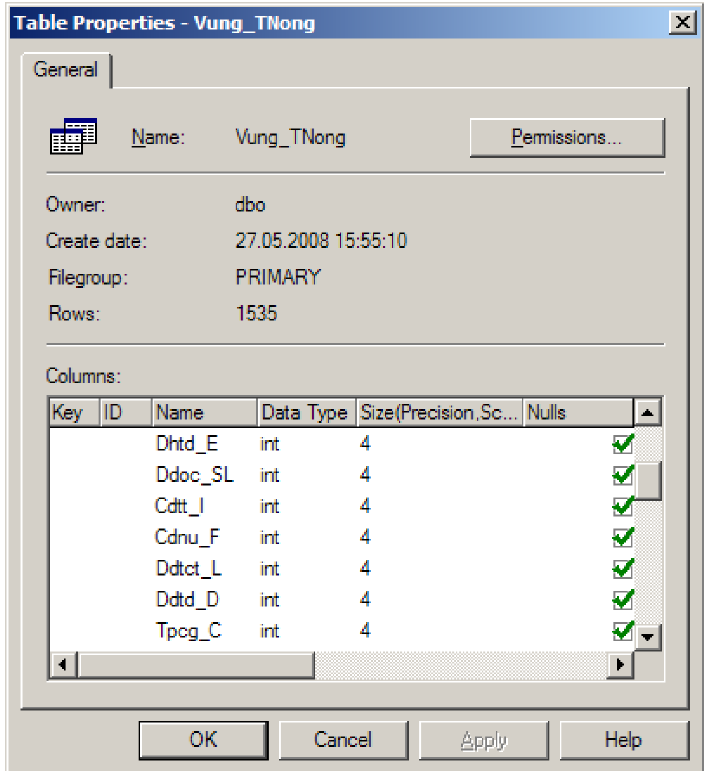

Fig. 6.6 *Table Properties on SQL Server 2000 with database in TamNong.*

Data obtained from the files of map data (MapInfo) in Tam Nong district have the following columns:

- *Objective (Muctieu)* $X_1, X_2 \ldots X_n$, muctieu
- *Constraint (Rangbuoc)* $X_1, X_2 \ldots X_n$, bj
- *TamNong* Obj, ID, DVDD (LMU), Ldat_G (Soil type), Ddoc_SL (Slope), Ddctc_L(Thickness layer cultivassions), Ddtd_D (Soil depth), Tpcg_C (Soil Texture)..,

The program can get data from GIS software (MapInfo) and show base map and data from MapInfo and SQL Server with the same file name *.tab

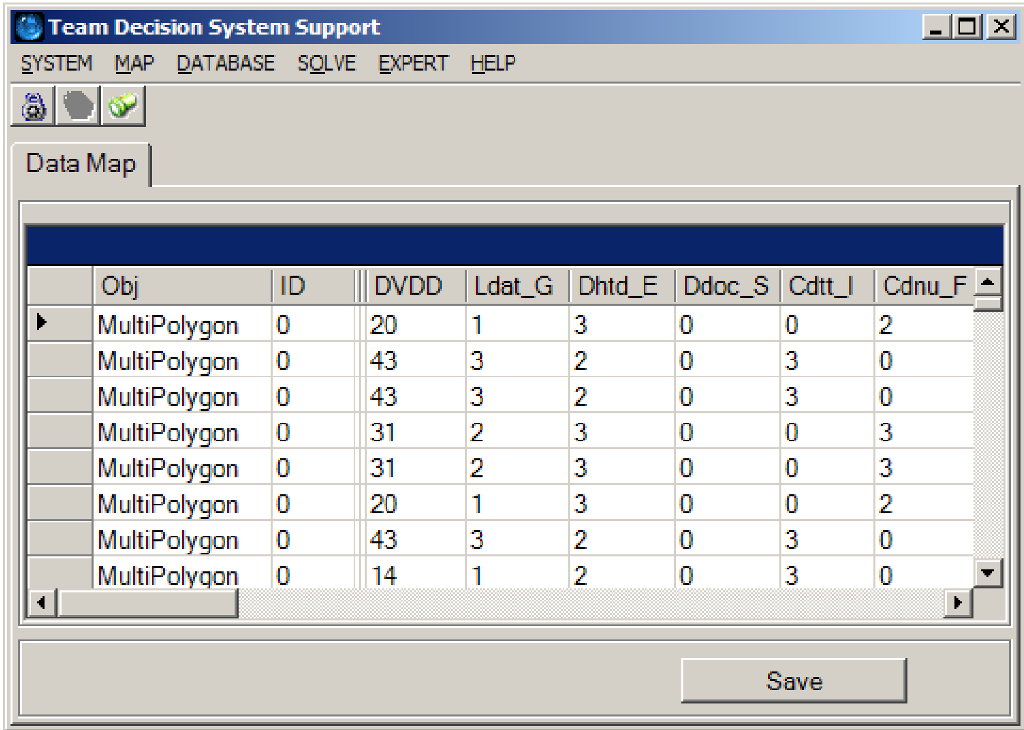

Fig. 6.7 *Getting data from MapInfo Professional version 7.0*

After being shown data on Data Grid is stored into database by clicking on ***save as*** database button. Data after shown on the Data Grid could be saved in a database by clicking on the left menu **Save Data** to Database.

