

CHAPTER 2

LITERATURE REVIEW

The optimal multiple-goal resource management research received widespread international attention. There was progress in the development of the tools needed for land use planning analysis; and the indicator measurements showed encouraging changes in this area with the help of participatory stakeholders. These were integrated together with decision planning for optimal and sustainable resource management that was used widely in many countries. This chapter provides a review of some of the literature on the three topics relating to the concepts and methods for evaluating sustainable resource management. These are the indicators for sustainable agricultural systems and multiple-goal programming. This method has many tools using modern software developments which can use input from participatory stakeholders which can be analyzed by the analytic hierarchy process (AHP). Furthermore, this chapter also reviews some of the existing platforms for the evaluation of optimal resource management with multiple-goals of the farming systems at the farm and the watershed level.

2.1 Indicators for sustainable agricultural systems

The literature on the sustainability evaluation of natural resource management systems has increased since 1990 as there has been an increase in the awareness of natural resource conservation (Azar et al., 1996). At present, a measurement of the sustainability of natural resources at national, regional and global level, or “multi-scale”, focuses on the definitions of the three pillars of sustainability in social, economic and environmental dimensions (Moldan et al., 2012). In each pillar, there are differences in the details to measure the efficiency and sustainability of systems, e.g. farm, community, city, regional, national and global scales respectively (Bossel, 2000).

The number of indicators needed to measure such systems properly should not be excessive, but need to be effective and efficient for the systems being studied. For example, Masera (1999) explored five categories of indicators for sustainable natural resource management systems, these being productivity, stability, resilience, equity and self-reliance.

- a) Productivity can be measured in either yield per land unit, energy efficiency, cost benefit ratio, investment and income or labor productivity.
- b) Stability can be measured by plant species or ethnic group, natural resource conservation, risk of disease and insects, product and trend and life quality.
- c) Resilience, reliability and adaptability can be measured by the acceptance of new ideas, the learning processes of farmers and willingness to accept new innovations and changes.
- d) Equity can be measured by benefit distribution among the parties involved and employment.
- e) Self-reliance or self-empowerment can be measured by participation, self-reliance, ability to control resource use, the decision making process and related organizations.

Meanwhile, Perez-Grovas (2000) explored five categories of attributes, namely,

- a) Productivity was measured by five indicators which are yield, product quality, marginal cost per benefit, labor demand and net income per total income.
- b) Stability, resilience and reliability were measured by the number of managed species, income from non-coffee crops, market diversification, erosion, nutrient balance, input availability, fluctuations in coffee prices and the permanence of coffee producers in the system.
- c) Adaptability was measured by the number of producers and area cultivated per system.
- d) Equity was measured by decision-making mechanisms, distribution of returns and benefits.
- e) Self-reliance was taken into account by the attendance to assemblies and other events, the number of producers trained and the reliance on external resources.

Lefroy et al. (2000) evaluated sustainable land management practiced in three case studies located in Indonesia, Thailand and Vietnam by identifying indicators with five pillars of sustainability.

- a) Productivity was measured from yield per land unit, soil cooler, plant growth and leaf cooler.
- b) Security was measured from average annual rainfall, residue management, drought frequency and income from livestock.
- c) Protection was measured by the decrease in topsoil erosion, cropping intensity and extent of protection and cropping patterns.
- d) Viability was measured from net farm income, off-farm income, the difference between market and farm price, availability of farm labor, land holding size, availability of farm credit and percentage of farm produce sold in markets.
- e) Acceptability was measured by tenure status, access to extension services, access to primary schools, access to health centers, access to agricultural inputs, subsidies for conservation practices, training in conservation practices and village road links to major roads.

These were studied using the weighed indicators given by farmers and the measure of sustainability by sorting the indicator scores of sustainability in each village from high to low. The villages which got low scores from the indicators were considered as unsustainable.

Kammerbauer et al. (2001) studied sustainability with 3 groups of indicators.

- a) All production systems are measured by diversity of species and plants, area and soil organic matter etc.
- b) The social and economic effectiveness was measured by the indicators such as input price, sale price, production costs, available labor, new technology, nutrition and level of education.
- c) Institutional sustainability was measured by access to agricultural extensions, property rights and land for sale, credit, savings and marketing.

The results from this research measured the effectiveness of social and economic sustainability between 1955 and 1995 and the index of environmental degradation in that period. This demonstrated the potential of selection when a conflict arose between the various objectives.

