Adaptation of Land Suitability Evaluation for the Malaysian Agricultural Land Use

Goma Bedawi Ahmed*[12], Abdul Rashid M. Shariff[1], Mohammed Oludare Idrees[1]

1-Geospatial Information Science Research Center (GISRC),
Institute of Advanced Technology, Faculty of Engineering,Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor Darul-Ehsan, Malaysia

2- Arab Center for Desert Reseaech and Development of Desert Communities Morzok- Libya

** Corresponding author's email: joma762001 [AT] gmail.com*

ABSTRACT--- ***In this study, the position of land suitability evaluation in Malaysia within the time frame of last ten years (2005 till date) wasreviewed from the view point of methods and applications. Although there had been some useful works done, no research had been done with a view of informing the research community on the development in this aspect. The objective of this paper is to review published studies to identify and discuss progress in land suitability evaluation methodology, usage, challenges and recommendation for future research direction. The study reveals that Analytic Hierarchy Proses (AHP), Analytic Network Proses (ANP), Parametric System are the three main land suitability evaluationmethods widely used in Malaysia.Similarly, three key application areas, agriculture, urban planning and coastal area management have benefited from these methods. In addition, the strengths and weaknesses of each method are identified and discussed in relation to different purposes to which they have been put to. In summary, the review indicates that land suitability evaluation methods specifically for agricultural use have been focused on evaluating land suitability for single crop rather than a multi-purpose approach that can increase agricultural productivity and maximization of land as a scares resources.***

Keywords -Land suitability, multi-criteria, agriculture, crop cultivation

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1. INTRODUCTION

The Malaysian national economic agenda to achieve high-income country status by 2020 and the increasing population growth resulted to major investments in infrastructure development with far reaching consequences on land available land for agricultural use. Rapid expansion in physical development such as transportation network, industrialization, recreational facilities, etc. is not limited to urban settlement only; rural communities are also experiencing pressure on land resources. Similarly, increasing population in Malaysia has also increase the demand for food production and agricultural raw materials for industrial and domestic uses. Unfortunately, the available land mass remain fixed against population growth and infrastructural development. According to Malaysia historical population (1960 - 2015)data published on the 1st of January, 2015 (http://countrymeters.info/en/Malaysia), the country has a population of 8 160 975and an estimated population of 30 644 293in 1960 and 2015 respectively (see Fig. 1), while the total land area remains 329,847 square kilometers. This implies that in 1960 an individual can have access to about 40417 square meters in 1960 compared to 10764 square meters in 2015. So, within the last six decades, it means that access to land by individual have reduced by 73 per cent.

The aforementioned, in addition tothe traditional agricultural practices, pose great challenges to sustainable land use to support the demand for food and agricultural raw materials. These facts have put the question of how land resourcescan be efficiently managed to maximize productivity.Consequently, several land evaluation frameworks have emerged with different objectives and scope of interest in mind. The United State of America pioneers this drive with a number of land evaluation schemes. In the 1920s, the United States Bureau of Reclamation (USBR) developed a scheme to classify land for irrigated land use[1].The resultant limitation of this system led to the development of land capability classification (LCC) by the U. S. Department of Agriculture in 1961 in response to land limitation properties [2]. Failure of these two systems to produce satisfactory level of implementation gave birth to the parametric evaluation system in 1970. The then novel approach was designed to assess actual and potential soil productivity for the United States based on calculated productivity index [2]. The drawback of these schemes are (1) they have specific objective with limited scope, (2) they are localized, that is, designed for use in the United States, and (3) they focused primarily on land physical criteria.

In order to provide standard land evaluation mechanism that can be adopted across the globe, the Food and Agriculture Organization (FAO),in 1976, developed a framework for land suitability evaluation based on physical, socioeconomic and environmental criteria [3]. Up till today, the FAO framework remains the fundamental structure upon which land is evaluated for different purposes. Brief background information is presented in Section 2. Advancement in computer and geospatial technologies have added additional values and new insight into the ability to assess land in spatial context [4]. Land evaluation is a multi-criteria problem and geographic information system (GIS) provides capability to combine multiple criteria and data from multiple sources for objective analysis. This has invariably changed the approach to analyzing land for sound decision making although still based on FAO framework. Furthermore, some novel approaches have emerged in line with the functionality of GIS and multi-criteria decision support systems [4].