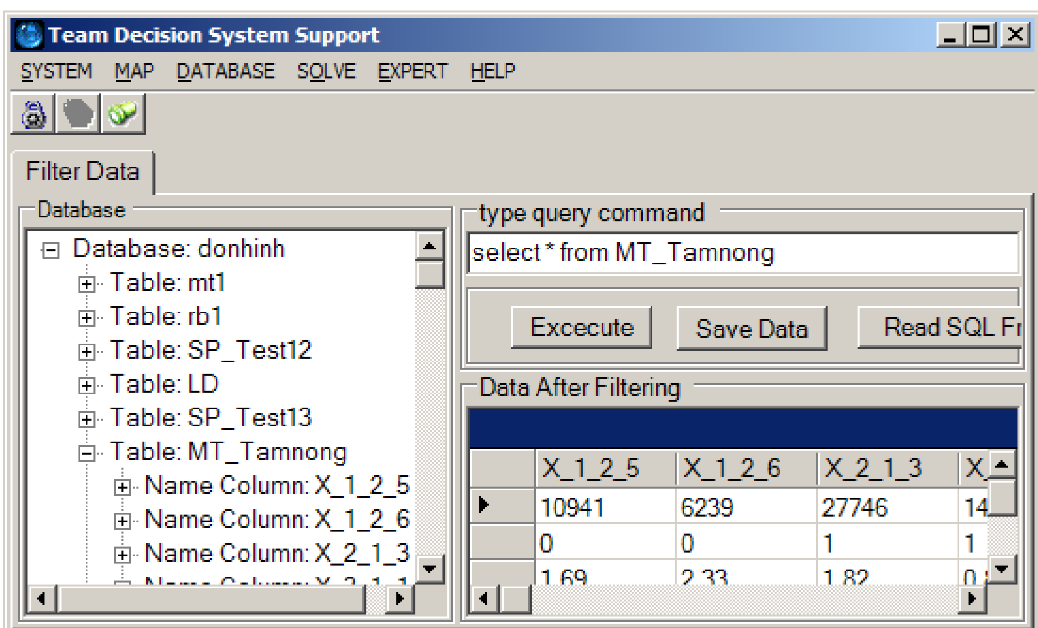

Fig. 6.8 *Data filter Interface on the System Program*

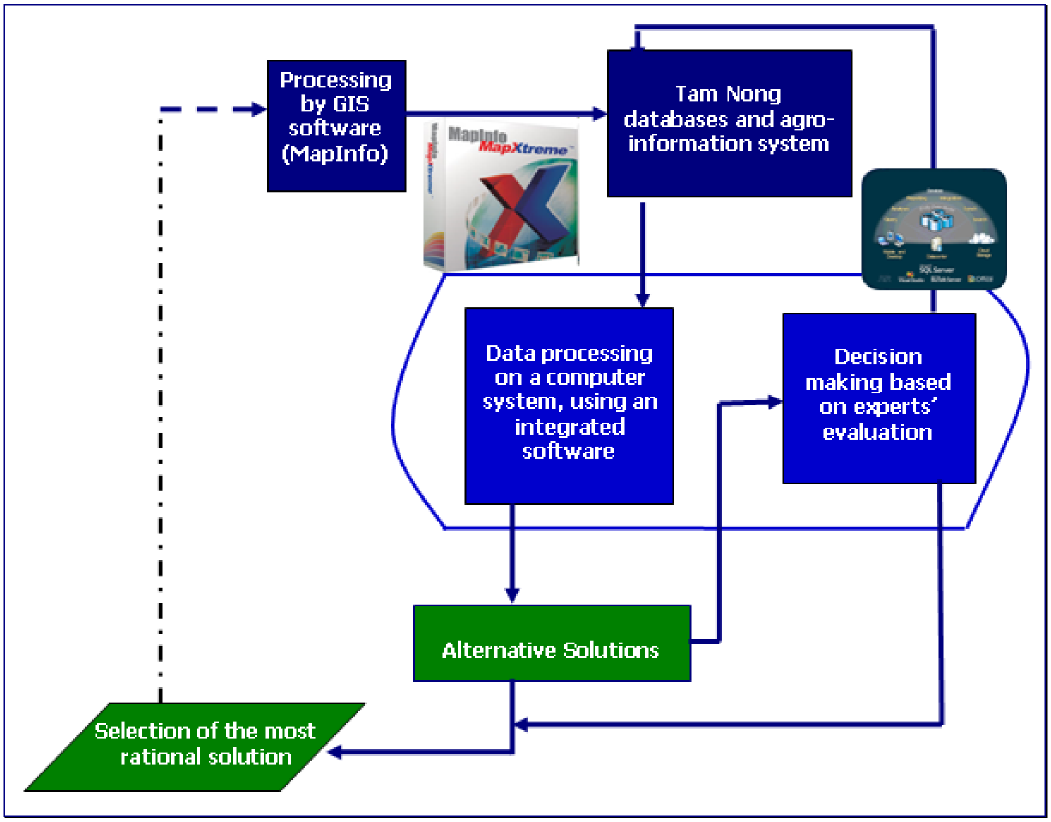

Fig. 6.9 *The diagram of the DSS data processing on a computer system using an integrated software in Tam Nong*

