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Research Paper

GIS based land evaluation decision support system

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ABSTRACT

There is a pressing need to develop an optimal land evaluation decision support system to identify the part of a region that selected crops could be grown in high yield. Matching the requirement of land use with land's capability ensures that production level does not exceed the capacity the land can sustain. The purpose of this study is to develop an agricultural land suitability evaluation system that relied on the FAO framework of 1976, with some necessary modifications to suit the local environmental conditions. The developed model for land suitability is based on a classification structure rather than a set of guidelines as in FAO framework. Fourteen land characteristics and their threshold values were determined and grouped into nine land qualities. The land suitability model was constructed with GIS capabilities and integrated with modeling function using Visual Basic. The model was implemented and accepted by the Department of Agriculture in Kula Lumpur. It showed that it can serve as a decision support tool for farmers and decision makers.

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Key words: GIS, evaluation, land, decision support system, agriculture.

INTRODUCTION

When the 1976 Framework was developed, the technology of GIS was not available yet. According to the framework for land evaluation (FAO 1976), Automated Land Evaluation Systems (ALES) is a framework within which evaluators can express their own knowledge for use in projects or regional scale land evaluation, taking into account local conditions and objectives (Rossiter and Wambeke, 1997). The entities evaluated by ALES are map units, which may be defined either broadly, such as in reconnaissance surveys and general feasibility studies, or narrowly, such as in detailed resource surveys and farm-scale planning (FAO, 2010). The disadvantage of this system is that it is not user friendly and it has no GIS functions, as such, it cannot display maps (Nwer, 2006) .

One early implementation of the FAO framework was the Land Evaluation Computer System (LECS) in Indonesia (Wood and Dent, 1983). The final output provides individual crop recommendations for each land unit on an economic basis. The disadvantage of LECS is that it does not offer simple model in comparison with the complex computer systems that are now being developed elsewhere beside it is developed for a specific area (Summatra) (Nwer, 2006).

MicroLEIS (Rosa et al., 1992, 2004, 2009) is an integrated system for land data transfer and agro-ecological land evaluation. Currently, MicroLEIS have been integrated with GIS (Hoobler, 2003). This system provides a computer-based set of tools for an orderly arrangement and practical interpretation of land resources and agricultural management data. Recently, two components have been added in order to comply with rising environmental concerns on prediction of global change impacts by creating hypothetical scenarios, and incorporating the land use sustainability concept through a set of tools to calculate the current status, potentiality and risks, impacts and responses (Rosa et al., 2004). The disadvantage of this system is that it does not allow the user to build his personal expert system (Nwer, 2006).

The development of information technology and spatial/numerical tools during the last twenty years has enabled researchers to make rapid progress in the analysis of interactions between land resources and agriculture landuse. One of the most significant developments has been the incorporation of Geographic Information Systems (GIS) and Multi Criteria Analysis (MCA) (Chuong, 2008). MCA-based GIS has potentiality to provide a rational, objective and non-biased approach on making decisions in agriculture land suitability evaluation (Ceballos and Blanco, 2003).

Land Evaluation using an Intelligent Geographical Information System (LEIGIS) is a software application resulting from research by Kalogirou (2002). LEIGIS was designed to support rural planners with the first view of the land suitability for cultivation of certain crops according to the FAO methodology. The aim of this work was to produce a physical evaluation of land capabilities and to use this to provide a physical evaluation of land for different types of agriculture. The implementation of LEIGIS included models for general cultivation and for specific crops (wheat, barley, maize, seed, cotton, sugar beet) (Kalogirou, 2002). This system was limited to five crops and it did not include land characteristics such as climate.

The model computer programs can also be implemented on the Internet through a web server, so that users can apply the models directly via a web browser. Jayasinghe and Machida (2008) developed an interactive web-based GIS online consulting system with crop-land suitability analysis, which provides information on tomato and cabbage cultivation. This system has the benefit of availability online, but also it is limited to two types of crop. There is a need for flexibility in the system with friendly user interface that allows the user to identify and change the requirements based on his local condition. Also, if new crops arise in the future, the system can accommodate these crops. Automated land suitability for crops in countries where the information technology is in its very early stages, should be more friendly and accessible for the average computer user. In Malaysia, the levels of information technology penetration in DOA (Department of Agriculture) are still relatively low. Therefore, the need for a practical automated land evaluation tool in Malaysia is apparent and needs to be taken into consideration. This study highlights a new decision support system as utility for assessing land suitability for different type of crops. It can help the decision maker to determine the quality of land for agricultural uses and assess sites or land areas for their agricultural economic potential. This system provides method of land evaluation that hybridized with advanced computer modeling, GIS and Multi Criteria. It will give a push to the process of decision making to be more efficient, and well optimized.

MATERIALS AND METHODS

Software platforms

Geographic information system (GIS)

The power of GIS is in creating maps, integrate information, visualize scenarios, solve complicated problems, ideas, and develop effective solutions (Santhakumar et al., 2003).

Visual basic 6.0

Visual Basic 6.0 was used in this study as a platform programming language for the purpose of developing an independent program integrated with GIS objects.

Basic design

The Visual Basic program was developed with flexible user interface to be useful, clear and easy to non-GIS users or programmers. The input information was in different forms, each form was assigned to one information type, such as climate data, soil data and topography data. Figure 1 shows the system's main forms relationship in Visual Basic.

The selection from list is the easiest way to form and unify the input information in standard alternatives. Data input for each field would appear in the list in the desired field, and the system considers the selected items as the input information. Figure 2 shows the System's Main forms relationship in Visual Basic.

The main panel in a simple platform (Figure 3), representing the six primary tasks, offers the user an opportunity to explore and switch between forms from the same platform.

Crop selection form

Selection of crop type was the first step to proceed with the system. The list of the alternative inputs changes depending on the crop type (Figure 4). The system offers the ability to add new type of crops by appending a new record to the crops record. Adding new crop record is executed in the Excel program through the system (Figure 5), and the calculation will be apply on the new crop information after the user has saved the record.

