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Land suitability evaluation criteria for agricultural crop selection: A review

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ABSTRACT

Land suitability study for agriculture is a very important technique in deciding future agricultural cropping pattern, planning and activities. Land suitability analysis is an assessment of an area to determine how proper or appropriate it is for a particular use of the land (such as growing a crop variety) in a particular location. Land suitability tools have been extensively applied to identify better management practices in agricultural areas. Soil and landscape properties are essential in this type of evaluation, fact that makes especially interesting, is the coupling of this type of model with Geographic Information Systems (GIS) and Remote sensing (RS). The integration of RS-GIS, Fuzzy-logic and application of Multi-Criteria Evaluation using Analytical Hierarchy Process (AHP) could provide a superior database and guide map for decision makers considering crop land substitution in order to achieve better agricultural production. A review was carried out for different multi-criteria analysis to develop land suitability maps. Fuzzy-logic integrated with Multi-Criteria Evaluation in GIS environment found most suitable for agricultural crops.

Key words: AHP, Fuzzy-logic, GIS, Land suitability, Multi-criteria.

Land suitability study is necessary for selection of crops and crop rotation for a particular piece of land. The concept of 'land' should not be confused with 'soil' because soil represents only one aspect of land, alongside vegetation, physiography, hydrology, climate, infrastructure, etc. Physical areas that are homogeneous in all aspects of land are land units. To describe a land unit one refers to its major land characteristics, which do not affect the suitability of land for a certain use in an indiscriminate way. A combination of one land unit and one land utilization type (with one set of land-use requirements) constitutes a land-use system. So, the agricultural land suitability is a function of crop requirements and soil or land characteristics. Matching the land characteristics with the crop requirements gives the suitability. So, 'suitability' is a measure of how well the qualities of a land unit match the requirements of a particular form of land use (FAO, 1976). MacDonald (2006) defined land suitability analysis as the separation of the nature or quality of land into its component parts based on the land's ability to serve a particular use or purpose.

Baja *et al.* (2007) reported two general kinds of land suitability evaluation approaches: qualitative and quantitative. By qualitative approach, it is possible to assess land potential in qualitative terms, such as highly suitable, moderately suitable, or not suitable. In the second approach, quantitative assessment of land suitability is given by numeric indicators. Land suitability refers to the ability of a portion of land to tolerate the production of crops in a sustainable way. Operationally, land suitability analysis describes a procedure of land appraisal with a specific land use objective in mind (Corona *et al.*, 2008). More specifically, land suitability evaluation will recommend for growing or not growing a particular crop, in a particular field.

The paper highlights the use of different techniques of land suitability evaluation for sustainable agriculture in developing countries.

Geographic Information System (GIS): GIS technique can provide a powerful tool in agricultural planning of an area for the land use suitability. The technological approach defines GIS as a set of tools for the input, storage and retrieval, manipulation, analysis and output of spatial data (Kushwala *et al.*, 1996). This approach however ignores the problem solving aspects of GIS and it has been argued that GIS functionality can play a crucial role in a comprehensive decision-making process. Application of GIS in land use planning was well documented and implemented (Salem *et al.*, 2008).

Potential land suitability for agriculture based on, not only biophysical but also infrastructural preference in accordance to the framework for land evaluation developed by FAO (1976). Using GIS based on the physical parameters (such as climate, soil texture, soil reaction, nutrient availability, and slope etc.) directly related to crop production were considered for analysis in southern Vietnam (Son and Shrestha, 2008); with the help of various land from attributes developed by the suitability index in Ethiopia (Rabia, 2012, Fig. 1); in Senoi district (M.P., India) suitability developed

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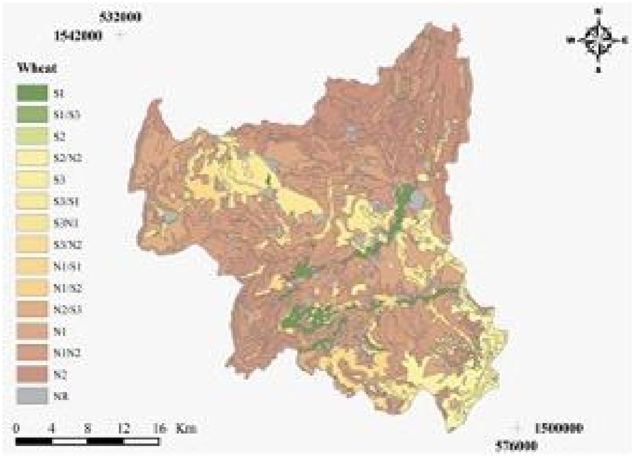

Fig 1: Land suitability map for Wheat based on GIS technique in Kilte Awulaelo district, Ethiopia (Rabia, 2012).

by combining the climatic and soil site factors (Bobade *et al.*, 2010). With GIS based land suitability assessment, both land utilization types (livestock and crop) were allocated in combination instead of exclusive land use allocation(Gurmessa and Nemomissa, 2013). This Type of land use allocation is purposeful especially for sustainability of land productivity.