Mueller, (1997) evaluated the sustainability of agriculture at three levels: the plot, the farm-household and the watershed. The plot level was measured by yield, soil of cultivated plots, soil on pastures and pesticide residues from the crops. The farm-household level was measured by production technology and socio-economic factors. The watershed level was measured by the water taken from 8 sample points along the river and some of its branches. The results showed that the main problem regarding sustainability was the visibility of environmental indicators, particularly soil and water resources. The economics of horticultural production could still be considered a profitable occupation, providing average incomes were well above the basic needs income. However, around one fourth of the households earned farm incomes below the basic needs income. Also, technical efficiency and economic performance, the average levels of which were still satisfactory, tended to decrease over time.

Panell and Glemm (2000) presented a conceptual framework for the economic evaluation and prioritization of sustainability indicators. The framework was based on Bayesian decision theory, particularly its use to calculate the value of information under conditions of uncertainty. They evaluated a set of indicators in terms of reliability (standard measurement, accuracy, an ease of understanding, low cost of monitoring and checks, and stability of time measurement) and the ability to display by mapping.

Lopez-Ridaura et al. (2005a) classified the indicators into two groups of attributes for the evaluation of sustainability at the farm and watershed levels.

At the farm level, the indicators were namely:

- a) Productivity and stability were measured by: yield, yield gap, benefit per cost ratio, income, crop production per crop consumption, income generated per unit labor, food produced per unit labor, external inputs per total inputs, period of forage

deficiency, organic matter incorporated into the soil, nutrient balances and nitrogen fixed by leguminous species.

- a) Resilience, reliability and adaptability were measured by: yield standard deviation, number of activities in the natural resource management system, income generation per activity and costs of investment, farm income per total family income, added value of production by improving household knowledge, minimum yield in the driest years, frost probability after sowing, time to recover from catastrophic events (crop loss, forest fire, animal death or robbery), yield variation with temperature variation and yield variation with rainfall variation.

At the watershed scale, the indicators selected were:

- a) Productivity and stability were measured by: total production, value of the production, maize production per population in primary activities, maize production per total regional population, area of soil eroded, net deforestation, animal exceeding carrying capacity and nitrogen lost by leaching, use of fertilizers and biocides sprayed.
- b) Resilience, reliability and adaptability were measured by: regulations for the access to and the management of resources, areas under communal management, number of communal societies practicing rural production, variation in the value of production with temperature variation, variation in the value of production with rainfall variation, standard deviation in the value of production, non-harvested areas, value of production in the driest years, value of production in coldest years, number of activities in the natural resource management system and income generated by different activities.
- c) Stability was also studied by Conway (1994) and consisted of two important components; the first is the constancy of useful production from season to season; the second is constancy from year to year.

Xu and Mage (2001) studied the concepts and criteria for assessing the health of the agro-ecosystem. They found that the agro-ecosystem health can be characterized from four different perspectives relating to the agro-ecosystem: structure, function,

organization and dynamics. Other criteria, such as resource availability, diversity, and accessibility are some of the existing concepts capable of depicting the structural state of the agro-ecosystem health. Concepts including productivity, efficiency and effectiveness appear very useful for assessing the functional performance of agro-ecosystems. On the other hand, organizational criteria such as autonomy and self-dependence are also useful to characterize the organizational nature inherent to the agro-ecosystem health while stability and resilience are two appealing concepts capable of revealing the characteristic dynamics of the agro-ecosystem health.

Acosta-Alba et al. (2011) selected indicators for exploring sustainable farming scenarios at a regional scale for dairy farms using several attributes.

- a) Autonomy was measured by the additional area needed to produce crop-based inputs, (e.g., concentrated food fodder), and the input of total nitrogen such as found in fertilizers, concentrated feed and fodder.
- b) Environmental efficiency was characterized by three indicators quantified in nitrate leached, non-renewable energy use and greenhouse gases.
- c) Productivity of agricultural activities was taken into account by the milk produced, total nutritional energy and the total protein contained in animal products.
- d) Social contribution was signified by the employment indicator.
- e) Economic viability indicators were measured by total income, total costs, farm profit and milk marginal revenue and gross operating surplus. Other attributes such as social sustainability were signified by total labor and seasonal labor employment (Gómez-Limón and Riesgo, 2008).