Climate form

The developed system considers the climate input as a rule to the assessment process of land suitability. Climate information in the system was described by two

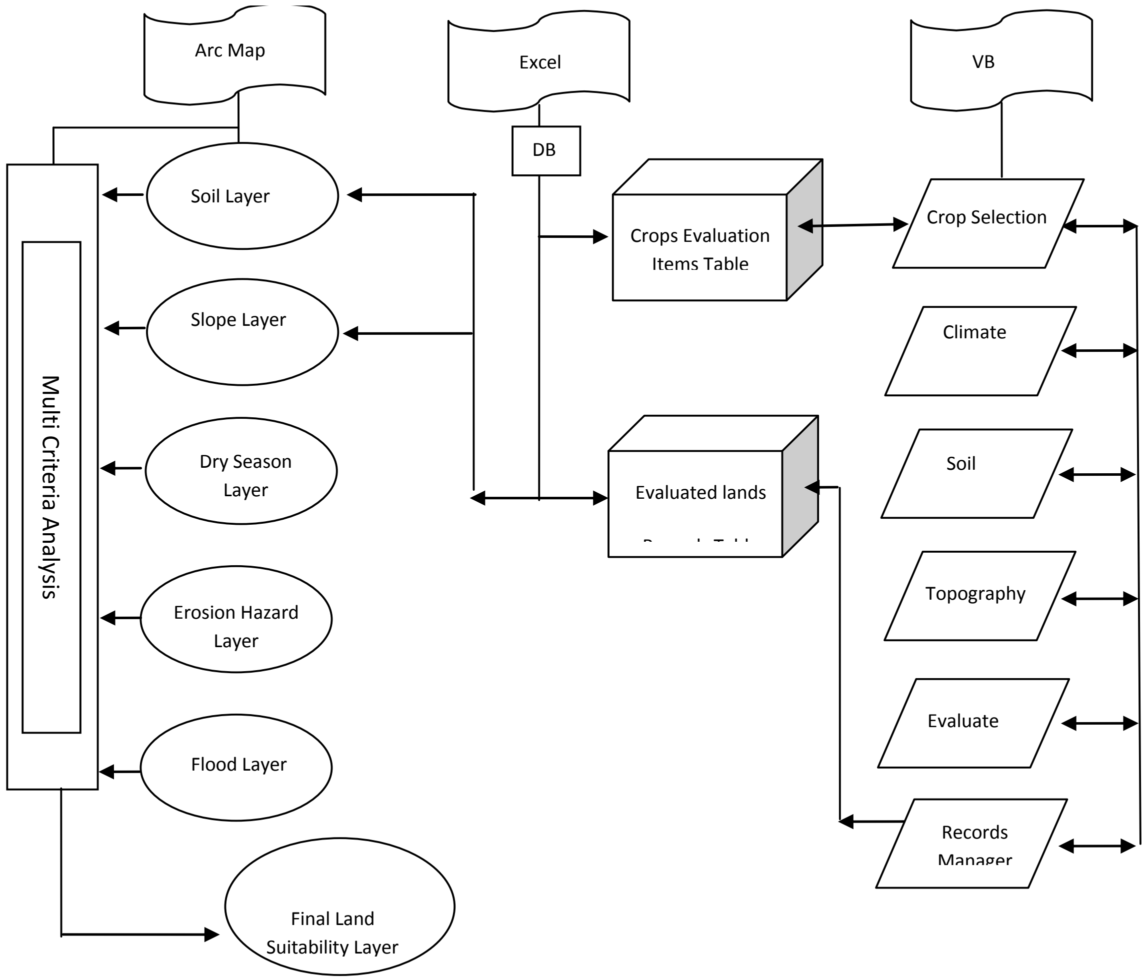

Figure 1. Flow chart of the system.

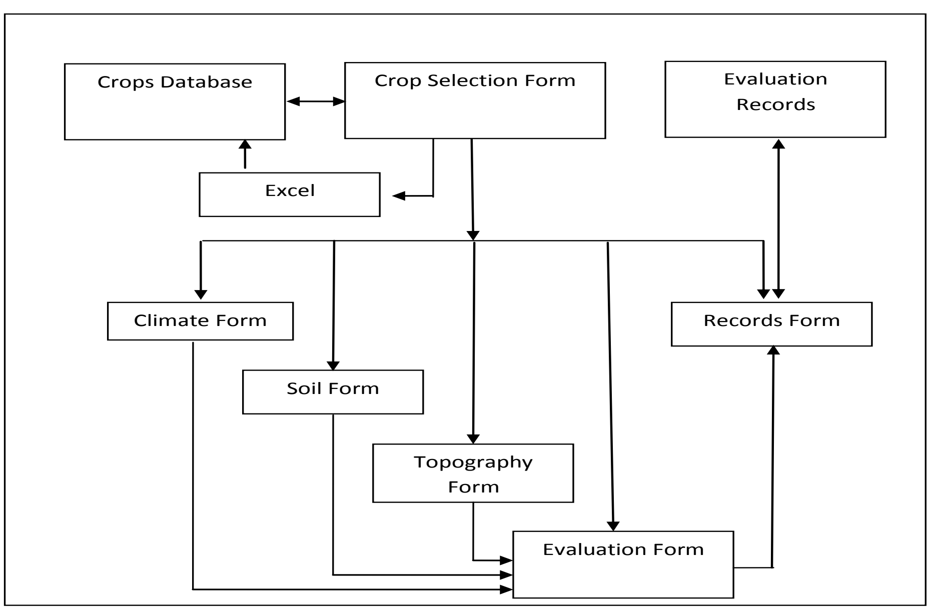

Figure 2. System's main forms relationship in visual basic.