6.3 Modeling Problems of Land Use Planning for Tam Nong

When building the LUP model we should focus on the suitability, feasibility, practicality and sustainability. Land use on a sustainable basis should satisfy three requirements: economically sustainable in terms of plants that achieve high economic efficiency and are accepted by the market; environmentally sustainable in terms of being able to prevent degeneration of land and protect the natural environment; socially sustainable in terms of attracting workers and ensuring that social life develops.

To choose the appropriate formula for cultivation in accordance with the land's conditions and also to reach the desired efficiency, a multi objective optimization model needs to be addressed while considering the three following objectives:

- Economic Efficiency
- Land Suitability
- Sustainable Environment

6.3.1. Decision Variables

In Tam Nong district six goals of land use with 11 major land use types were defined. After classifying land suitability for each type of land use, we conducted the grouping of LMU based on the level of appropriate LUTs by use purpose, there were total 11 groups (see table 5.11).

Based on the results of identifying land use type, evaluating and classifying land suitability and land purpose, the decision variables X_i (i = 1, 2, …, n) are different areas to be determined with 3 levels of land suitability and 11 land use groups.

6.3.2 Coefficients of the Problem

Coefficients of the problem are that of decision variables in the objective function and some constraints which are calculated with the results obtained from analyzing current status of land use and grouping of land suitability in Tam Nong district (results have been presented in Chapter 5)

Through the land classification research in Tam Nong district, the entire area of cultivated land is divided into M types. Also from results of the research on potential cultivation on that land, N different formulas of rotation cultivation are assessed at L levels of suitability. For testing program in Tam Nong, we choose M=11, N=24, and L=3 based on the information in the tables 5.8 and 5.11 in chapter 5)

6.3.3 Identify Constraints

Based on the selected variables for testing Program in Tam Nong, we have formulas of Identify Constraints as follows:

Consider decision variables x_{ijk} denoting the area under cultivation formula i (i = 1, 2... 24) with the suitability level j (j = 1, 2, 3) and the land type k (k = 1, 2… 11).

Also, consider coefficients a_{ijk} related to decision variables x_{ijk} in type k land area. The value of aijk can be determined as: a_{ijk} =0 if the cultivation formula i is not applied to land type k and a_{ijk} =1 otherwise. Besides, let b_k be the total area of land type k with k = 1, 2… 11.

Therefore, the binding conditions or the constraints of the LUP multi objective optimization model can be stating as follows:

$$\begin{cases} \sum_{i=1}^{24} \sum_{j=1}^{3} a_{ijk} \; x_{ijk} = b_k \quad (k = 1, 2, ..., 11) \\ x_{ijk} \geq 0 \qquad \forall i, \forall j, \forall k \end{cases}$$

Consider c_{ijk} the profitability multiplier on an area unit of land type k under cultivation formula i with the suitability level j, the objective set on economic efficiency is written as follows:

$$\sum_{k=1}^{11} \sum_{i=1}^{24} \sum_{j=1}^{3} c_{ijk} \, a_{ijk} \, x_{ijk} \rightarrow Max$$

To maximize the general suitability level, it is needed to maximize the total area of the rotation cultivation with the suitability level 1. Therefore, the following objective on the total level of suitability is stated:

$$\sum_{k=1}^{11} \sum_{i=1}^{24} a_{ijk} \, x_{ijk} \rightarrow Max$$

6.3.4 Identify the Objective Functions

The LUP model in Tam Nong is stated as the following multi objective optimization model with three objectives:

$$Z_1 = \sum_{k=1}^{11} \sum_{i=1}^{24} \sum_{j=1}^{3} c_{ijk}\, a_{ijk}\, x_{ijk} \rightarrow Max$$

$$Z_2 = \sum_{k=1}^{11} \sum_{i=1}^{24} a_{ijk}\, x_{ijk} \rightarrow Max$$

$$Z_3 = \sum_{k=1}^{11} \sum_{i=1}^{24} \sum_{j=1}^{3} m_i\, a_{ijk}\, x_{ijk} \rightarrow Max$$

Linear planning problem with multi objectives is shown as follows:

Max Cx with binding $x \in D$, where*: C is the matrix* $p \times n$ *and* $D = \{x \in R^n : Ax \leq b\}$ *wherein A is the matrix* $m \times n$ *and* $b \in R^m$

Rows of the matrix C is the gradient vector c1, c2... cp of the objective function $z_1 = c_1^T x$, $z_2 = c_2^T x$,..., $z_p = c_p^T x$.

6.3.5 Software Design for Solving the MOLP Model

The program is able to create databases or filter data stored in store procedure. Administrators simply create a store procedure once updating data then the problem will be automatically generated.