During the last 10 years, serious researches have focus on land suitability evaluation in Malaysia for different applications e.g. agriculture, urban planning, and coastal area management. The objective of this paper is to explore land suitability evaluation studies in Malaysia over the last decade so as to identify the various techniques used, their strengths and weaknesses, and adequacy with respect to land evaluation for agricultural purpose.

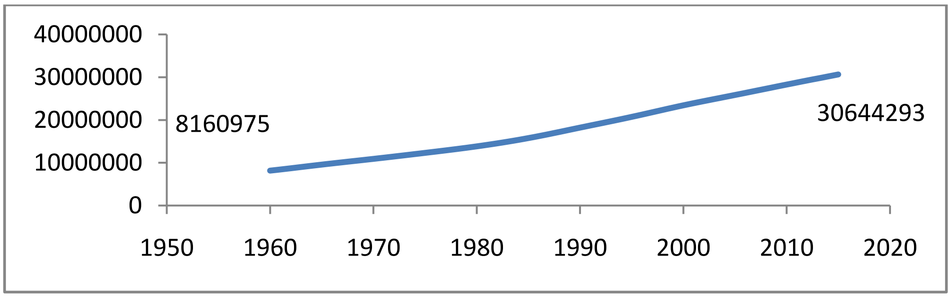

Figure 1: Malaysia historical population (1960 – 2015)

2. THE FAO FRAMEWORK

The Food Agriculture Organization (FAO), an organ of the United Nations, in 1976 established a standardizedframework to evaluate land suitability following series of consultations and inputs of experts in land evaluation around the world.The framework was developed in line with one of FAO’s main objectives “…*sustainable management and utilization of natural resources, including land, water, air, climate and genetic resources for the benefit of present and future generations*.” (http://www.fao.org).Eradication of hunger and food insecurity is tied to agriculture, hence, the need for a structured mechanism that can guarantee achieving these set objectives without the geographical limitation.

One of the success of FAO framework for agricultural applications is the level at which land can be assessed. One, land can be evaluated based on suitability at broader scale, and two, land can be assessed on the basis of capability at micro level. Although the two terms are often used interchangeably, they are not the same. Generally, land suitability defines a statement of fitness for purpose of a given area for specific land use. On the other hand, land capability expresses common productive ability for cultivated crop or plants without depreciation over a long period of time [3]. This makes the framework a relevant tool for agricultural use because it views criteria that facilitate evaluating both suitability and capability.

To make the framework more adaptable, some fundamental principles are germane and therefore must be critically observed during practical applications. The principles emphasize the need for land suitability evaluation to: assess and classifyland suitability based on specific land utilization type (LUT); have a balance judgment of the benefit obtained relative to inputs needed on different types of land; incorporate multidisciplinary approach; harmonize the physical, economic and social environment of the land under consideration; be sustainable, and considers land for multiple use[3].

Three major factors are very important in defining land utilization types:the need for accurate information about land performance, the ability to provide a range of alternative technical possibilities, and a tool that offers planners wealth of information based on unified concept and procedure [5].Land on its own cannot be productive without input. Three levels of inputs can be recognized – low, intermediate and high[3, 5].Inputs come in different forms (e.g. produce, market orientation, capital intensity, labour intensity, mechanization, land tenure system and infrastructural requirements).

FAO framework recognizes three main evaluation criteria: physical, socioeconomicand environmental suitability evaluation[4]. Define physical suitability evaluation as an expression of the degree to which the sustain implementation of LUT on a certain land unit is feasible without unacceptable risk to the human or natural community. Indices observed include climate related parameters, soil condition, topography, flood, and erosion hazard. On the other hand, economic suitability is computed based on economic returns which may be expected if the LUT in question is implemented on that unit [3].