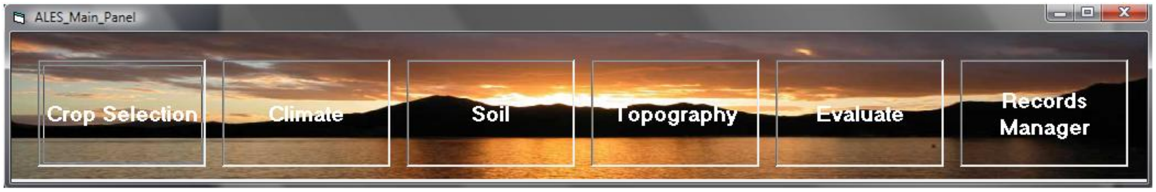

Figure 3. The main panel and the main tasks buttons in visual basic program.

Figure 4. Crop selection form.

A	B	C	D	E	F	G
ID	Crop	Annual.R.P (95%)	Annual.R.P (85%)	Annual.R.P (60%)	Annual.R.P (40%)	Annual.R.P (25%)
1	BANANA	>1800	1800-1500	<1500-1250	<1250-1000	*
2	CITRUS	3000-1500	<1500-1200	<1200-1000	<1000-800	*
3	GUAFA	>2000	2000-1000	<1000-500	<500-200	*
4	PAPAYA	1400-1600	<1400-1000	<1000-800	<800-600	*
5	MANGO	>2000	2000-1000	<1000-500	<500-250	*
Annual.R.P = Annual Rainfall Precipitation (mm)						

Figure 5. Crop types with suitability alternatives records.

characteristics; the annual precipitate (mm) and the length of the dry season. The final evaluation of the climate suitability to a specific crop will be shown in an evaluation box at the right side of the form. For mango crops within the study area, the climate form was developed as shown in Figure 6

The system stores the selected input information and computes the suitability level of the annual precipitate (mm) and the length of the dry season per month. The final evaluation of the climate suitability was calculated based on particular crop requirement.

Soil form

Soil suitability in the soil form consisted of five main qualities; Nutrient Availability, Nutrient Retention, Rooting Conditions, Soil Workability and Oxygen Soil Drainage class (Figure 7). The overall physical suitability of land, for land utilization type, is taken from the most limiting land quality (LQ whose rating is the worst). The advantage of this method is that it is simple and the severity levels of LQs are defined according to a standard set of yield reductions. In general, according FAO practice, S1 corresponds to 85-

Figure 6. Climate form.