Marten (1988) explored the relationship between productivity, stability, sustainability, equitability and autonomy. For example, higher productivity can be associated with lower stability if the higher production is achieved by means of high-yielding varieties. Factors such as High-yielding varieties are more vulnerable than local varieties to fluctuating environmental stresses such as droughts and pest attacks and high yields can lead to a glut on the market that depresses prices.

However, greater productivity and stability can also lead to lower equitability. If the overall supply of water is not sufficient to provide reliable irrigation to all the farmers in the area, only some of the farmers may receive an irrigation service. This will increase the overall productivity of the area but will also increase the spread of incomes. In the same way that higher productivity can lead to greater household autonomy, the higher productivity may decrease autonomy in times of scarcity if it forces people away from an attitude of self-reliance.

Evaluating the sustainability of complex socio-environmental systems, López-Ridaura et al. (2005b) developed the MESMIS¹ approach in the selection, transformation and aggregation of economic, environmental and social indicators for a sustainability analysis. The MESMIS operative structure is a seven step cycle. The first three steps are devoted to the characterization of the systems, the identification of critical points and the selection of specific indicators for the environmental, social and economic dimensions of sustainability. In the fourth to sixth steps, the information is obtained by means of the indicators integrated through mixed, (qualitative and quantitative), techniques and multi-criteria analysis. This will obtain a value judgment about the resource management systems to provide suggestions and insights aimed at improving their socio-environmental profile. For the seventh step, the scenario building and interactive optimization is the last step of the cycle. Then the applied five general attributes of sustainable natural resource management systems are defined, based on scale and discipline-independence properties, (productivity, social contribution, autonomy, stability and resilience).

In the case of the sustainability evaluation in Northern Thailand by Praneetvatakul et al. (2001), the indicators used were developed to evaluate the sustainability of upland farmers. The results found that the rights of land ownership and water scarcity issues were scoring at a minimum level under the various economic, social and environmental indicators.

¹ MESMIS - “Marco para la Evaluación de Sistemas de Manejo de Recursos Naturales Mediante Indicadores de Sustentabilidad” (Framework for the Evaluation of Natural Resource Management Systems Incorporating Sustainability Indicators)

Praneetvatakul and Sirijinda (2001) evaluated the sustainable agricultural systems from Mae Sa Mai village in Northern Thailand using an evaluation framework of sustainable land management (FESLM). There was a broad guideline for land management consisting of 5 elements: productivity, security and stability, conservation and protection, viability and acceptability.

From the FESLM, the created indicators to evaluate the 3 pillars are:

- a) Economic measured by net household income, net farm income and land holding size.
- b) Social measured by education, household labor and type of agricultural land.
- c) Environmental measured by cropping systems, effects of chemicals and biodiversity.

When ranking the sustainability indicators, the level of chemical pesticide use had the lowest score. It was found to be the biggest individual issue which could make the village unsustainable, followed by the issues of biodiversity and land type respectively. Amongst the 3 objectives, the environmental objective was the biggest unsustainable factor for the village. The lower use of chemical pesticides practiced in highland agricultural systems are recommended.

Ekasingh, B. et al. (2001) studied sustainability indicators of agricultural systems and natural resources in upland locations from an economic and social perspective. In this study, the 4 sites compared are Angkrang, Nonghoy, Meahae and Prabat Huay Tom using the criteria:

- a) Productivity measured by revenue per household per year and revenue per person per year.
- b) Sustainability measured by land and water conservation practices.
- c) Equality evaluation measured by the poverty line.
- d) Diversity measured by the source of cash income.
- e) Social stability.

The results obtained varied according to the physical environment, biological potential, production systems and the resources used in each area. The study suggested that the indicator analysis should be expanded to all areas in the future for an agricultural planning policy on sustainable upland areas.

All the research mentioned above showed clearly the sustainability indicators but did not give optimal resource management planning. To achieve optimal resource management planning, we would use the indicators for multiple-goal programming which can determine the goal objectives by analysis.