Analytical Hierarchy Process (AHP): Analytical hierarchy process (AHP) can be used as a consensus building tool in situations involving a committee or group decision-making (Saaty, 1980). AHP is a procedure that seeks to consider the context of the spatial planning decision, identifying and arranging the criteria into different groups (Vogel, 2008). AHP is based on three principles: decomposition, comparative judgment, and synthesis of priorities (Eldrandaly *et al.*, 2007). With assessing the relative importance of factors to analyze the suitability of land for agriculture in Golestan province, Iran using the AHP method, indicated that soil capacity, slope and precipitation were second and third important factors (Kamkar *et al.*, 2014) of assessment of land suitability and the possibility and performance of canole soybean (Fig. 2). The weighting of parameters for AHP suitability can be estimated using geometric mean method (Prakesh, 2003, Table 1).

Table 1: Criteria weights using AHP (Geometric mean method)

Chemical	pH	Fertility	OC	Weights
pH	1	1/4	3	0.2176
Fertility	4	1	6	0.6910
OC	1/3	1/6	1	0.0914

Source: Prakash (2003)

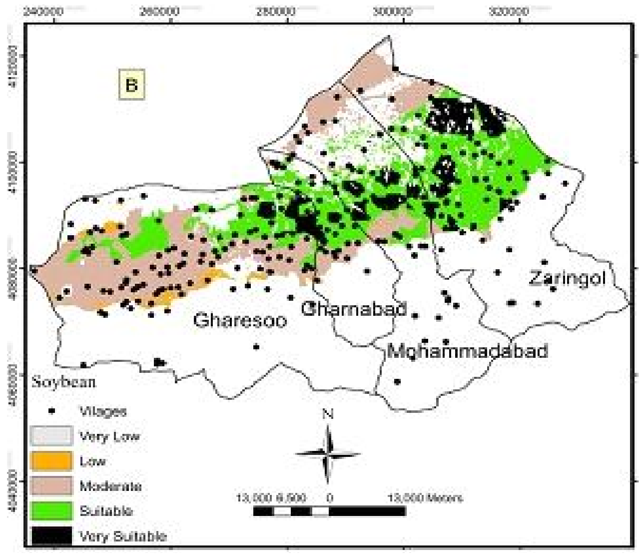

Fig 2: Land suitability map of soybean cultivation using AHP technique in Golestan province in northern Iran (Kamkar *et al.*, 2014).

Fuzzy Logic Technique: Zadeh (1965) proposed a new theory called 'Fuzzy sets', is a body of concepts and a technique that gives a form of mathematical precision to human thought processes that are imprecise and ambiguous in menu ways. A fuzzy set is a class of elements or without any definite boundaries them. The fuzzy logic is useful to define the real world objects which are characterized by vagueness and uncertainty (Prakash, 2003). Kurtener *et al.* (2008) used this technique of individual fuzzy indicators (IFI) and combined fuzzy indicators (CFI) of different soil attribute data (texture, organic C, inorganic C, Total C, Total N, Total P, extractable P, NO_3 and NH_4) located in Bell County, TX on the Elm Creek watershed provides an integrated estimation of agricultural land suitability.

Multi-criteria decision-making (MCDM) with GIS

Multi-criteria decision-making (MCDM) : Spatial multi-criteria decision-making (MCDM) is a process where geographical data is combined and transformed into a decision. Multi-criteria decision-making involves input data, the decision maker's preferences and manipulation of both information using specified decision rules. In spatial multi-criteria decision-making, the input data is geographical data. Spatial multi-criteria decision-making is more complex and difficult in contrast to conventional multi-criteria decision-making, as large numbers of factors need to be identified and considered, with high correlated relationships among the factors (Drobne and Lisec, 2009).