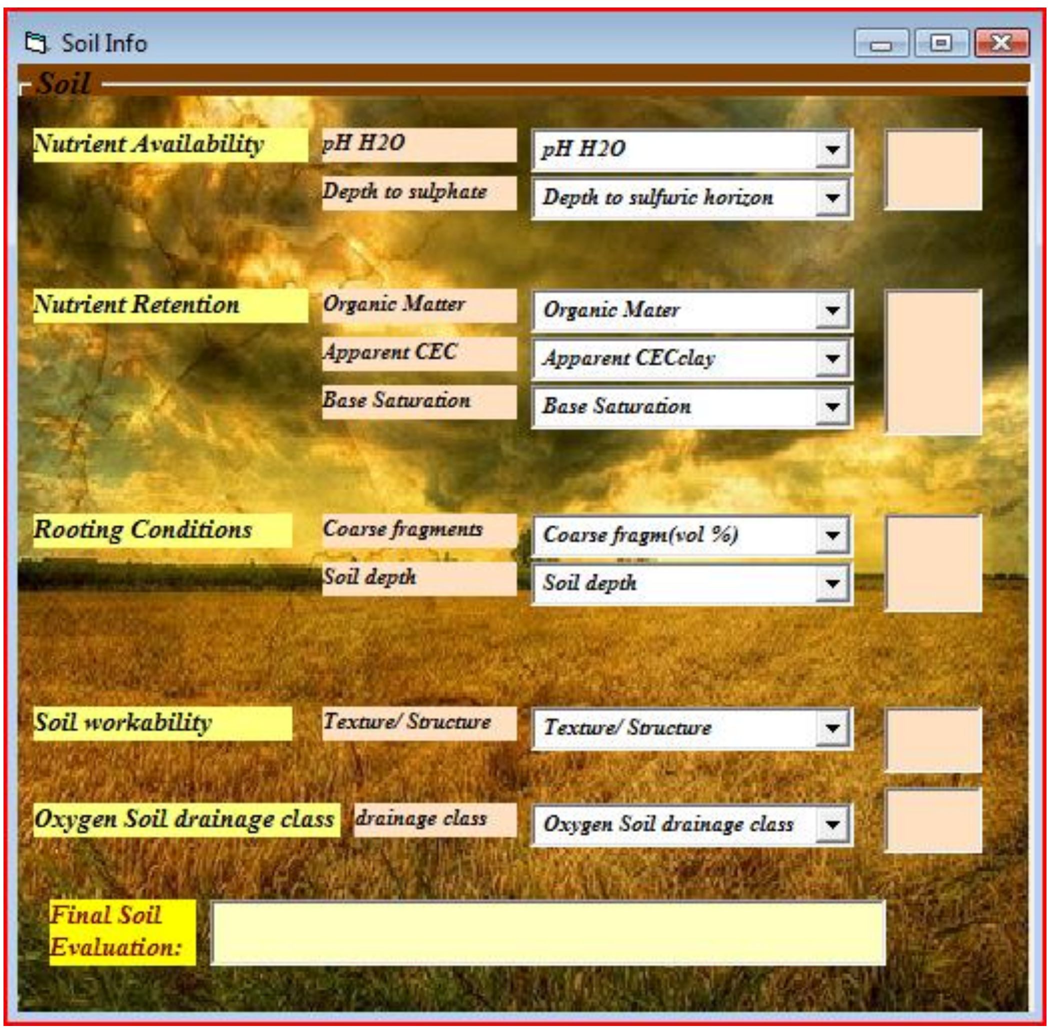

Figure 7. Soil form developed in the program for the study area

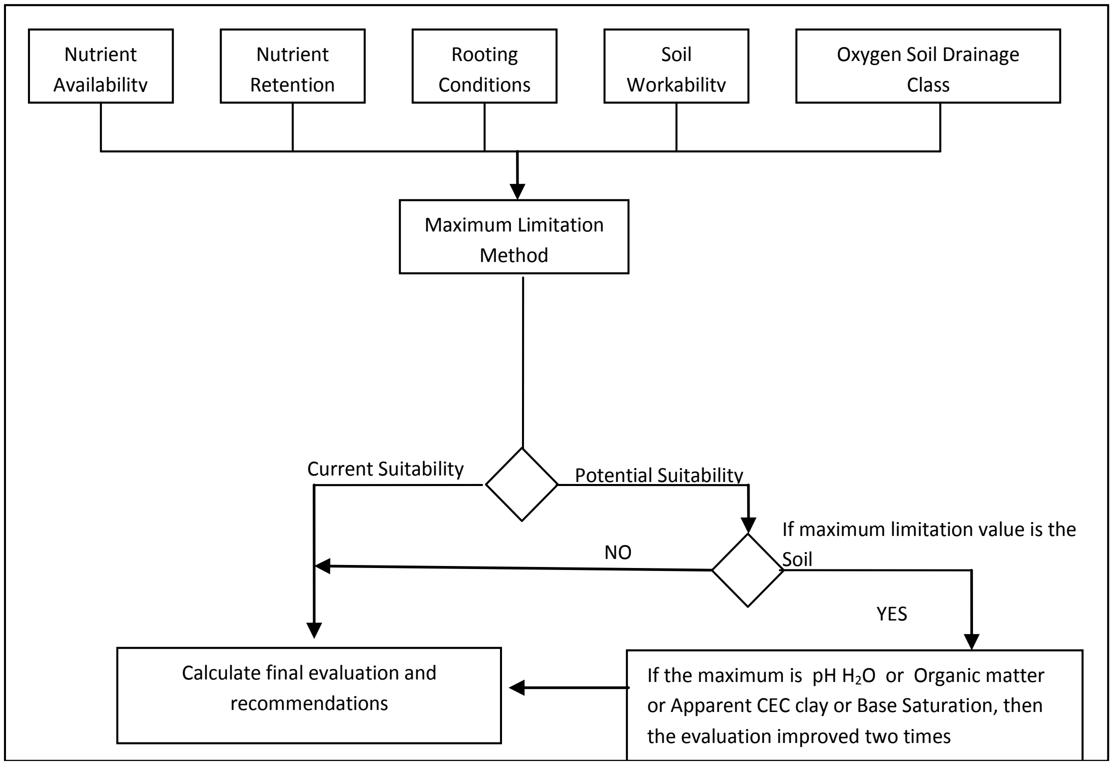

Figure 8. Flow chart of soil suitability calculation.

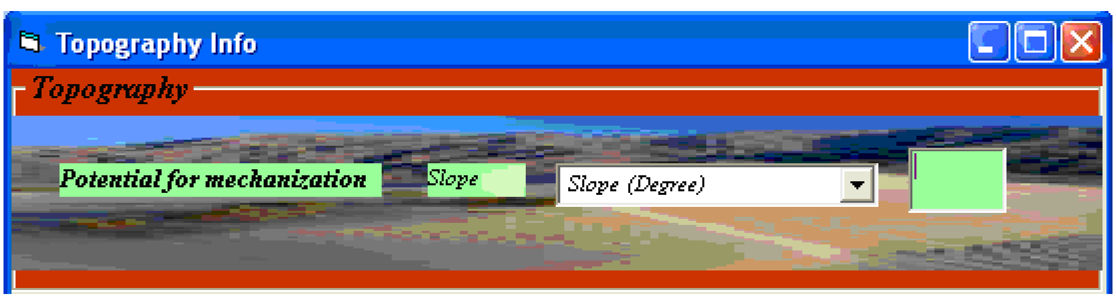

Figure 9. Topography form.

100% of optimum yield, S2 to 60-85%, S3 to 40-60%, N1 to 25-40% and N2 to 25-0%. The user can view the result in two ways: (i) Current suitability which refers to the suitability for a defined use of land in its present condition, without any major improvements in It. (ii) Potential suitability, which is for a defined use of land units in their condition in the future (Figure 8).

Topography form

The system classified different slope ranges into five categories based on the potential for mechanization (Figure 9) Potential for mechanization indicates the topography of the area. The impact of the topography on the land suitability was measured by slope in degrees. Each crop type has suitable range of slopes.

Suitability evaluation form

The suitability evaluation process starts after the user enters the crop name and other necessary information on climate, soil and topography of the land. There are two ways to evaluate the suitability, such as potential suitability and current suitability evaluation (Figure 10).