Until today, FAO framework remains a standard reference and systematic procedure that is universally accepted for land suitability evaluation especially for agricultural use because of three major advantages. First, the framework indicates the physical suitability for individual crops. Second, land is defined broadly in the system and not only by soil characteristics. Third, land can be evaluated physically and economically using the framework.

3. LAND SUITABILITY EVALUATION IN MALAYSIA

Over the last decade, there had been growing concern for how to efficiently manage land resources in response to increasing demand for various use in Malaysia. The capability of GIS as a multi-criteria decision system with respect to spatial dimension coupled with the standard guideline and procedure provided by FAO, three distinct land suitability evaluationmodels have found their prominence in Malaysia. The FAO established comprehensive framework that allow inclusive mechanism toview the three vital components of land evaluation criteria (socioeconomic, physical and environmental) in isolation or combination. Similarly, GIS provide a convenient environment to integrate spatial and non-spatial data to enhance objective decision making process. The common land suitability evaluation approaches discussed here areAnalytic Hierarchy Process (AHP), analytic network process (ANP)and parametric models. Summary of land suitability evaluation studies in Malaysia since 2005 and their applications are presented in Table 1.

3.1 Analytic Hierarchy Process (AHP)

The AHP is popular Multi Criteria model first introduced by Saaty in 1980. He defines AHP as "a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales" [6]. In principle, the model perform dual function of comparing the alternatives with respect to several criteria and to estimate weight. The model construct decision problem in a hierarchical order, breaking down the decision top to bottom, with the goal at the top level while the criteria and sub-criteria occupy the middle levels. Usually located at the base of the hierarchy are the alternatives [7]. The GIS-based AHP gained high popularity because of its capacity to integrate a large amount of heterogeneous data and the ease in obtaining the weights of enormous alternatives (criteria), and therefore, it is applied in a wide variety of decision making problems.

In the AHP, every criterion under consideration is ranked in the order of the decision maker's preference. To generate the criterion values for each evaluation unit, each factor is usually weighted according to estimated significance.So, individual judgment which do not agree perfectly with the degree of consistency achieved in the ratings, is measured by using Consistency Ratio (CR). The rule of thumb is that a CR less than or equal to 0.1 indicates an acceptable reciprocal matrix, while a ratio above 0.1 indicates that the matrix need to be revised.The advantage of AHP is that it is simple to use, scalable, and not data intensive [6]. However, the problem of interdependence between criteria and alternatives, inconsistencies in judgment and ranking criteria, and its inability to grade instrument in isolation are drawbacks of the system [6].

In current land suitability applications, AHP is consistently been used as a GIS-based evaluation system [8].The first published work using AHP for land suitability evaluation in Malaysia was integrated with GIS to determine suitable hillside land for urban development and planning [7, 9, 10].The authors used Expert choice 11 (a decision support system package) to assigned weights to four criteria: land accessibility, topography, land cover and economic factors. The result of the study produced a novel model for hillside development in Penang, Malaysia. The same author in 2013, go a step further to validate the model using statistical methods to test the robustness of the reliability of the decision-making decision[10, 11] used the same technique to addressed land use analysis using AHP for costal management planning in Marang region, Malaysia.The authors conclude that although AHP can provide precise and acceptable decision and personal judgment, the outcome is dependent on expert knowledge.

One of the earlier agriculture land suitability evaluator (ALSE) using AHP was utilized by [12]. The researcherused spatial tools in conjunction with expert knowledge to derive criteria weights with their relative importance to land qualities and mango crop cultivation requirements which include soil, flood potential area, erosion risk, topographic, and climate maps.The result of the study produced agriculture land suitability evaluation for Mango cultivation in Terengganu, Malaysia.Furthermore, the study revealed that soil, slope and erosion are critical criteria while climate and flood are less important. However, the use of the system for a single type of crop without consideration for the land capability for concurrent crop production is a concern in today's need for efficient use of land as scares resources. The same authors, in 2015, measured the stability of ALSE using Sensitivity Analysis and mathematical variations (SAMV).

The validation shows that the method can improve the reliability of multi-criteria decision problems. Not that alone, it provides mechanism for non-experts to explore the priority of each criterion and reduce subjectivity of weights.