Multi-criteria Decision Analysis (MCDA) was designed in the 1960s to assist decision-makers to incorporate many options, reflecting the opinions of the actors concerned, into a potential or retrospective framework. MCDA in general includes a set of alternatives which are assessed on the basis of conflicting and incommensurable factors which are quantitative and/or qualitative in nature (Elaalem, 2010). This method combines all the spatial factors that are important and results in a map with the best locations for a certain type of land-use.

Multi-Criteria Evaluation (MCE) approaches and GIS is useful because various production variables can be evaluated and each weighted according to their relative importance on the optimal growth conditions for crops (Perveen *et al.*, 2008). The integration of GIS and MCDM methods provides powerful spatial analysis functions. In the MCDM approach, GIS are best suited for handling a wide range of criteria data at multi-spatial, multi temporal and multi-scale from different sources for a time-efficient and cost-effective analysis. Therefore, there is growing interest in incorporating GIS capability with MCDM processes.

Suitability Analysis: Joshua *et al*. (2013, Fig. 3), used the GIS and multi criteria decision analysis technique for agricultural land suitability in Nasarawu, Nigeria. GIS overlay in spatial analysis operation was also used to combine the different map layers of soil, geology, slope, topography and drainage to determine the most suitable lands for agricultural development. The evaluation criteria are considered to address the land suitability decision making based on i) land use; ii) soil type, pH, texture, depth, fertility, capability and drainage; iii) lithlogy type, iv) Ground water, v) topography, vi) climate.

Baniya (2008) found that the MCE along with GIS is a useful tool for integration of socioeconomic and environmental data (Khoi and Murayama, 2010). Using different soil parameters and chemical parameters, Das and Sudhakar (2014) derived thematic layer from GIS by the integrated MCDM technique and GEO spatial technology for land suitability analysis for pineapple in East Hills, Megalaya, India.

For the land use suitability, the combination of GIS capabilities with MCDM techniques provides the decision maker with the support in all stage of decision making, that is, in the intelligence design and choice phases of the decision making process (Chakhar and Mousseau, 2008). Jayasinghe and Machida (2008) developed an interactive web-based GIS consulting portal with crop-land suitability analysis, which provides information on Tomato and Cabbage cultivation in Sri Lanka. Soil pH, topography, average annual temperature, and average annual rain fall were considered as important criteria to determine crop-land suitability.

Remote sensing (RS) with GIS: In land suitability analysis, remote sensing play a vital role both at regional and local levels. It also offers an efficient and reliable method of mapping agricultural lands. Integrated remote sensing and GIS can clearly visualize the spatial distribution of the agricultural land suitability.

GIS has the ability to perform numerous tasks utilizing both spatial and attribute data stored in it. It has the ability to integrate variety of geographic technologies like GPS, Remote sensing etc. Krishna and Regil, (2014), (Fig. 4) brought out the spatial distribution of agricultural land suitability areas derived from remote sensing data in conjugation with evaluation of other variables like soil, landform, geology, landuse and topographic information in GIS context in the Kannur district of Kerala state.

The land suitability study in Turkey for rice cultivation based on GIS and statistical analysis considered factor rating of land quality parameters, including nutrient availability index and soil quality index (Dengiz, 2012). Khan and Khan (2014) used various soil series data for different crop requirements, soil properties, land use LandsatTM data and secondary data to using this approach for multiple crop land suitability in Bulandshahr District, UP, India, carried out.

GIS based cartographic technique: These tools include direct manipulation controls for specifying arbitrary class boundaries and graphs, representing statistical distribution of attribute values, means for automatic classification, calculation of statistical quality of classification, and various colour schemes that can be applied to represent classes on a choropleth map (Andrienko *et al*., 2001). Soil choropleth maps which give a visual impression and spatial variation of soil properties of selected crops (Oil palm, cassava and citrus) in Adansi West District and analysis crop-land suitability chropleth map with GIS environment (Forkuo and Nketia, 2011).

Simple Limitation Method (SLM) and parametric methods : The simple limitation method implies that the crop requirement tables are made for each land utilisation type. For each characteristic, the tables define the class-level criteria. Land classes are determined according to the most

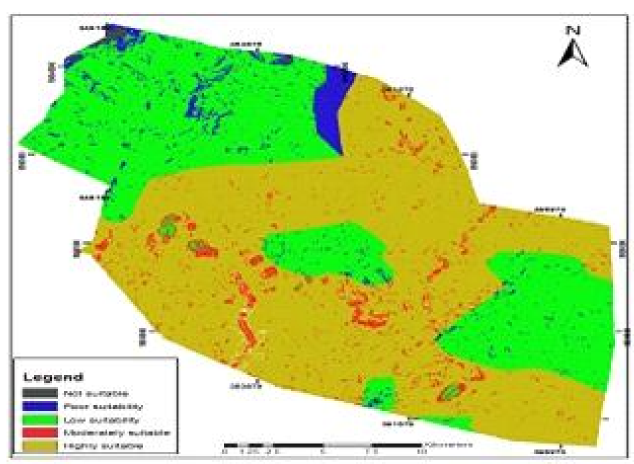

Fig 3: Final suitability map for agriculture land-use based on GIS and Multicriteria decision analysis approach in Nigeria (Joshua, 2013).