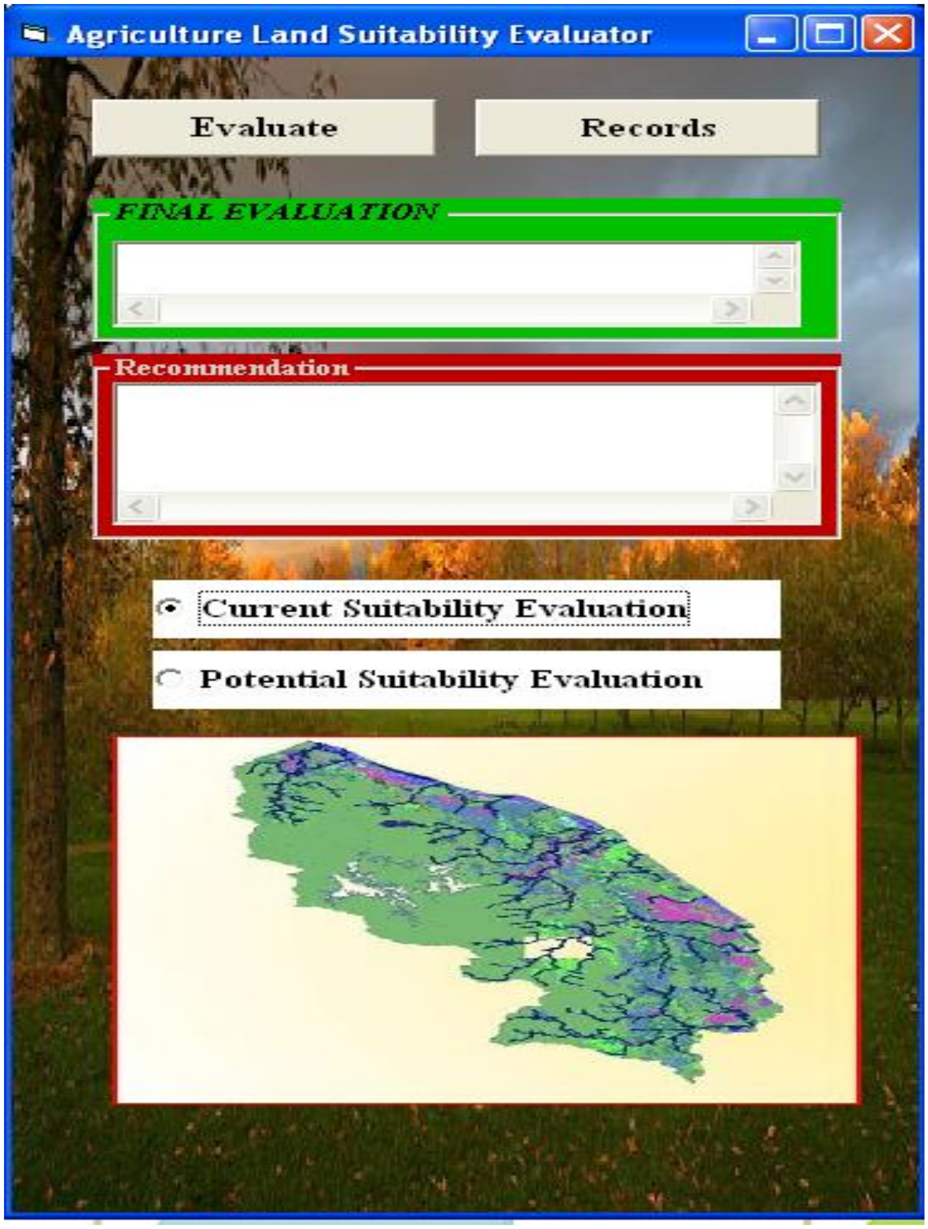

Figure 10. Evaluation form developed in visual basic.

Record manager

The final result could be recorded by creating a new record in the database. The user is allowed to write down the primary information about the field evaluation, such as land index number, user information, record information, and other basic data (Figure 11). The record manager is linked to the record database directly, and allows the user to enter, explore, open, and edit the record. The record database table is the linkage bond between the system and the GIS program. Every land parcel has a unique code through which GIS software can relate to with the system outputs.

Land suitability model builder

A land suitability model was constructed using GIS capabilities and modeling functions. A model is a set of spatial processes, such as overlay, that converts input data into an output map. A spatial model in Model Builder is easy to build, run, save and modify (ESRI, 2000). The GIS Model Builder was used to organize and integrate spatial processes to model the land suitability in the study area.
Soil, climate, slope, erosion and flood hazard are factors which are important for land suitability. Those factors were integrated into the GIS environment as information layers and then overlaid to produce overall land suitability

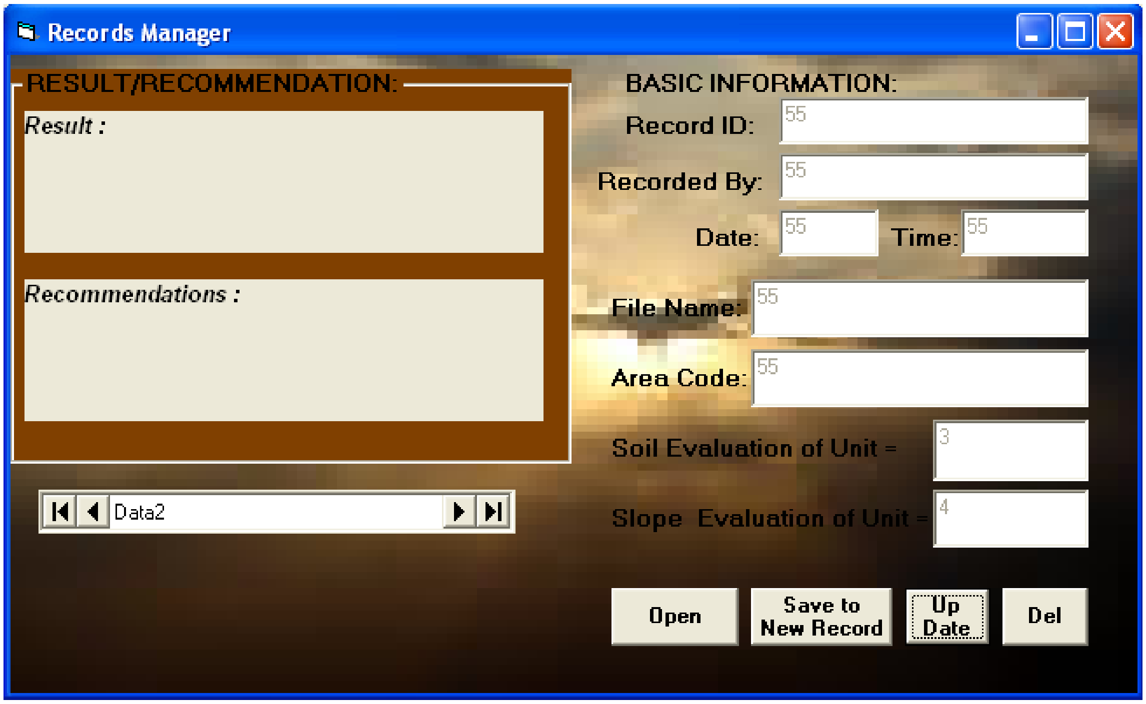

Figure 11. Record manager form.

assessment for particular land utilization type.