2.2 Multiple goal programming

The study of Multiple-Goal Linear Programming (MGLP) was an appropriate analysis use to achieve the benefits being studied. For example, the regional studies conducted by Hijmans and Van Ittersum (1996) had aggregate spatial units in an Interactive Multiple-Goal Linear Programming (IMGLP) model. These were analyzed for both a schematized and existing IMGLP model (GOAL) which explored land use options for the European Union. Discrimination was made between the effects on objective functions for the system as a whole and the effects on related optimum land use allocation within the system. In GOAL, the effects on land use allocation tended to be more important than effects on the values of the objective functions. Several rules or factors were identified that determined the effects of aggregation, amongst which the degree of curvilinearity in input-output relations and the method of aggregation error was difficult to predict. Therefore, in land use studies using IMGLP, the motto is “First optimize the linear programming model at the non-aggregated level and then aggregate to the appropriate policy level”. If aggregation is inevitable because the Linear Programming (LP) models become too big, it is aggregated according to the agro-ecological criteria. This means that the aggregation of unit-similar output-input ratios and constraints result in the smallest errors.

Leborte et al. (1999) provided a mechanism for improving the scientific basis for land use planning in support of natural resource management. System methodologies are being operationalized into a land use planning and analysis system, (LUPAS). This is a decision-support system based on the interactive multiple-goal linear programming (IMGLP) method. This is used with other analytical tools required for exploratory land use studies. The three main methodology parts of LUPAS are land evaluation including assessment of resource availability, land suitability and yield estimation, scenario construction based on policy views and land use optimization in the form of an MGLP model. In optimizing land use under different sets of multiple goals, different scenarios are analyzed based on land evaluation quantified by input-output relationships for current and alternative production activities and formulation of constraints and policy views as mathematical functions. There are two types of optimization results: goal achievements and the corresponding land use allocations. The IMGLP method is the concept underlying LUPAS. This method is currently applied in these studies to deal with conflicting land use objectives of stakeholders at the regional level where the target regions are provinces or states. Results for a given region reveal the extent to which various goals can be met given the technical and physical constraints. This will provide estimates for analyzing trade-offs between the costs and benefits incurred in attaining the various goals.

Lu (2005) explored a scenario of strategic land uses in northern China using ecological production principles. He used simulation modeling and multiple-goal linear programming as integrative tools for exploring four scenarios. These represented major directions of agricultural development in the region and took into account the views of national and local stakeholders. The results indicated that by using crop rotation with alfalfa, soil conservation, food self-sufficiency and income for the rural population can be substantially improved by efficient resource use. The large rural population and the lack of off-farm employment opportunities were the most important factors affecting rural development in Ansai. This study contributed to the understanding of regional problems. The results demonstrated that agricultural development potentials showed agro-technical possibilities for alleviating unsustainability in this region.

López-Ridaura et al. (2005a) used linear programming for the quantitative analysis of indicators and their trade-offs using a schematized example. The basic characteristics of the Multi-scale Multiple Goal Linear Programming (M-MGLP) method are described. In M-MGLP, indicators pertaining to different scales of analysis can be set as objectives or constraints for optimal resource management. In this way, stakeholders interacting in a specific region can be made aware of the consequences of alternative natural resource management systems. The stakeholder can set the different indicators at the same scale or set the indicators for other scales of analysis.

Hung et al. (2006) used an approach which integrates the multi-attribute and multi-objective decision making methods. This contained three main steps to solve the multi-objective programming problems. These included selecting the relevant indicators needed for the decision model, the alternative scenarios prioritized by the fuzzy AHP method and combining these approaches in the model. A case study of food waste management conducted in Taiwan was used to demonstrate the practicality of this approach.

Acosta-Alba et al. (2012) used results from the Life Cycle Assessment (LCA) in Multiple-Goal Linear Programming (MGLP). To generate future land-use configurations to meet environmental targets, the approach required a defined set of current and alternative land-use types and characteristics of these land-use types. They quantified these characteristics for all land-use types and estimated the regional sum of each indicator for current land-use types to establish the baseline scenario. The defined scenarios consisting of a set of goals aimed to maximize production and profit without violating environmental issues and per-hectare limits on nitrate leaching, non-renewable energy use and greenhouse gas emissions. In this study, existing dairy farms were classified into 5 groups from organic to intensive by considering: the mode of production, quantity of milk production, fodder-crop and the grass area to find an alternative replacement with 100%-grass-based dairy systems and forest. The major benefits of coupling MGLP and LCA results include:

- a) Taking into account social and economic indicators while considering environmental concerns.
- b) Quantification of potential environmental impacts to optimize agricultural production from an LCA perspective.
- c) Consideration of a variety of complementary production modes in a region.
- d) Generation of scenarios that can be discussed with stakeholders as support information for environmentally-conscious decision making regarding land use.

