Chapter II

LITERATURE REVIEW

Steward (1968) defined land evaluation as "an evaluation of land suitability for land use in agriculture, forest, designing irrigation, land use planning…". In other words, it is "evaluating land aiming to supply information about advantages and disadvantages of land use that is a premise to make decision for land use and management". Term of land evaluation was used in workshop of soil science in Amsterdam in 1950. But until 1970's conception of land classification and explaining land research were used to replace land evaluation. Term of land evaluation was reconsidered in 1968 in seminar of land evaluation organized by CSIRO in Cambera. This time, term of land evaluation was used as Steward (1968)'s definition. This term is popular widely through framework for land evaluation of FAO in 1976. Continuing this document, a series of guidelines of land evaluation for specific components was published such as guideline for rainfed agriculture (FAO, 1983), for forestry (FAO, 1984), irrigated agriculture (FAO, 1985) and land evaluation and farming systems analysis for land use planning (FAO, 1992). Document for guiding land evaluation of FAO that applied and accepted as a best method to assess land potential for land use planning was worldwide.

2.1 FAO land evaluation procedure

The critical step in the FAO method is to define objective since it relates to the levels of planning the study can be applied. This controls the range of limitation needed and the types of survey required. The objective of land evaluation consists of the comparison between existing suitability of a particular use with other feasible uses of the same land. Environmental conservation is also taken into account for the objective (FAO, 1976).

The FAO framework recognizes that four main kinds of suitability classification namely, quantitative and qualitative classification, classification of current suitability and classification of potential suitability.

There are 4 categories in the suitability classification: (Table 2.1)

1) Land suitability orders reflect kinds of suitability.
2) Land suitability classes reflect degrees of suitability within orders
3) Land suitability subclasses reflect kinds of limitation or kinds of improvement required within classes
4) Land suitability units reflect minor difference in required management within subclasses

Table 2.1 The symbols used in the FAO land evaluation method

Order	Class	Subclass	Unit
S	S1		
	S2	S2n	S2n-1
	S3	S2f	S2n-2
		S2nf	
N	N1	N1w	
	N2	N1s	

The framework for land evaluation manual from FAO (1976) seems to be a worldwide application. It is based on the concepts and procedures of land evaluation that have evolved during FAO assisted development projects. Figure 2.1 illustrates this procedure.

2.2 Automated method in land evaluation

The evaluation method requires voluminous data and is tedious if many possibilities are to compare. Manual procedures, both for construction of matching tables or transfer function and for calculation of suitability, are time-consuming and error prone (FAO, 1984; Rossiter, 1995). However, these can be easily facilitated by using a computer in storage and retrieval of data for data manipulation and graphic presentation. Along with convenience in handling large amounts of data, computerized methods will quickly be the set of results when the initial data changed (FAO, 1984).

Computer systems and programs have been involved in land evaluation procedure. A program such as Land Evaluation Computer System (LECS) had been developed and published (Wood and Dent, 1983). Automated Land Evaluation System, ALES (Rossiter, 1994) has been implemented widely. Computerized processing substantially reduces data on current and potential suitability viability and related degradation risk to sustained cultivation (CSR/FAO, 1983).

Tsoumakas and Vlahavas (1999) described ISLE, an Intelligent System for Land Evaluation that automates the process of evaluation and graphically illustrates the results on digital maps. Its main features are the support of GIS capabilities on the digital map of an area, and the support of expert analysis of regions of this area, through one sophisticated user interface. ISLE's knowledge base, models the evaluation of land in accordance with the FAO-SYS model for Land Evaluation. The system has an input as digital map of an area and its geographical database, displays this map, evaluates the land units selected by the user and finally visualizes the results coloring properly the analyzed land units.

Until now, many computer programs for land evaluation are already available and the power of microcomputer is still increasing. It will make it possible to do basic land evaluation queries even in the provincial offices.

2.3 Evaluating Overall Physical Suitability Method

The FAO evaluation process requires multidisciplinary approach from the field of natural science, technology of land use, economics and sociology. The suitability evaluation is made in the relation of the physical, economic and social context of considered area. The comparison between different areas will be difficult to carry out for their different consumption. The assumption should be definitely expressed to avoid misunderstanding and to assist comparison between different areas.