The suitability analysis for soil, slope and climate was calculated in Visual Basic forms and integrated within the GIS Model Builder through linking the two tables, considering matching in ID. The environmental factors such as erosion and flood also can be considered and added as layers to produce suitability input layers.

The model was designed to achieve the suitability result directly from one click. It operated specific analysis through ten different steps. Using the output tables from the Visual Basic program, the model linked the suitability results to the soil and slope shape file of the same area by area index.

However, complicated data structures are straight forward to work with in Python. Python is simple to integrate with C++ and FORTRAN, and can be integrated with Java. Finally, Python is free to be downloaded from the internet and has a widespread community (ESRI, 2009).

The model operates on five layers, which are soil, flood, dry, erosion and the slope of land. Soil and slope layers are features; the others are in raster images. The first step was to assign the suitability results, which were obtained by Visual Basic system, to the soil and the slope layer using the area index code. “Join Field” is a tool used to make this step two times; one for the soil layer and another for the slope layer.

The second step in the model was to convert the joined soil and slope features to raster image to construct all the layers in raster format and allow the model to weight the overlaying layers using weights obtained by Multi Criteria Analysis. Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input to create an integrated analysis (ESRI, 2008). The resulted layer is the suitability raster calculated from the five basic layers. The next two steps were to classify the weighted overlaid raster into five classes based on suitability values, and then to convert the classified raster into polygon feature layer. Each polygon had a grid code that equals to the suitability value. The suitability values refer to one of the five alternatives, 1, 2, 3, 4 and 5, where the value 1 is the most suitable, and 5 is the least suitable.

The resulted polygon features contained many scattered polygons assigned with suitability values, but without information on the area code and other land data. This polygon feature was split to the original land parcels using a split tool.

The polygon features at this step were split to parcels shape, and the results were represented in many shape files. Each file is one parcel. The parcel shape contained some polygons with deferent suitability values. To assemble the parcel shape files into one feature shape, a special Python script was developed to copy all of the parcels features to one shape file. The final step in the model was to add the parcel information to each polygon within the parcel boundary. A spatial join tool was used to append parcels’ information to parcel location in reference to the soil shape. Figure 12 shows the Model Builder for land suitability evaluation developed for the study area. The land suitability model was designed to accomplish a couple of spatial analyses, from the scratch layers up to the final suitability evaluation layer. The integration of the

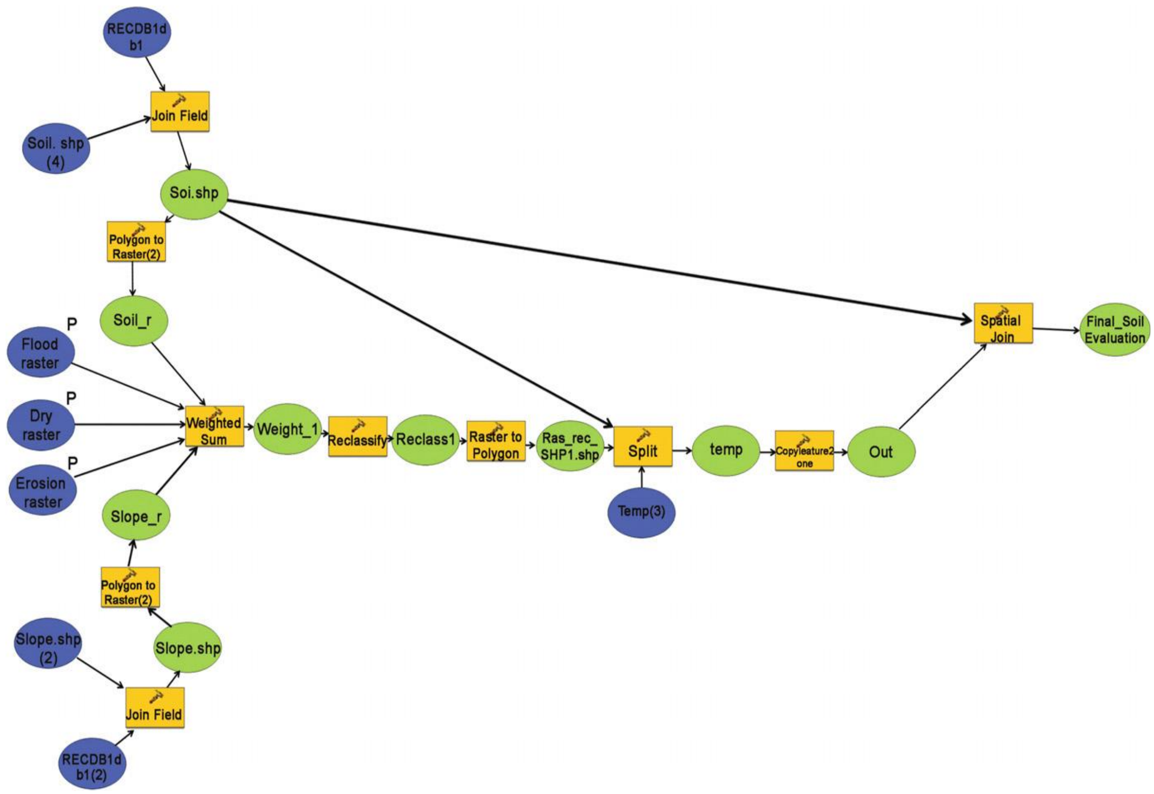

Figure 12. The land evaluation model from the basic layers up to the final suitability layer.

information with the Visual Basic evaluation system was executed automatically through the model.

RESULTS AND DISCUSSION

System implementation

System implementation is a very essential step to ensure that the system properly implements the required specifications.