When users want to solve the MOLP problem, users select the target table data and table data binding, respectively by clicking on the left menu to select a problem, and then clicking the checkbox to select the target table data.

After selecting the problem, users can click on the left menu to solve the problem; the program will address each goal. When the solution process has completed each goal, a results page appears to users the results for each goal of the MOLP problem can be seen.

After the request is entered correctly, click the left menu and choose **Solve problem**

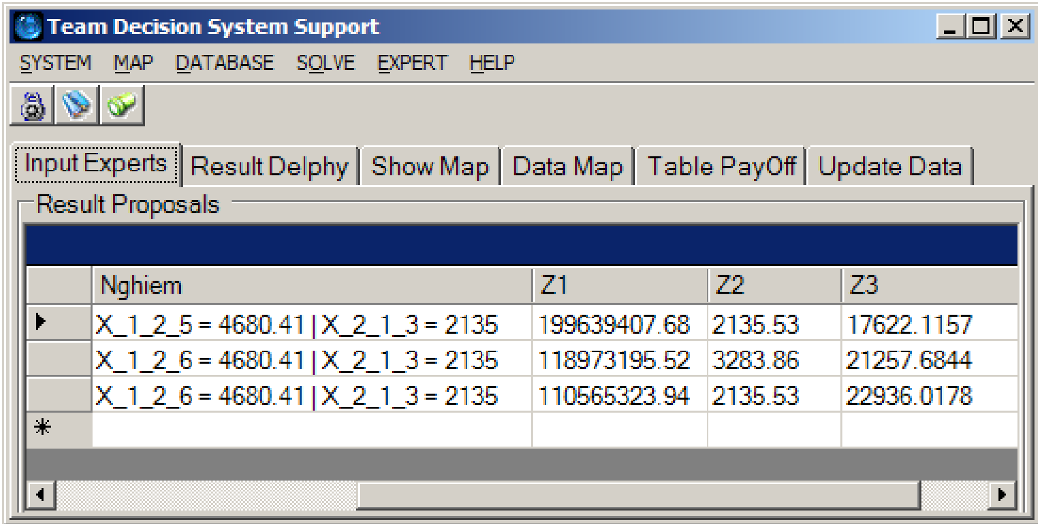

Fig. *6.10 The result of solving the MOLP Model*

Cut Method

The method of cutting is implemented by entering a cutting value between Zmax and Zmin.

After entering the value of **Cut**, click on Cut method in the left menu to get the results. After completion, the results can be stored in a database to serve the ongoing process of selecting a plan for implementation.

If the users are not satisfied with the set of results, they can cut or change the value of objective function to continue the search for other projects.

6.4 Designing a Delphi Algorithm

A modification of the Delphi algorithm can help to synthesize experts' opinions as follows:

Initialization

N experts give their opinions regarding evaluation of obtained solutions at different levels: very good, good, very consistent, inconsistent, and inefficient.

Experts	Alternative 1 Maximize Economic efficiency	Alternative 2 Maximize the general suitability level	Alternative3 Maximize environmental effect
Expert 1	Very good	Good	Very consistent
Expert 2	Inconsistent ...	Very consistent ...	Inefficient ...
Expert N	Good	Very good	Very consistent

Fig. 6.11 *Making a group consensus decision from experts' evaluation and assessment.*

Select value i to indicate the number of classes into which opinions of experts are classified (usually chosen i = 3 or 4).

Select k_{max} is the maximum number of iterations needed to carry out (usually choose k_{max} from 10 to 12)

Iterations

Step 1

Using the method of classifying data (opinions) based on approximate clustering algorithm using minimal variance criterion and minimal distance criterion.

Step 2

- If at least 75% of experts' opinions is in a class, move on to step 3.

- If less than 75% expert opinions is in any class but $k+1 > k_{max}$ then also move to step 3.

- Else, notify to the experts the average value and ask experts refine their opinions based on the information and move to step 1.

Step 3

Inform experts about the average of all the opinions and based on the result take the decision that is the solution in the class with most consensus opinions which is closest to the average of the class.

CHAPTER 7

CONCLUSION AND FURTHER RESEARCH

7.1. Summary

7.1.1. Decision Making Process in LUP

In order to make decisions in LUP, it is necessary to collect data from various sources. Map data are required, so the work of digitizing maps and importing data for the map is very important. Also, there is a need to have data on the land use, the appropriate level of crops and productiveness of crops. In terms of LUP in agriculture, a database of land resources based on the criteria of land suitability classification needs to be established to identify the characteristics of land.

Setting up a database of suitable cultivation formulas should be based on both traditional farming and biotechnological advances. Factors including economic efficiency and social, ecological, and environmental effects must be taken into consideration. Regarding the evaluation on ecological and environmental effects, it is necessary to continue to study and propose more precise quantitative assessment methods.

The information of the database is processed through mathematical models including the optimal mathematical model to determine optimal crop rotations, the model of land use classification and evaluation, and the forecast statistical and simulation models to find out measures for improving the efficiency of comprehensive land use and ensuring sustainable development in agriculture.