Land evaluation is carried out by matching land quality (LQ) and land use requirements (LUR). Overall physical suitability of each land-mapping unit (LMU) for each land use type (LUT) is result of combining the single factor ratings of each LQ in some ways into overall measure of suitability (Rossiter, 1994). Some ways to combine the single factors are, maximum, minimum, multiplying, fuzzy, ect. Fuzzy Sets are sets (or classes) without sharp boundaries; that is, the transition between membership and non-membership of a location in the set is gradual. A Fuzzy Set is characterized by a fuzzy membership grade (also called a possibility) that ranges from 0 to 1.0, indicating a continuous increase from non-membership to complete membership. Four fuzzy set membership functions are provided in IDRISI: Sigmoidal, J-Shaped, Linear and User-defined. (Eastman, 2001)

Several methods can be used to perform the evaluation, some of them are:

a) The maximum limited method

The overall physical suitability of land area for a LUT is selected from the most limited land quality. The Liebig's "law of the minimum" was used to define the severity levels of land quality according to a standard set of yield reduction. In FAO practices, S1 class productivity relates to 80-100%, S2 from 40-80% and S3/N1 from 20-40% of optimum yield. The overall suitability will be corrected if yield factors do not interact. However, some physical factors do not affect yield, they just make management more difficult.

b) Algebraic combination of land quality rating

Method based on algebraic calculation (addition, subtraction, multiplication and division), computed following scores or percentages with stipulated coefficients and score rate. For example, the following rule can be used:

$$\mathbf{S1+S2+S1=S1} \qquad (1)$$

Some combination methods are a subjective method that takes economic performance into consideration.

c) Multi-criteria decision making approach

A multiple criteria decision making approach to geological information system (GIS) based land suitability evaluation can be used to combine factors in suitability analysis of land with taking care potential use.

This technique has been applied in conjunction with a GIS and developed from local rule of combination as described by Eastman, *et.al* (1993), Pereira and Duckstein (1993). Weighted linear combination is used to combine the criteria and estimate the suitability index according to the following form:

$$\mathbf{S} = \sum (\mathbf{w}_i \mathbf{x}_i)^* \prod \mathbf{c}_j \qquad (2)$$

where $\boldsymbol{S}$ = *suitability scores*, $\mathbf{w}_i$ = *weight of factor* i, $\mathbf{x}_i$ = *criterion score of factor i*, $\mathbf{c}_j$ = *criterion score(0 or 1.0) of constraint j*, $\prod$ = *product*

A decision is a choice between alternatives that can represent different turn of action, different hypothesis, different land allocation and so on. Rational human behavior involved the evaluation of alternative choices based on several criteria related. This could involve the setting of various weights to apply for different factors concerned.

Land suitability will be rated according to the developing criteria for each LUT. The criteria will be composed factors and constraints. Land quality for each land-mapping unit will be used as factors. The factor is a criterion that enhances or detracts from the suitability of a specific alternative for activity under consideration and it is measured on a continuous scale.

A constraint aims to limit the alternatives under consideration such as water bodies, villages, and road. Weighting for each factor will be determined by Satty technique (Eastman *et al.*, 1993) using information from relevant references, expert opinion and from farmer' interview.

d) Ad-hoc combination of land ratings

The overall physical suitability of a land area for a LUT is calculated according to another decision rule. Land qualities can be weighted and not have to be on the same scale of "goodness".

2.4 Application of geographic information system in land evaluation

Burrough (1989) described methods of data analysis in geographic information system (GIS) and linkage with spatial modeling. Besides the mapped data, information was also available relating the soil series and sets of land qualities that could be used for determining the suitability of the area with various types of land use. FAO land evaluation has a terminology as "Land Utilization Type". He showed an example that conducted from a small study area in Kisii district in Kenya using the Map Analysis Package (MAP). Scenarios of land utilization were integrated with empirical soil erosion in the land evaluation procedure to estimate soil loss such as absolute rate of soil erosion, benefit of trash line, and how soil depth might be reduced by erosion.

Elberson et al., (1988) suggested that the use of GIS to generate terrain mapping unit (TMU) from digital remote sensing in Sumatra, Indonesia. Soil information, which is one of the important components of ILWIS, was integrated with geomorphologic description for TMU in the relational database. The Land Evaluation Computer System (LECS) that was developed in Indonesia by FAO as a planning tool was interfaced with a small-scale scenarios approach.