3.2 Analytic Network Process (ANP)

The analytic network process is an improvement on AHP that essentially broaden the general form of the AHP[6].Contrary to AHP which is linear and hierarchical, ANP is has a network structure and is nonlinear in nature. ANP has become a famous MCDM toolin the last decade and has seen wide use in combination with other methods.For instance,[13] combined ANP and decision making trial and evaluation laboratory technique (DEMATEL) to apply to a sourcing decision about keeping IT function in house or contracting to a third party provide. ANP allows dependent and independent assessment of criteria. Further, ithas the ability to prioritize groups or clusters of elements, can handle interdependence better than AHP,and can support complex networked decision-making with various intangible criteria[7]. Nevertheless, its disadvantagesinclude those associated with AHP, in addition to it negligence of the different effects among clusters[7, 14-16].According to[7, 14-16],ANP has gained remarkable use in project selection, product planning, green supply chain management, and optimal scheduling problems.

As a relatively new concept, ANP have not gained wide use for land suitability in Malaysia. The work of Sharareh [17]which determined optimal land use suitability for future sustainable development in the coastal area of the Kuala Langat District, Selangor, is the only publication available on ANP for land suitability evaluation. The criteria considered in this study include those of the socioeconomic, environmental and physical factors.The method was tested by relevant authorities and declared to be a valuable tool within spatial planning framework for efficient planning of future coastalland use development based on land use suitability.

3.3 Parametric approach

The parametric approachis one of the earliest land evaluation model employ mathematical functionsto evaluate soil fertility by finding good correlation between crop yield and one or more key land factors [18]. The modelquantifies soil productivity using additive, multiplicative or complex functions. Parametric approach combinesfactors with relevant impact on the land use potential by allocating numerical values from 0 to 1, with 1 being the highest potential. The most widely used parametric model, the Storie-Index, first appeared in 1930s, but have passed through some modifications and adapted to suite different environmental conditions [18]. Storie-Index was first devised for agricultural rating of Citrus in California for taxation purpose. The legal role accorded to the index earn it a global acceptance and popularity as a multi-criteria decision making instrument. Generally, parametric models are easy to apply, simple, and quantitatively accurate and specific but do not take the land use requirement into account [18]. However, its reliability depends on choice of determinant factors, their weighting, and validity of the assumed interaction between factors.

Parametric method is one of the oldest method that evolve for land evaluation. In Malaysia however, [19]published the first application where assessment of an array of physiochemical soil properties from a sample of rubber smallholdings managed by a group of Orang Asli (original people) in northwest Pahang, Peninsular Malaysia. The authors determined the predominant physiochemical characteristics of these soils and evaluate them with an established rubber suitability classification system. They were able to group soils according to region, geomorphic position, and estimated soil series that allow generalizations about soil limitations for certain soil types and to mitigate the effects of these limitations. The study uncover the fact thatthere exist a great deal of heterogeneity within soil samplewith respect to type and limitation.