With necessary data, the program will use modules to create linear programming problem. Another module helps solve the planning optimization. Besides, a module with maps provides decision makers with an overview of LMU to identify suitable crops. Decision support systems can produce various options on each LMU. Finally, an integrated module with experts' evaluation helps decide the optimal solution.

Decision-making process in LUP includes the following steps:

(i) Retrieve data stored on GIS software (MapInfo).

(ii) Transfer data to SQL Server database.

(iii) Create local data collection tables.

(iv) Activate modules to generate solutions automatically.

When the problem is created, the program can run the tests to find the optimal output suitable with the proposed requirements. A MapInfo module displays essential information on LMU such as the total area in each region.

7.1.2. Advantages of Decision Making Support System in LUP

Derived from the urgent practical needs, we designed and built a system to support decision making in LUP with the following advantages. First, the system can create a model with specific applications, combining many different components (optimize calculations, integrate experts' opinions, apply GIS technology). Second, this system serves as the foundation for building a complete system to meet actual needs. The system is designed with the database storing the dynamic data tables. Administrators can use the profiles to match necessary queries based on these data to obtain the desired data. Third, the system helps draw maps to have a visual overview on the issue of planning. Another module reads MapInfo data which are shown in the Data Grid to help users store necessary data in the database for their problems. Fourth, the system enables creating queries automatically. When users update data in the database, the problems will be automatically updated. Data are stored in the data table; a module to solve single and multi-objective optimization linear planning problems will retrieve the data from this table to find the answer to the query of the optimal solution. Finally, the system has integrated the linear planning module with a three-phase method (design the encoding module, decode and store optimal solutions) and used the module based on experts' opinions to support decision making to select the proper solution for LUP.

7.2. Results of the Study

The study has provided the foundation to design and build decision-making support systems in LUP for agricultural production in the area within district level. The research covers the important topics including the components of the decision-making support system, database design of land use on the basis of integrated spatial data and GIS data attributes such as horticultural formula, cost, and profit, and modules of computer program integrated into decision support system for LUP and agricultural production.

Strengths of the system are the ability to use database tables with dynamic data to retrieve the desired data, the ability to create problems to which objectives and required conditions are automatically added or removed, and the ability to support selection of LUP through experts' evaluation and to integrate GIS technology to create reports and maps. There are three of the selected results feasible alternative of Tam Nong LUP map on the Program are shown.

The program results are tested with high accuracy. Data in Tam Nong district are processed with more than 44 variables and three target functions (more target functions can be possible). In addition, a number of supplementary constraint functions can be used when solving multi-objective optimization problems with cut methods.

7.3. Conclusions

Based on the results of the research, the following conclusions can be drawn. First, to evaluate the effectiveness of comprehensive land use and determine the optimal crop rotation, we need to integrate economic efficiency, social and environmental effects. Second, utilizing the information on land resource and LMU for LUP of agricultural land in area like Tam Nong district should be based on criteria such as types of soil, soil name, topographic feature, slope, irrigational conditions, flooding hazard, effective soil depth, soil depth, and soil texture. Third, determining the formulas of crop rotation should be based on economic, environmental, and ecological efficiency to ensure the diversification of cultivated production and to improve the coefficient of land use. Finally, applying multiple objective optimization models as a main quantitative tool to determine appropriate crop rotation enables users to select an accurate, logical and science-based formula of crop rotation which ensures a balance among economic efficiency, ecological and environmental sustainability, and land use efficiency.

7.4. Further Study and Development

For further study in the near future, it is important to complete the calculating procedures to address linear planning problem by the three-phase method. Currently, we have done the first two parts including encoding and decoding. We need to study methods and procedures for computing solution for the multi-objective optimization model, which can enable us to find out the structure of the optimal set of planning. This will also allow more effective decision making based on more complete information. Besides, we can continue to improve the system with the view to making it more user-friendly. We need to keep on examining and testing it on real problems as well. More relevant database and programs can be designed.

The research topic can be further developed in various aspects including researches on the procedures of solving Multiple Goal Linear Programming to find the structure of the set of optimal solutions, the models of LUP with the upgraded modules of mapping to solve the problem of LUP with more variables, developing the decision support system for LUP on client servers via the Internet, and integrating with other expert systems to improve and develop models of LUP in general and agricultural land in particular.

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GLOSSARY

Agro-ecological zoning (AEZ): The division of an area of land into smaller units, which have similar characteristics related to land suitability, potential production and environmental impact.

Agronomical attainable yield. The maximum yield that can be achieved by a given crop cultivar in a given area, taking account of climatic, soil and other physical or biological constraints.

Cropping pattern. The yearly sequence and spatial arrangement of crops or of crops and fallow on a given area.

Cropping system. A system, comprising soil, crop, weeds, pathogen and insect subsystems, that transforms solar energy, water, nutrients, labor and other inputs into food, feed or fuel. The cropping system is a subsystem of a farm system.

Database. An organized, integrated collection of data stored so as to be capable of use by relevant applications with data being accessed by different, logical paths. In theory the data are application independent.