The GIS was used to develop an overview of Nepal's natural resources status and to evaluate sustainability of food, animal feed, and fuel resource in the country. The study concentrated on land use dynamics, especially deforestation, the status of soil fertility for different type of land use and soil erosion from various land use and management practices. The GIS is now being used to support resource decision-making in Nepal (Schreier and Brown, 1992).

Liengsakul et al., (1993) described the use of GIS and digital remote sensing for land evaluation of northern Thailand to locate new sites for permanent cropland. The GIS was used for the preparation of terrain mapping unit (TMU), which integrated data from existing maps and data interpreted from satellite images. The GIS was also used to locate physical suitable, accessible and not yet used areas that could become potential new cropland site for highland people after resettlement.

Mongkolsawat et al., (1999) described land evaluation for combining economic crops using GIS and remotely sensed data in Song Kran Watershed covers extensively in the Sakon Nakhon basin, Northeast Thailand. In this study was performed the suitability assessment for each crop was conducted using the method as described in FAO guidelines for land evaluation for rainfed agriculture. For each crop, land unit was created from overlay process of the defined theme layers or land qualities on which the suitability is based. The overlay process was then performed on these map layers with selection criteria of only highly and moderately suitable classes. The resultant map obtained is a result of combination of the defined suitability class of combining crops within the area. Economically, the planning alternative that best matches land use to land suitability should therefore be the most valuable and efficient.

2.5 Land mapping unit delineation

FAO (1976) defined land-mapping unit (LMU) as “an area or parcel, which has a relatively homogenous of natural factors and a differentiation of one or many factors comparing with neighboring area”. Each LMU has a quality and suitability with fixed land utilization types. LMU is a premise for calculation of land evaluation and land use planning. Soil mapping units are commonly selected as LMU. In another word, land includes soil characteristics and other characteristics such as topography, geology, climate, and hydrography, creatures that affect to ability of use a fixed parcel or region.

Vu et.al (1997) described establishment of LMU map in Dongnai province based on the relationships among soil characteristic, effective soil depth, terrain, water availability and climate so that LMU map was a scientific background for evaluating land suitability of land utilization types that were selected in each land unit. LMUs were expressed on the map as polygons which have enough characteristic and quality to create differences from other units aiming to guaranty their suitability with different land use types. LMUs can be described by their characteristics and quality:

- Land characteristic is a relative simple attribute that can be measured and counted such as average annual rainfall, different soil textures, etc.
- Land quality is a complex characteristic that can be impressed normally by internal relationships of many soil attributes (soil erosion, flooding, ability of remaining nutrients, etc.)

Institute of Planning and Designing Agriculture of Vietnam (IPDA) from 1991-1995 proposed norms for land evaluation following FAO method with different map scales from 1/10,000 to 1/500,000 (at district, provincial and national level) (IPDA, 1995).

Many methods have been used to define the LMU (Meijerink et al., 1993). The interrelations between materials, forms and processes result in morphological boundaries frequently reflect geo-morphological and geological differences. A LMU groups follow main aspects such as geomorphological origin, physiography, lithology, morphometry and soil geography. The term "geomorphologic unit" is not fully appropriate because sub differentiation may be based on soil distribution. The word "physiography" has been avoided because the meaning varies from the American Geological Institute's "study of the genesis and evolution of land form" to description of land that includes vegetation and land use.

A LMU describes a natural division of terrain that can be distinguished on aerial photographs and can be verified on the ground. In term of GIS, a LMU may be described as the geographic location (polygon) of entities that relate to a unique set of attributes. The boundaries of LMUs will coincide with the boundaries of fairly homogeneous lithologic unit. However, there may be more LMUs within a lithologic unit. A LMU has characteristic of having morphometric properties, considerably (1) internal relief or relief amplitude, (2) valley density and type of valley, (3) slope forms and population of slope steepness and slope length. It can consist of subunit and have a specific sequence of slope facets and associated changes in kind of soil and erosional hydrologic processes. (Meijrink, 1988)

Land mapping unit or terrain unit or homogeneous domain is the portion of land surface, which contains a set of ground conditions, which differ from the adjacent unit across definable boundaries. By definition, the LMU must be mapped at effective cost over the entire region through criteria, which are objective. When this is accomplished, all the subsequent analyses will be referred to and treat each LMU as a spatially homogenous domain. (Carrara *et al*, 1995)

Vu et.al, (1997) also described selecting and classifying norms for LMU map in Vietnam bases on 4 backgrounds: (i) characteristic of natural condition in the study area, (ii) land use requirements of selected land utilization types, (iii) scale of presented map, (iv) existing document and supplementary ability.