A sample area was selected for the purpose of validating and verifying the model's soundness and applicability and a Mango crop was selected as single case study for landuse. The selected sample area was located in the Northeast of Terengganu, coordinated at 496847E, 621426N upper left, and 501847E, 616426N lower right corners and covering 21.10 km^2 (Figure 13). The sample area consisted of 63 parcels of lands and 11 soil types (Figure 14). The parcels area varied from less than 4,000 m^2 up to 2.8 km^2. The implantation of the system indicates the suitability and limitation factors for each polygon (Figure 15).

It is noted that validation and accuracy of physical and evaluation that use a qualitative method is not possible (FAO, 1984; Rossiter, 1996). One of the methods that could be used for validation is to investigate if the selected crops were already produced in the region and then a subjective comparison could be made. If the condition exists in a region, it reflects the results in a logical and acceptable manner, and then the findings become more viable.

Local experts' judgments and knowledge were consulted in the current study to validate the results of the model. There were 30 respondents in total with 20 managers and 10 officials from other fields. The model outputs for the selected crops were viewed by the local experts. The experts' opinions (DOA officials), which were based on experience in the local context, revealed that the results of the model are in agreement with what is expected of the land in the study area. The officials were satisfied with the results and they keyed in the data into the system successfully.

The classification system used by the DOA in the Ministry of Agriculture is known as the Wong classification. For further validation, Table 1 was constructed to compare between the results of the sample area based on 10 soil series type with Wong (soil-crop suitability classification for Peninsular Malaysia). From the table, it was observed that the results were in agreement with Wong classification in term of soil suitability. The disagreement appeared when the whole factors were considered, including environmental factors. This makes the current classification generally accepted since it evaluates the land by considering the physical and environmental factors.

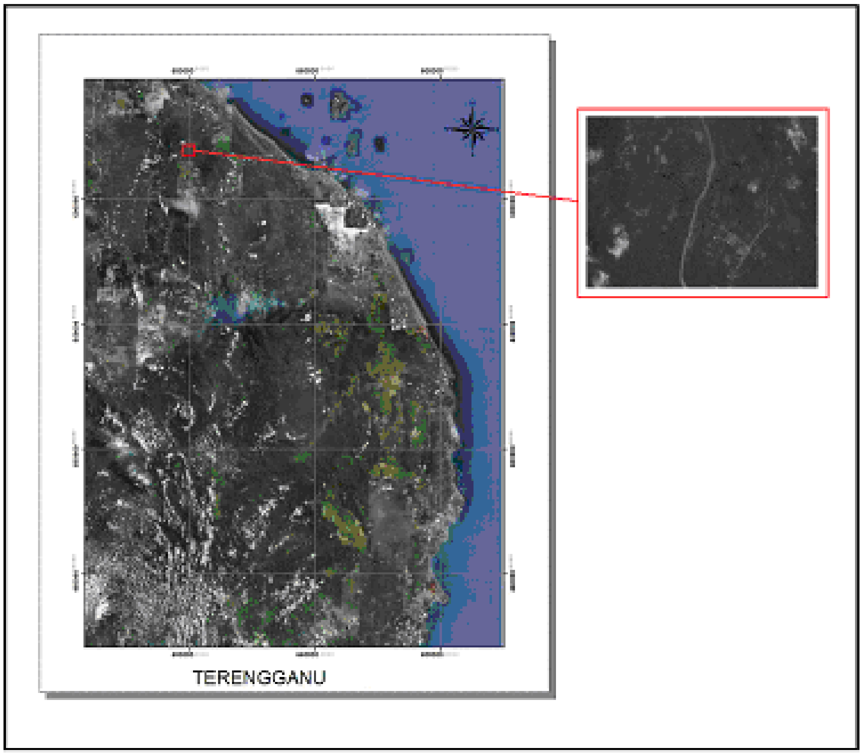

Figure 13. Location map of sample area used for verification of model.

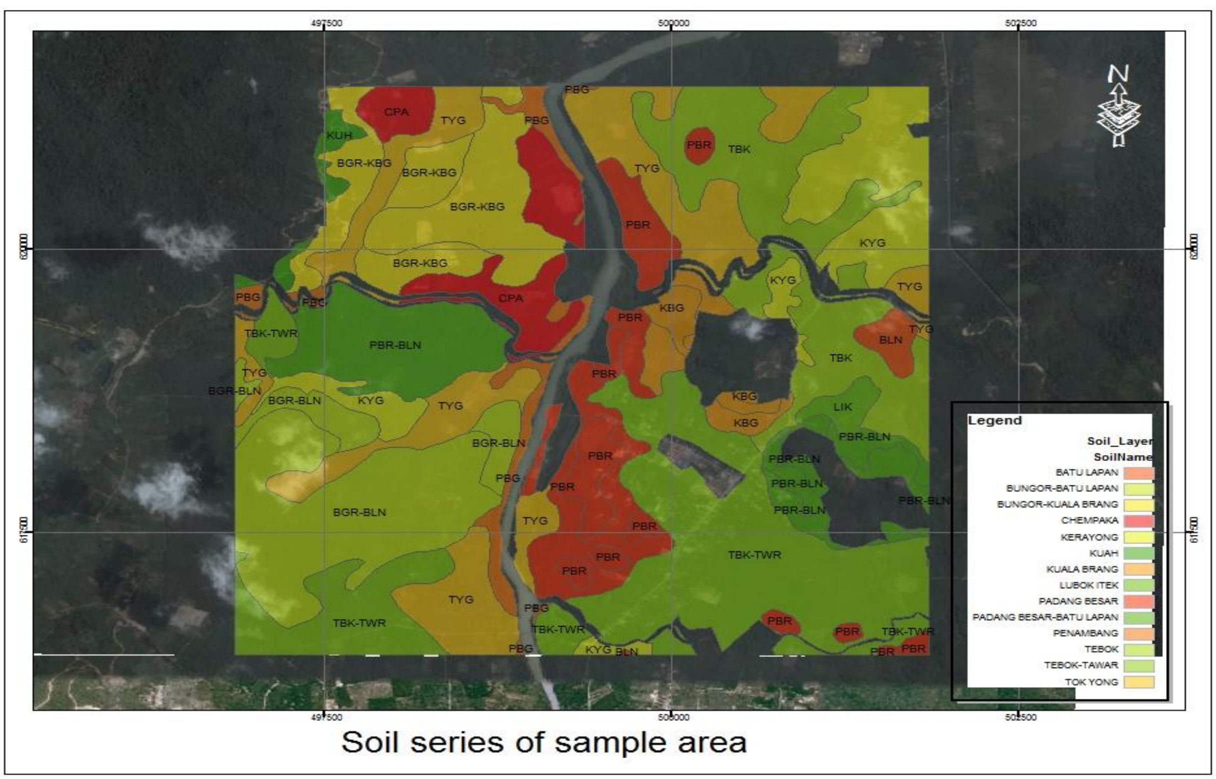

Figure 14. Soil series of sample area.