Ecological-economic zoning. A kind of zoning which integrates physical land resources elements with socio-economic factors and a wider range of land uses in zone definitions.

Ecotype. A crop cultivar adapted to a particular range of climatic or soil conditions.

Farming System. A decision making unit, comprising a farm household, cropping and livestock systems, that produces crop and animal products for consumption and sale.

Geographical Information System (GIS). A system for capturing, storing, checking, integrating, manipulating, analyzing and displaying data which is spatially referenced to the earth.

Land Characteristic. A property of the land that can be measured or estimated.

Land equivalent Ratio (LER). The ratio of the area needed under sole cropping to one of intercropping at the same management level to give an equal amount of yield. LER is the sum of the fractions of the yields of the intercrops relative to their sole crop yields.

Land Evaluation The process of predicting the use potential of land on the basis of its attributes. It does not include optimal land allocation. However, land evaluation supplies the technical coefficients necessary for optimal land allocation.

Land Mapping Unit (LMU): A specific area of land that can be delineated on a map and whose land characteristics can be determined. It is the evaluation unit about which statements will be made regarding its land suitability. The LMU can be a grid cell, single map delineation (polygon), or a set of map delineations with common Land Characteristics, i.e. a legend category of a thematic map. Land that has not been, or can not be, mapped may be evaluated at specific locations.

Land Quality. A complex attribute of land which acts in a distinct way in its influence on the suitability of land for a specified use.

Land Suitability The fitness of a given Land Mapping Unit (LMU) for a Land Utilization Type (LUT), or the degree to which it satisfies the land user. In a more operational sense, suitability expresses how well the LMU matches the requirements of the LUT. It may be expressed on a continuous scale of 'goodness' (e.g. 0 to 100) or, more commonly, as a set of discrete classes, which are conventionally numbered from class 1 meaning 'completely suited' upwards to some maximum meaning 'completely unsuited'.

Land Use Requirement (LUR): a condition of the land necessary for successful and sustained implementation of a specific Land Utilization Type. A LUT may be defined by a set of LURs. A LUR expresses the 'demand' side of the land use- land area matching procedure.

Land Utilization Type (LUT): A specific land-use system with specified management methods in a defined technical and socio-economic setting, and with a specific duration or *planning horizon*. The description of a LUT may include a time-series of activities and outputs. The definition of a LUT is not a complete description of the farming or other land-use system: it includes only those attributes that serve to differentiate the suitability of land areas, for example, those that can be expressed as Land Use Requirements with critical values in the study area. The definition of a LUT also includes attributes that limit the land use options by discarding those that are *a priori* unfeasible over the entire evaluation area.

Land. An area of the Earth's surface. In the context of land evaluation, land includes all properties of the surface, soil and climate, together with any resident plant and animal communities.

Model. A simplified representation of a limited part of reality with related elements.

Multi-criteria decision analysis (MCDA). A set of techniques used to solve problems which involve several objectives being considered simultaneously. In the context of integrated LUP and management, MCDA techniques are applied to analyze various land use scenarios considering simultaneously several objectives such as maximizing revenues from crop and livestock production, minimizing costs of production and environmental damage from erosion.

Potential yield. The maximum yield that can be achieved by a given crop cultivar in a given area, based on radiation and temperature.

Production system. A particular series of activities (the management system) carried out to produce a defined set of commodities or benefits (produces).

Soil mapping unit. An area of land delineated on a map. A soil mapping unit may consist either of a single soil type, or of multiple soil types occurring as a complex or association.

Soil type. A specific unit of soil with definable ranges of characteristics. May correspond to the lowest hierarchical unit of a soil classification system, including specification of phase.

Stakeholder. An individual, community, government or NGO which has a traditional, current or future right to take decisions on land.

Sustainability: Sustainable land use is that which meets the needs of the present while, at the same time, conserving resources for future generations. This requires a combination of production and conservation: the production of the goods needed by people now, combined with the conservation of the natural resources on which that production depends so as to ensure continued production in the future

Sustainable land use. Use of the land that does not progressively degrade its productive capacity for a defined purpose.