(i) In land classification, norms for land classification need to be united not only nationwide but also for the entire world. On the contrary, norms for establishing LMU map don't need to be united throughout the country but they belong to characteristics of natural condition in study area. For example, in coastal delta area, besides overall norms such as: soil, terrain, water availability, agricultural climate, selected norms must be tide regime, salt contamination, relative terrain and flooding regime. In a hilly area, norms that need to select are different from norms in coastal delta area such as: slope of terrain, soil depth, norms of clotting level of laterite, mixed stones and exposed stones.

(ii) Norms for LMU map may depend on land use requirements of land utilization types in project area. For example, crops in rainfed agriculture area such as cashew, on land crops may exclude water availability but for paddy rice, and crops that need to be watered such as coffee, pepper and vegetable, etc, water availability must be included in LMU map.

(iii) The larger scale of the map (more detail), the more information is contained and vice versa. For example, to separate LMUs in the scale of 1/50,000, classes can be divided into 3 units.

(iv) Existing and supplementary ability of documents determine quality of LMU map and allow selecting and classifying norms because LMU map is a result of overlaying process of many information layers (soil, water, agricultural climate, etc.) that are existing in functional departments. In Vietnam, these documents are not synchronous in quality and quantity as well as map scale and establishing time. Thus when necessary unique documents are used, adjustment and supplementary inspection in the fields are necessary (Vu *et al*, 1997).