In the case study at regional and farm level, Zander and Kachele (1999) present a modeling system which consists of a set of hierarchically-linked modules. These modules describe production activities in a way that allows an economic and ecological analysis of these techniques. The heart of the modeling system is a multiple-goal linear programming model which was generated by database modules. Simulations of single farm models as well as regional models based on simultaneously optimized farm types were possible. The modeling system appears to be a highly flexible tool with respect to the number and type of farms, sites and production techniques. Environmental objectives can easily be included and different levels of goal achievement can be simulated. It was well suited for single farm analysis as well as for regional models including static as well as dynamic approaches. It allows for the rapid adoption of the model and the rapid calculation of scenarios. Therefore it was suited for use in interactive environments, with users who are interested in repeated runs with little change in the goal function, prices, subsidies or technical coefficients. The results can be used for policy decisions as well as the strategic planning of individual farmers.

Senthikumar et al. (2011) developed a multi-objective linear programming model (MGLP) to explore the impact of:

- a) Modified rice cultivation including water-saving irrigation on farm profit.
- b) Water pricing and water quota government policies on adoption of modified rice cultivation by farmers.
- c) A combination of (a) and (b) to achieve the objectives of both farmers and society at large.
- d) To study the trade-offs between income, water and nitrogen use.

The analysis was carried out on four rice-based farm types. Model results showed that the observed farm profit for all four farm types could be increased using current practices simply by optimizing land use for specific crops. Adoption of modified rice cultivation further increased farm profit. Water-saving practices were selected only when water pricing was introduced. Farm profits were reduced even at low water prices but farmers were compensated through the adoption of modified rice cultivation. The combination of policies that stimulated the adoption of modified rice cultivation was effective in achieving both increased farm income and water savings. Water prices differed across farm types and seasons and impacted poorly resource-endowed farmers the most. Providing water quotas could protect the poorly resource-endowed farmers. The model helped to identify the optimal water price and water quota for each farm type to achieve both the objectives of farmers and society at large. Opportunities for reducing water use and avoiding environmental pollution at acceptable profits are available for all farm types, but need to be tailored to the farmer's resource endowments.

Ekasingh et al. (2011) developed software to facilitate solving the optimal options in multiple-objective agricultural land use planning. They based the software on the interactive multiple-goal programming (IMGP) at the provincial level. The main project components consisted of spatial analyses using geographical information systems to enable the construction of land resource units (LRU) using spatial databases. This used a field survey enabling the construction of model coefficients and using the IMGP modeling formulation. This including the development of an *IMGP-LPlan* program to facilitate users in constructing, editing and analyzing an IMGP model and to display the results. The basic linear programming model they constructed consisted of 200 decision variables comprising of planted areas with identified cropping systems, labor hired in each period and the amount of loans. There were 536 constraints related to the model objectives and the availability of resources: planted areas in each cropping system, labor requirement, hired labor, capital, rice consumption, sources of loans, land availability by type of land resource units, water availability according to different time periods and areas suitable for different cropping systems. Stakeholders and decision makers in the

study area collectively identified the main objectives in agricultural land use planning covering 3 dimensions of land use policy. These were the economic, social and environmental dimensions which were further divided into eight objectives. Their priorities were rated using the Analytic Hierarchy Process (AHP) and were listed from high to low so as to maximize total net returns, water productivity, employment and total agricultural land areas respectively. It also minimized total production cash costs, quantities of pesticide use, quantities of nitrogen fertilizer use and overall total soil erosion. The *IMGP-LPlan* program was developed to facilitate the use of an IMGP model and to modify objectives and constraints, analyze results to obtain optimal agricultural land use and to help planning in the province.

Roetter et al. (2007) advocated a multi-scale modeling approach embedded in a sound participatory process. To this end, the Integrated Resource Management and Land use Analysis (IRMLA) Project developed an analytical framework and methods for resource use analysis and planning for four sites in Asia. In the envisaged multi-scale approach, the results were integrated from field, farm, district and provincial level analyses. These were based on interactive multiple goal linear programming (IMGLP), farm household modeling (FHM), production ecological concepts and participatory techniques. The approach comprised of the following steps:

- a) Inventory/quantification of current land use systems, resource availability, management practices and policy views.
- b) Analysis of alternative innovative land use systems/technologies.
- c) Exploration of the opportunities and limitations to change resource use at regional scale under alternative future scenarios.
- d) Modeling decision-making behavior of farmers and the identification of feasible policy interventions.
- e) Synthesis of results from farm to regional level for negotiation of the most promising options by a stakeholder platform and the operationalization of dual-scale analysis were illustrated by the outputs (development scenarios, promising policy measures and innovative production systems) from various component models as shown by the case study in Ilocos Norte, Philippines.