Table 1 land suitability evaluation methods

No	Application	Authors/years	purpose	criteria	Method
1	Agriculture	Colleen J. Howell1, Kurt A 2005	quantify and evaluate the important rubber-related soil characteristics of smallholder rubber fields	Physical criteria Soil data	Parametri c approach
2		Rayna Elsheikh 2013	Agriculture land evaluation using GIS and multi-criteria	Physical criteria Soil –slop – erosion hazard-flood – climate	AHP
3		Adzemi Mat Arshad1 2013	Evaluate climate suitability follows the FAO Framework for Land Evaluation.	Physical criteria Climate data	Parametri c approach
4		Adzemi Mat Arshad1 2015	Establish spatial land evaluation for oil palm cultivation using GIS	Physical criteria nutrient availability, oxygen availability, water availability, workability and availability	Parametri c approach
5		Muhammad Rendana 2014	Find suitable and available areas for development of rubber crop using Geographical Information System (GIS) technique.	Physical criteria Water available Nutrient available Oxygen available	Parametri c approach
6		Ranya Elsheikh 2015	produce an agricultural land suitability evaluation system using Geographic Information System and Multi Criteria Analysis	Physical criteria Soil ,erosion hazard , flood , climate , slop	AHP
7		Adzemi Mat Arshad 2015	Development of a land evaluation system for oil palm cultivation.	Physical criteria Climate data	Parametri c approach
8	Urban	Ahris Yaakup2004	Development planning and monitoring toward sustainable metropolitan development.	Socioeconomic and environmental criteria namely, residential, conservation, tourism and industry	AHP
9		Imtiaz Ahmed Chandio 2011	determine suitable land for public parks for Larkana City Malaysia	Physical and socioeconomic criteria (Population density) (land value) (Land availability)	AHP
10		Imtiaz Ahmed Chandio 2013	development of the spatial multi-criteria analysis decision approach of present and for the coming multifaceted developments	Physical criteria Agriculture land Slop Road Wet land Forest land	AHP
11	Coastal	Mui-How Phuaa,∗, 2005	presents a (GIS)-based multi-criteria decision making approach for forest conservation planning at a landscape scale	Socioeconomic , environmental and physical criteria	AHP
12		Sharareh Pourebrahima 2011	Develop an integrated plan to determine the optimal land use suitability for future sustainable development in the coastal area	Socioeconomic, environmental and physical criteria.	ANP
13		M Bagiri 2012	Evaluate land use of costal area	Environmental criteria	AHP

In another development,[14] conducted a research to assess suitable climate for rubber cultivation in Peninsular Malaysia. Harnessing the easily available climate data from nine meteorological stations, on the foundation of FAO framework, the authors were able to model potentially suitable climate for rubber cultivation for all the nine regions studied. The climate parameters used include the mean annual temperature, mean daily maximum temperature, mean daily minimum temperature, mean annual rainfall, length of dry season, amount of sunshine, maximum wind speed and mean annual relative humidity. However, variation in the climatic indices coupled with limitation of the interpolation algorithm is a question. In same year,[14, 15] experimented with oil palm cultivation using GIS in the KESEDAR region of Kelantan, Malaysia. The results shows that parametric technique in GIS environment for mapping land suitability produced similar results and permits more meaningful interpretation of the output. Aside that, it provide easy visualization for qualitative assessment. For agricultural use also, Muhammad [20]demonstrated spatial-based parametric modeling to find land suitable for rubber crop in Ranau District of Sabah. The process involves a spatial matching method between land qualities and crop requirements. The study has delineated that land suitability classification of FAO and GIS technique helps land suitability analysis to find potential suitable areas for rubber crop in the study area.

4. DISCUSSION

The last ten years have seen renewed efforts to use modern technology for evaluating how suitable a piece of land is for the intended use. From our investigation, three land suitability evaluation techniques (AHP, ANP and parametric approach) have been used in recent past. Similarly, three major areas of applications have benefited from this development as well. These are agriculture, urban and coastal land management, however, land suitability evaluation for agricultural purposes is dominant with approximately 54 percent of the investigated studies while the remaining 46 percent are shared between the other two applications. This values indicate the obvious pressure on agricultural land management for productive use in Malaysia as identified by[21][14][16][20][22][15].

In another development, it can be observed that some specific criteria are much more relevant, or better still, emphasized, in evaluating land for the different applications under consideration. For example, nearly all studies on evaluation of agricultural land use focus on physical and environmental criteria. In a similar manner, socioeconomic and physical criteria are the basic factors of influence in urban land suitability assessment, while physical, socioeconomic, and environmental issues constitute major concerns for coastal land management and planning to evaluators. A critical question here is why differing criteria among these land use types?

To a discerning mind, emphasis on socioeconomic and environmental factors for urban and coastal applications may not be far from the direct and instantaneous impact on the well-being of the populace.In the event of unsustainable land use, the inhabitants are always the first to be affected.Worse still in the extreme conditions, life loss,social and economic disruption and infrastructural damages are inevitable[23]. Another argument put forward for the differences in factors considered for land suitability is the local environmental and climatic conditions. According to [21], variation in climatic indices and local environmental dynamic do not make standardization of evaluation criteria possible across all regions of the world. In addition, development of land suitability evaluation system is largely subject to expert opinion.