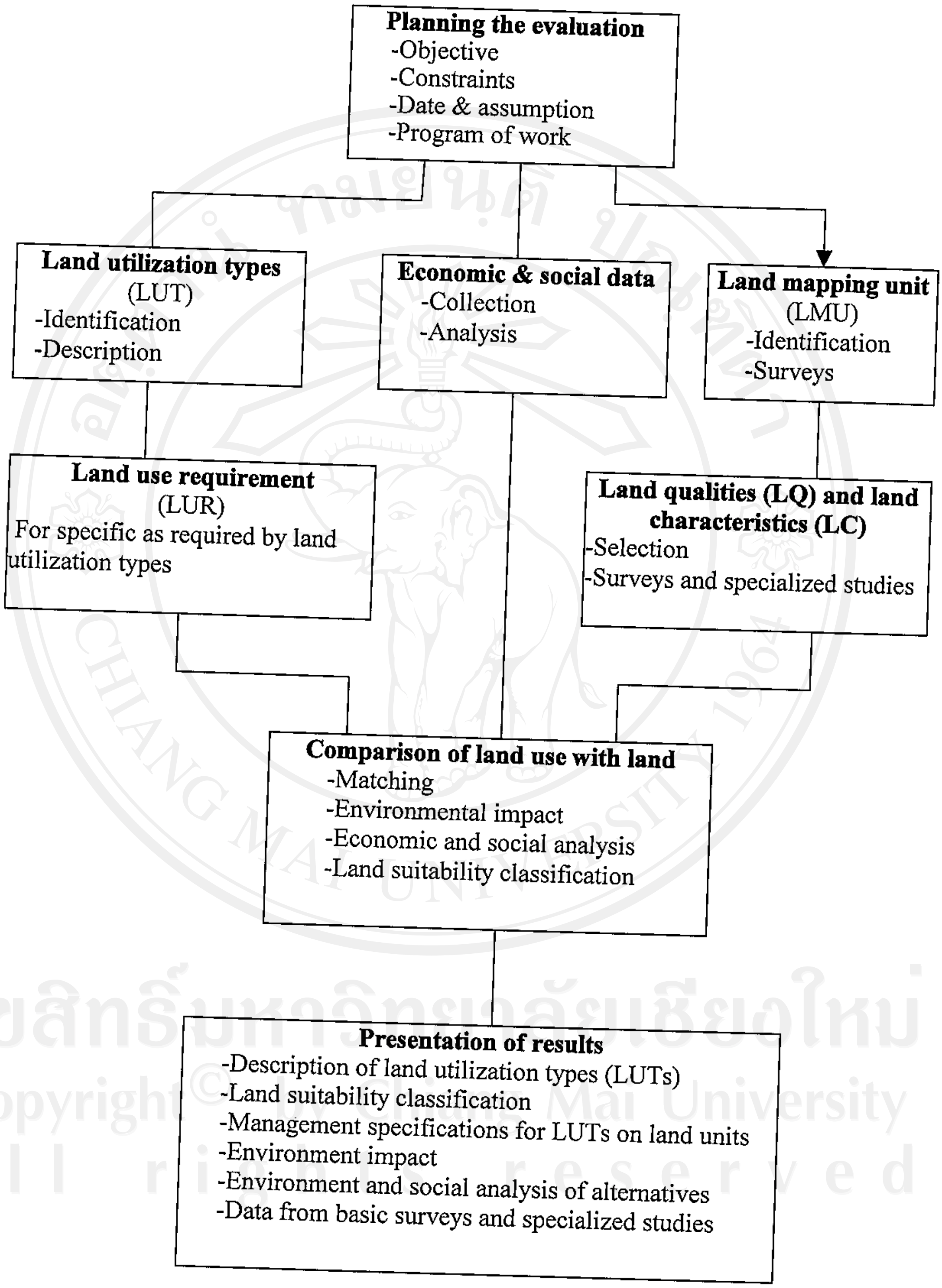

Figure 2.1 Procedures in land evaluation (FAO, 1984; Dent and Young, 1987)

In Dongnai province, most of soil types in Vietnam are formed except soil type in high mountains. Terrain consists of plain, hill and mountain. Land utilization types are diverse including perennial crops and annual crops. However, LMU map aims to serve for supporting land use projects; it should have a high generalization, not be so complex.

2.6 Land evaluation in Vietnam

In Vietnam, the concept of land classification is old-established. Land was divided into *"Tu dang dien, luc hang tho"* aiming to serve for taxation without considering disadvantages of land and methods to upgrade for land rank. In period of 1972-1974, Vu Cao Thai and Bui Quang Toan carried out land classification in district and commune in Dong Hung commune, Thai Binh province. Until 1983, the general of holding management department of Vietnam composed guideline documents for classifying paddy rice land in district class. This method divided paddy rice land into 8 classes and the main criteria based on crop yield.

Vietnam soil scientists assessed land evaluation method of FAO and there were some meaningful preliminary results (Bui, 1986; Vu *et al*, 1995; Vu *et al*, 1996; Nguyen, 1992). From 1990 to 1993, Institute of Planning and Designing Agriculture of Vietnam (IPDA) had done many land evaluation programs for 9 ecological regions of Vietnam with map scale of 1/250,000, confirmed application of FAO method in land evaluation as a scientific progress that is necessary to apply widely in Vietnam. Soil encrustment on the surface of weathering mantle has played an active role in a biological cycle. The soil encrustment carries all of ecosystems and agro-ecosystems. It is also a surface to develop wholly national economics. It is a carrier that may have multi-dimension impacts on nature and human. Thus, researching soil encrustment is focused specially on these following fields: (i) soil pullulation and classification, (ii) physical, chemical and biological characteristics of soil, (iii) building soil maps in different scales and the lastly land information on quantity and quality to make a scientific premise for land use and management.

Within the limits of the National Programe of comprehensive investigation for the Eastern region of the South Vietnam (Programe 60-G) the creating a newest soil map at scale 1/250,000 for this region was carried out by a collective of authors in Sub-Institute for Agricultural Planning and projection in South Vietnam. The soil map was established on the basis of inheritance of numerous results in researches of soil geography of studied territory, including the last achievements obtained by many investigators in a period of 1976- 1988 years. The new soil classification is based on two basic principles: "soil properties" and "identification of elementary soil process". The delineation, rectifying and amending boundaries of spatial distribution of soil units was completed by a comparison of the correlation between existing soil maps and the base geological maps in 1982-1986 of the Region. The field verification was conducted in establishing soil classification and in correcting contours of mapping units. In this area, there are 8 soil groups and 44 soil units that are generally corresponding to the "soil type" level in Dokuchaev's recognition. (Phan, 1992).

A program for land evaluation in Baclieu province in Mekong delta, applied GIS with Arcinfo and Mapinfo softwares and FAO land evaluation method. It was called "parallel land evaluation method" (Figure 2.2). The results aimed to create thematic maps serving for land evaluation such as, mapping unit, land suitability maps for crops. This study contributed an important role in land use planning in Baclieu province (Nguyen, 2000).