APPENDIX

Appendix A1 Future Suitability Land Mapping Units to Land Use Type

L M U	Character	Area (ha)	2R + 1C	1R 2C	1R 1R	1R 1C	1R F	Vege table	Cs	Pe. In.	Fr. Cr.	Ag.+ Fo.	Fo.
1	11221	3,88	S3e	S2el	S3e	S2el	Ne	S2	S2il	Ng	S2ic	S2	S2
2	11311	20,16	S3ie	S2ie	S3ie	S2ie	Ne	S2ei	S2i	Ng	S2ic	S2	S2
3	11312	5,68	S3ie	S2	S3ie	S2	Ne	S2	S2ic	Ng	S2ic	S2	S2
4	11321	12,65	S3ie	S2	S3ie	S2	Ne	S2	S2il	Ng	S2ic	S2	S2
5	11322	50,42	S3ie	S2	S3ie	S2	Ne	S2	S2	Ng	S2i	S2	S2
6	11323	13,30	S3iec	S2c	S3ie	S2c	Ne	S3c	S2c	Ng	S2c	S2c	S2c
7	12111	29,48	S2cl	S1	S2lc	S1	S3ec	S1	S2e	Nge	S2ec	S3e	S3e
8	12112	218,49	S1l	S1c	S1l	S1c	S3e	S1c	S2ec	Nge	S2e	S3e	S3e
9	12121	56,24	S1c	S1l	S1c	S1l	S3ec	S1l	S2el	Nge	S2ec	S3e	S3e
10	12122	677,82	S1	S2cl	S1	S2cl	S3e	S2cl	S2	Nge	S2e	S3e	S3e
11	12212	123,72	S2il	S1c	S2il	S1c	S3e	S2ic	S2	Nge	S2ie	S3e	S3e
12	12221	25,84	S2ic	S1l	S2ic	S1l	S3ec	S2il	S2	Nge	S2	S3e	S3e
13	12222	293,29	S2i	S2cl	S2i	S2cl	S3e	S2	S2	Nge	S2ie	S3e	S3e
14	12311	301,05	S3i	S2i	S3i	S2i	S3ec	S2i	S2ie	Nge	S2	S3e	S3e
15	12312	94,00	S3i	S2ic	S3i	S2ic	S3e	S2ic	S2	Nge	S2ie	S3e	S3e
16	12321	411,13	S3i	S2il	S3i	S2il	S3ec	S2il	S2	Nge	S2	S3e	S3e
17	12322	73,89	S3i	S2	S3i	S2	S3e	S2	S2	Nge	S2ie	S3e	S3e
18	13122	49,96	Nfe	Nfe	S3f	Ne	S3f	S3fe	S3fe	N	Nfe	Nfe	Nfe
19	13212	287,03	Nfe	Nfe	Nf	Nef	S2gl	Nf	Nf	N	Nfe	Nfe	Nfe
20	13221	185,32	Nfe	Nfe	Nf	Nef	S2c	Nf	Nf	N	Nfe	Nfe	Nfe
21	13312	230,05	Nfe	Nfe	Nf	Nef	S2g	Nf	Nf	N	Nfe	Nfe	Nfe
22	13322	527,08	Nfe	Nfe	Nf	Nef	S2gl	Nf	Nf	N	Nfe	Nfe	Nfe
23	13323	34,37	Nfe	Nfe	Nf	Nef	S2	Nf	Nf	N	Nfe	Nfe	Nfe
24	21313	7,29	S3gic	S3gc	S3ie	S3gc	Ne	S3gc	S3gc	Ng	Ng	Ng	Ng
25	22312	11,93	S3gi	S3g	S3i	S3g	S3e	S3g	S3g	Nge	Ng	Ng	Ng
26	23212	79,11	Nfe	Nfe	Nf	Ne	S2f	Nf	Nf	N	N	N	N
27	23213	50,25	Nfe	Nfe	Nf	Nef	S2fc	Nf	Nf	N	N	N	N
28	23222	115,15	Nfe	Nfe	Nf	Nef	S2fl	Nf	Nf	N	N	N	N
29	23223	251,26	Nfe	Nfe	Nf	Nef	S2	Nf	Nf	N	N	N	N
30	23312	35,41	Nfe	Nfe	Nf	Nef	S1	Nf	Nf	N	N	N	N
31	23321	46,53	Nfe	Nfe	Nf	Nef	S2c	Nf	Nf	N	N	N	N
32	23322	75,48	Nfe	Nfe	Nf	Nef	S1l	Nf	Nf	N	N	N	N

Appendix A1 Future suitability Land Mapping Units to Land Use Type (to be con.)