An approach was discussed for the integration of results from the different model components at two different decision making levels (farm and province).

Onpraphai et al. (2009) studied a system of alternatives for agricultural careers based on resources in the watershed. His research applied the results to assist the decision-making process at local government level to suggest alternative agricultural crops for farmers which would be appropriate for the available resources in the Mae Tha watershed. The study applied an information system to assess the watershed status using aspect, attitude, local knowledge, experience of local people and farmers themselves from the viewpoints of agriculture, forest resources, livelihoods and socio-economics of communities in order to help understand the inside circumstances in the Mae Tha watershed. Furthermore, the study also gives precedence to beneficial resource data and an uncomplicated spatial information system for communities and official units in the local area. This will assist them to plan and manage areas and resources within the Mae Tha watershed by themselves. The results produced:

- a) The “Nam Tha” programming system which can present uncomplicated spatial information that communities and local administrative organizations can utilize by themselves without any expenditure for the software.
- b) A practical spatial database in the “Nam Tha” program in which communities and local administrative organizations can apply the information to assist in planning and resource management within the watershed and sub-district themselves.
- c) An applicable spatial database as criterion data layers for the assessment of sub-watershed status with the program of Multi-Criteria Decision Analysis in GIS (MCDA-GIS).
- d) Results of the assessment of sub-watershed status in terms of spatial information layers in which communities and stakeholders participated and prioritized criteria within the Mae Tha watershed. Regarding the assessment of the sub-watershed status, the results could be changed as various scenarios depended on the criterion values assigned for each factor.

- e) The main purpose of this study had a pattern of analysis procedure of agricultural alternatives applicable for farmers in the Mae Tha watershed if the farmers felt it would be appropriate to change any crop type.

Praneetvatakul and Sirijinda (2003) studied sustainable agricultural systems planning in highland areas by using a qualitative and quantitative analysis which showed results such as costs and returns of each cropping system, sustainability index and goal programming. Praneetvatakul and Sirijinda (2005) studied sustainable agricultural systems on highland areas at the farm and regional level using Linear and Goal Programming. At the farm level, a sustainable evaluation of land used selected rainfed upland and irrigated areas. A further consideration was a change in the weighting value of environmental and human health. At regional level, this consisted of 3 farming types such as the market oriented farming systems, semi-market oriented farming systems and subsistence farming systems. Four objectives of sustainable agricultural planning are maximizing net cash income over 15 years and minimizing the environmental impacts from chemical pesticide use, human health impacts from swine rearing and the user costs of soil.

Jullo et al. (2005) used a multi-period model based upon a multi-criteria objective function. This has been developed for a representative area of the Guadalquivir Valley, dividing the irrigated area into homogeneous types of farming as identified by cluster analysis. The model was applied to different future scenarios with a time horizon of 10 years and several different farming environments. A set of eight sustainability indicators have been evaluated for the model. The results show that the evolution of crops over time is closely related to the political environment regarding the Common Agricultural Policy and the application of the water framework directive. Methodological innovation has included the successful simultaneous introduction of MCDM and multi-period programming techniques applied for agricultural and scenario development.

The farmers know their problems well and are aware of what their want. If the study wants to make the best optimal resource management possible, the study must include

the participatory stakeholders. If the study does not do so, it would be less acceptable and the results are less likely to be put into action. It is well-known that the analytic hierarchy process (AHP) includes the participatory stakeholders being included in setting the weigh value of indicators.

2.3 Analytic hierarchy process (AHP)

The Analytic Hierarchy Process (AHP) is a multiple criteria decision-making tool that has been used in main applications related to decision-making. Many outstanding works have been published based on AHP: they include the applications of AHP in different fields such as planning, selecting better alternatives, resource allocation, resolving conflict, optimization and numerical extensions of AHP. The specialty of AHP is its flexibility to be integrated with different techniques like Linear Programming, Quality Function Deployment and Fuzzy Logic. This enables the user to extract benefits from all the combined methods, and hence, achieve the desired goal in a better way.