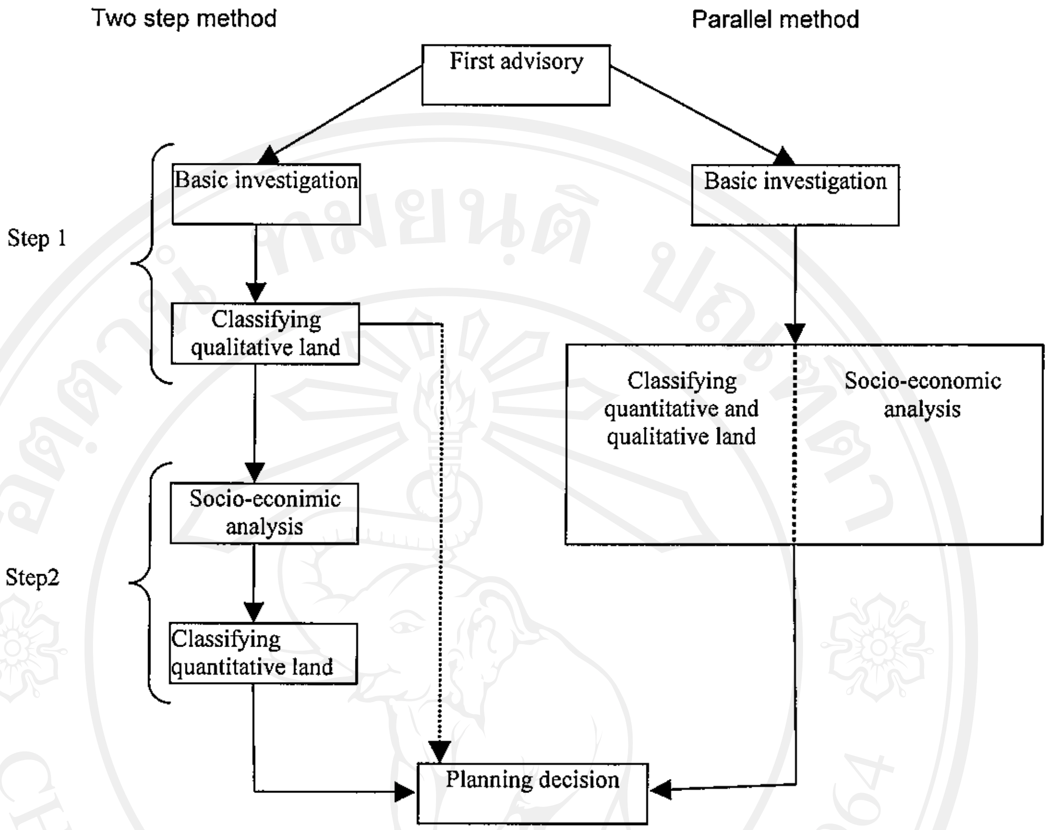

Figure 2.2 Two-step method and parallel method in land evaluation (Nguyen, 2000)

In Dongnai province, one of provinces in the Eastern region of the South Vietnam, land evaluation is under investigation. Land in Dongnai has been evaluated in general programs of Eastern region of the South Vietnam. Specially, in 1992-1995, land evaluation in the whole of Eastern region of the South Vietnam was done from the maps with scale of 1:250,000 (Phan, 1992 and Vu, et.al, 1995). Dongnai was evaluated as a province that has potential of agricultural land in the primary class. In the present and future, it is suggested that industrial perennial crop, fruit tree, soya bean, corn, cotton will become the strength of the province. Maximum limitation method was applied but procedure it had been done manually.

In 1996, land evaluation in Dongnai has been done. This study was based on the view of the system, researching land in relation to natural environment, socio-economic and environmental impacts. The results consisted of (i) investigating soil map by FAO/UNESCO method; (ii) deciphering aerial photograph to build existing land use with the scale of 1/50,000; (iii) evaluating land following FAO method. (Vu, et al, 1996)

With differences of landscape and typical soil properties in a volcanic region that have just stopped eruption, Dinhquan has a diverse land use types that changes continuously every year. Defining land use correctly is very important; land evaluation need to be practical, and contributes vital information for land management. Therefore in this constantly changing land use, comparison of existing and potential land use will help farmers and decision maker to support an effective land use planning.