LMU	Character	Area (ha)	2R + 1C	1R 2C	1R 1R	1R 1C	1R F	Vegetable	Cs	Pe. In.	Fr. Cr.	Ag.+ Fo.	Fo.
33	31311	74,90	S3i	S2	S3ie	S2	Ne	S2	S2gi	S3ge	S3g	S3g	S3g
34	31321	114,08	S3i	S2	S3ie	S2	Ne	S2	S2	S3ge	S3g	S3g	S3g
35	31322	14,40	S3i	S2	S3ie	S2	Ne	S2	S2	S3ge	S3g	S3g	S3g
36	32111	43,30	S2	S2g	S2	S2g	S3ec	S2g	S2ge	Ne	S3g	S3ge	S3ge
37	32121	101,38	S2	S2g1	S2gc	S2gl	S3ec	S2gl	S2	Ne	S3g	S3ge	S3ge
38	32211	13,68	S2	S2g	S2	S2g	S3ec	S2gi	S2	Ne	S3g	S3ge	S3ge
39	32221	78,03	S2	S2gl	S2	S2gl	S3ec	S2	S2	Ne	S3g	S3ge	S3ge
40	32311	49,42	S3i	S2gi	S3i	S2gi	S3ec	S2gi	S2	Ne	S3g	S3ge	S3ge
41	32312	98,78	S3i	S2	S3i	S2	S3e	S2	S2	Ne	S3g	S3ge	S3ge
42	32313	11,39	S3ic	S2c	S3i	S2c	S3e	S3c	S2e	Ne	S3gc	S3	S3ge
43	32321	192,58	S3i	S2	S3i	S2	S3ec	S2	S2	Ne	S3g	S3ge	S3ge
44	33311	33,83	Nfe	Nfe	Nf	Nef	S2c	Nf	Nf	Nfe	Nfe	Nfe	Nfe
45	33321	68,71	Nfe	Nfe	Nf	Nef	S2c	Nf	Nf	Nfe	Nfe	Nfe	Nfe
46	41311	91,07	S3	S3gsl	S3	S3gsl	Nsl	S3ge	S3g	S2ic	S2ic	S2ic	S2ic
47	41321	226,01	S3	S3gsl	S3	S3gsl	Nsl	S3ge	S3g	S2	S2	S2	S2
48	41322	71,54	S3	S3gsl	S3	S3gsl	Nsl	S3ge	S3g	S2id	S2id	S2id	S2id
49	42312	59,36	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S3gsl	S2i	S2i	S2i	S2i
50	42321	323,56	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S3gsl	S2	S2	S2	S2
51	42332	71,58	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S3gsl	S3d	S3d	S3d	S3d
52	43311	84,40	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S2	S2	S2	S2
53	43312	332,14	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S2isl	S2il	S2isl	S2isl
54	43321	118,45	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S2	S2	S2	S2
55	43322	560,20	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S2	S2	S2	S2
56	43332	263,86	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S3d	S3d	S3d	S3d
57	44311	88,18	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S3sl	S3sl	S3sl	S3sl
58	44312	844,70	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S3sl	S3sl	S3sl	S3sl
59	44321	308,52	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S3sl	S3sl	S3sl	S3sl
60	44322	2263,8	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S3sl	S3sl	S3sl	S3sl
61	44331	107,96	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S3sl	S3sl	S3sld	S3sld
62	44332	86,75	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	Nsl	S3sl	S3sl	S3sld	S3sld
63	52332	45,44	Ngsl	Ngsl	Ngsl	Ngsl	Ngsl	Ngsl	Ngsl	S3gd	S3gd	S3gd	S3gd
64	53332	34,39	Ngsl	Ngsl	Ngsl	Ngsl	Ngsl	Ngsl	Ngsl	S3gd	S3gd	S3gd	S3gd

Appendix A2 Soil Classification of Tam Nong based on the classification of FAO

No	Soil Type Name of FAO	FAO Symbols	Vietnamese Symbol
I	**Fluvisols**	**FL**	**P**
1	***Eutric Fluvisols***	***FLe***	***P***
-	Hapli Eutric Fluvisols	FLe-h	P-h
-	Areni Eutric Fluvisols	FLe-a	P-a
-	Stagni Eutric Fluvisols	FLe-st	P-st
-	EpiGleyi Eutric Fluvisols	FLe-g1	P-g1
-	EpiPlinthi Eutric Fluvisols	FLe-pt1	P-l1
2	***Eutric Fluvisols***	***FLe***	***P***
-	Hapli Dystric Fluvisols	FLd-g1	Pc-g1
II	**Gleysols**	**GL**	**GL**
1	***Dystric Gleysols***	***GLd***	***GLc***
-	Hapli Dystric Gleysols	GLd-h	GLc-h
-	Thapiohisti Dystric Gleysols	GLd-t	GLc-t
III	**Acrisols**	**AC**	**X**
1	***Haplic Acrisols***	***Ach***	***X***
-	Areni Haplic Acrisols	ACh-a	X- a
2	***Gleyic Acrisols***	***ACg***	***Xg***
	Hapli Gleyic Acrisols	ACg-h	Xg-h
	Areni Gleyic Acrisols	ACg-a	Xg-a
	EndoLithi Gleyic Acrisols	ACg-l2	Xg-đ2
3	***Ferralic Acrisols***	***ACf***	***Xf***
-	Hapli Ferralic Acrisols	ACf-h	Xf-h
-	Areni Ferralic Acrisols	ACf-a	Xf-a
-	Epi Ferri Ferralic Acrisols	ACf-	Xf-fe1
-	EndoFerri Ferralic Acrisols	ACf-	Xf-fe2
-	EpiLithi Ferralic Acrisols	ACf-l1	Xf-đ1
-	EndoLithi Ferralic Acrisols	ACf-l2	Xf-đ2
4	***Ferric Acrisols***	***ACfe***	***ACfe***
-	Hapli Ferric Acrisols	ACfe-h	Xfe-h
IV	**Leptosols**	**LP**	**E**
1	***Lithic Leptosols***	***LPl***	***E***
-	Hapli Leptic Leptosols	LPq-h	E-h
2	***Ferric Leptosols***	***LPfe***	***Efe***
-	Hapli Ferric Leptosols	LPfe-h	Efe-h

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Researches and Publications

- Man, Q.H. (2009) & Kappas, M.. *Building tools on the Decision Support System for land use planning in Vietnam*. Abstract submitted to the Geoinformatics Forum Salzburg (GI_Forum), 6-9 July 2009, University of Salzburg, Austria.

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