2.3.1 Analytic Hierarchy Process: A multiple criteria decision-making tool

Saaty (2008) said that decisions involve many intangibles that need to be traded off. To do that, they have to be measured alongside tangibles whose measurements must also be evaluated as to how well they serve the objectives of the decision maker. The Analytic Hierarchy Process (AHP) is a theory of measurement through pairwise comparisons which relies on the judgment of experts to derive priority scales. It is these scales that measure intangibles in relative terms. The comparisons are made using a scale of absolute judgments that represents how much one element dominates another with respect to a given attribute. The judgments may be inconsistent, and how to measure inconsistency and improve the judgments to obtain better consistency is a concern with AHP. The derived priority scales are synthesized by multiplying them by the priority of their parent nodes and adding all such nodes.

2.3.2 The application of AHP in research

Karami (2006) used AHP for selecting an appropriate irrigation method. A sample of farmers was separated into four groups using cluster analysis. A panel of experts utilized AHP to determine the priorities of three irrigation methods (border, basin and sprinkler) for each group of farmers. The findings indicated that the highest priority of the irrigation methods differed with respect to each farmer's group. The appropriateness of the decision of each farmer's group regarding selection of the irrigation methods was determined.

Zhu and Allan (2001) used the AHP methodology to model an environmental problem, evaluate the relative desirability of alternatives and organize the information and judgments used in decision making. The results of the research can be displayed by Java AHP on the World Wide Web (www) and can be accessed globally. It takes advantage of the www's wide availability, web resource integration and cross-platform capabilities.

Ismail (2009) used the AHP method for multi-criteria evaluations (MCE), and has shown the capabilities of the integration of a geographical information system (GIS) and decision support systems. The data was prepared spatially in a GIS and then an analysis was performed with the systematic evaluation method. The MCE allows both constraint and criteria maps to be combined in an arithmetic operation in a suitability analysis, and also allows for criteria maps to be assigned variable weights. From the weights derived from the AHP method, it can be seen that slope and elevation were strong factors in allocating the suitable harvest zones, (0.63 and 0.29). The hydrological aspect is the third most important factor with a measurement of 0.07. The total suitable area for a productive forest zone was 9,757.3 hectares, (96.06%) and the designated protected forest zone was 399.2 hectares, (3.94%). This shows the importance of certain forest land to be classified as a restricted area for logging purposes to ensure the sustainability of the forest ecosystem and water resources. This result demonstrated that the methodology used has high potential and functionality for determining suitable

forest harvest zones from several criteria for the hill forest zones. Finally, it can be concluded that MCE incorporating GIS provides an ideal tool. It is essential for modeling with flexibility and has the ability for spatial modeling operations for site such as the suitability studies in the hill forest of Peninsular Malaysia.

In the studies of Kara and Köne (2012), the objective was to measure and compare environmental sustainability at sub-national level by using AHP. The proposed model was implemented both the selected sub-regions, (NUTS 2 level) and their provinces (NUTS 3 level). In the analysis, Super Decisions software v.2.2.1 was used and two alternative groups were evaluated according to eleven criteria: population density, energy consumption, green area, land use, disposal of waste, non-treated wastewater, water consumption, number of cars, traffic accidents, SO₂, (Sulfur-Dioxide) and PM₁₀ emissions, (Particulate Matter). Ismail and Abdullah (2012) had a new Environmental Performance Index, (EPI), using a decision making tool from the Analytic Hierarchy Process (AHP). Pairwise comparison scales in AHP were utilized to set new EPI for nine ASEAN countries. A new ranking EPI among ASEAN countries showed that Brunei had the highest EPI followed by Singapore. The new ranking may offer an alternative measurement for evaluating environmental performance, particularly for ASEAN countries.

From the above review of literature, most of the attributes are truly basic attributes of systems, irrespective of the scale of analysis or the disciplinary approach. The ability of a natural resource management system to provide the desired combination of goods and services to satisfy the objectives of society will depend on the degree to which each attribute is realized. For example, both the productivity and the stability of a field, a farm, a region, a country or a continent are definite characteristics of its optimal potential with regards to the relative importance placed on the three indicators. Similarly, the stability as well as the resilience of a system can be analyzed from any disciplinary perspective; in other words, the environmental, economic, social and/or political stability of a natural resource management system at any scale of analysis is a basic attribute that (co)-determines its optimal use.