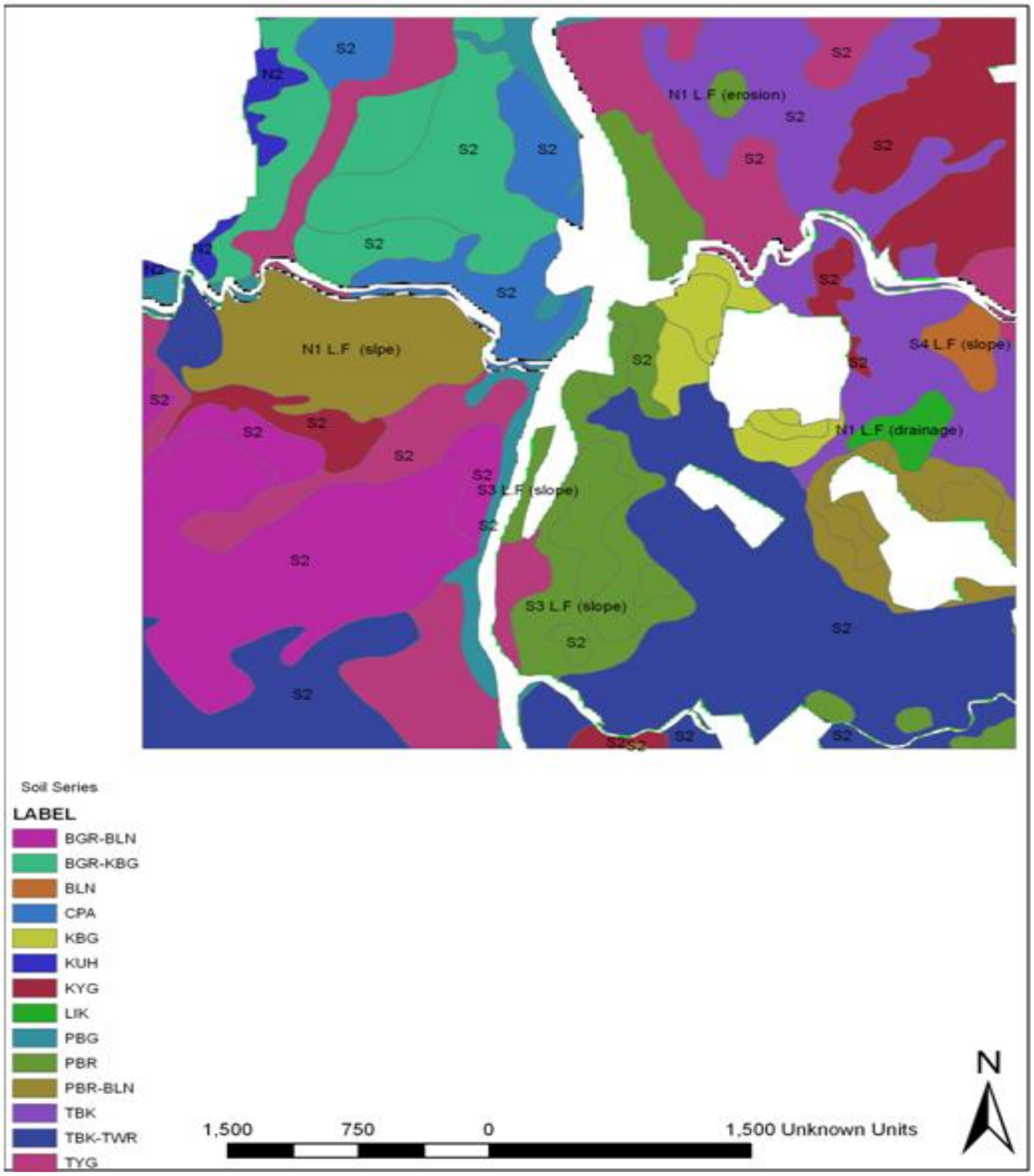

Figure 15. Suitability results and limitation factors for each polygon.

Table 1. Comparison between the current classification and Wong classification.

Soil type	Current classification	Wong classification
BGR	S2	S2
BLN	S2, N1	N1
CPA	S2	S1
KBG	S2,S3,N1	S3
KUH	N2	N2
KYG	S2	S2
PBG	N1	N1
PBR	S2,N1,S3	S2
TBK	S2	S2
TYG	S2	S2

Conclusion

In this study, GIS was used as a smart tool of utility for assessing land suitability for different type of crops. FAO framework was modified to adapt the local environmental conditions and the system was built upon this. The main program contains the commands and calculations for matching crop requirements with land qualities. The crop requirement information file contains parameters of soil, terrain, and climate that influence crop growth. The major advantages of the system is that the user can modify the crop requirements range based on the desired environmental conditions. The user also can introduce new crops. The second advantage of the system is that it can accept unlimited numbers of crops. The last module provides the result of evaluation associated with limitation reasons and recommendation for the current situation. The result can be presented as maps by using the Model Builder in GIS, and other spatial environmental factors, such as erosion and flood, can be added. The model was implemented and accepted by the Department of Agriculture in Kula Lumpur. It showed that it can serve as a decision support tool for farmers and decision makers.

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