Land tenure system plays important role in deciding access to and availability of land for use. Perhaps this may account for why economic value of land for agricultural use has been completely ignored in all the studies done in Malaysia. According to the Malaysia National Land Code (NLC) of 1965, the Torrens system is the substantive tenure system recognized by law [24]. This notwithstanding, the customary land tenure system practiced before and during the colonial era are still much influenced and practiced in relation to land matters, especially among the rural Malay society. But in the event that land are sold under customary tenure practice an outsider with consent from the tribe, ownership have been transferred and such land is no longer regarded as tribal land. Summarily, future studies need to explore further on land values and their evaluation in anticipation of potential future needs and policy change.

The three evaluation methods adopted in Malaysia follow the FAO framework entirely with modifications to suit the local environment. Of the three techniques, parametric and AHP are more frequently used. For agricultural applications, parametric approach has been exclusively used save for only two studies [21][22] that employed AHP. Contrary to this, AHP has been the main model adopted for urban and coastal applications. The only exception to this is a study conducted by[25] where he experimented with ANP. For urban and coastal environment are subject to different land use types. This factor make parametric approach a complication for suitability evaluation and renders the method unsuitable despite its simplicity and ease of use. Moreover, AHP can handle interdependence among criteria and alternatives better than parametric approach. From table 2 presents the advantages and disadvantages of AHP, ANP and parametric approach.

Shifting from this position, the work of[22] have extend the versatility of AHP to the domain of agricultural use. The author developed a land suitability evaluation system, Agricultural Land Suitability Evaluation (ALSE) for mango crop in Malaysia. The system work efficiently based on the criteria selected. The system is said to be applicable for evaluation suitable land for the mango family such as citrus, guava, banana, and papaya. Though the model is efficient, the weaknesses are it is only suitable for one crop type at a time, requires developing different database for different crop type and can only evaluate physical criteria. These notwithstanding, the work has opened new line of investigations into agricultural land suitability evaluation in Malaysia using AHP.

Table 2. Summary of MCDM Methods in Malaysia

Approach	advantages	disadvantages
AHP	Easy to use scalable not data intensive	Interdependencebetween criteria and alternatives inconsistencies between judgment and ranking criteria Subject to rank reversal.
ANP	Permits dependence and independence evaluation can prioritize groups or clusters of elements Handles interdependence better than AHP Supports a complex, networked decision-making withvarious intangible criteria.	It ignores the different effects among clusters
parametric approach	Allows any important factor to control the rating easy to apply simple Quantitatively accurate and specific.	landuse requirement not takeninto account subjectivity in the selection of the evaluation variables may affect accuracy

5. CONCLUSION

The FAO framework have remained the vital reference and guiding document for land suitability evaluation globally. The document is tailored to adaptation in different environment and conditions. This have resulted to the evolution of many land suitability evaluation models used for various applications. In Malaysia, this paper indicates that AHP, ANP, and Parametric system have been widely used over the last decade, employing eitherphysical, socioeconomic, and environmental criteria, or a combination of two or all the criteria, to evaluate land suitability for agricultural land,urban planning, and costal area management.

From this investigation, land suitability evaluation for agricultural purposes appears dominant as reflected from the previous case studies with approximately 54 percent of the investigated studies while the other two applications (urban and coastal management) share the rest. This resultshows the obvious pressure on agricultural land management for productive use in Malaysia and the need for improvement of the existing approach. In view of this, the future provides avenue for intensive studies on ways to improve land suitability evaluation techniques to a wider target users as decision making tool to support deliverables that can be beneficial to the nation in matters relating to land utilization. In conclusion, the following are recommended for further exploration.

1. Improving on ALSE to incorporate multi-crop suitability evaluation and deploring it on the internet, accessible to a wider community of users.
2. Investigate best approach to institutionalize wide adoption of geographic information system (GIS) in agriculture practices for easy updating and database archiving.
3. Embarking on national soil mapping and digital soil database development to strengthen model development and other soil-factored applications.
4. Extend investigation further beyond land suitability to land capability evaluation for maximum utilization of available land unit for multiple crop production.

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