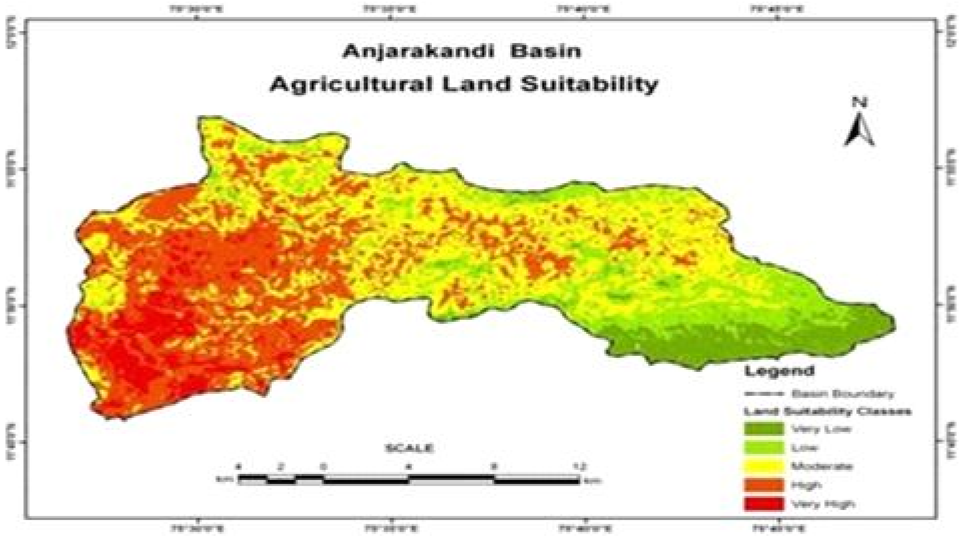

Fig 4: Agricultural land suitability maps based on RS and GIS tool in Kannur district of Kerala state (Krishna and Regil, 2014)

limiting characteristics. The advantage of this method is its simplicity and there is no overlap and interaction between, so many features can be used in evaluating (Sys *et al*., 1991). The parametric method in the evaluation of land characteristics consists in a numerical rating of the different limitation levels of land characteristics in a numerical scale from a maximum (normally 100) to a minimum value (0). In land use suitability qualitative carried out by means of simple limitation method (SLM) and parametric methods (storie and square root method) and comparing land and climate characteristics with crop needs and based on topography, soil properties (Albaji *et al.,* 2009), using these approach in East Azarbijan for wheat, barley, alfalfa, maize and safflower (Jafarzadeh *et al.*, 2008), wheat land suitability in Iran (Rabia and Terribile, 2013, Fig. 5).

GIS linked with genetic algorithm and artificial intelligence: The Genetic Algorithm (GA) proposed and developed by John Holland (1975) and discovered by Charles Darwin in "The Origin of Species (Penev and Ruzhekov, 2011), is an optimization and search technique based on the principles of genetics and natural selection (Malczewski, 2004; Koomen *et al*., 2007). Malczewski (2004) affirmed that the applications of GA to GIS-based land-use suitability analysis have gained popularity in recent years. Matthews *et al.* (1999) suggested that a GA can be a key component of the land-use planning and management support system.

Recent developments in spatial analysis showed that Artificial Intelligence (AI) offers new opportunities to land use suitability analysis and planning (Fischer and Opanshaw, 2000). It includes modern techniques of calculation that may help the modelling and description of complex systems for inference and decision making (Malczewski, 2004). Collins *et al.* (2001) identified three major groups of approaches to GIS-based land suitability analysis: (i) computer-assisted overlay mapping, (ii) multi-criteria evaluation methods, and (iii) artificial intelligence (Al) methods. Mansor *et al.* (2012) carried out land suitability evaluation for three main crops (wheat, potato and almond) based on defined Scenarios using above three programming in the Zayandehrood watershed, Iran.

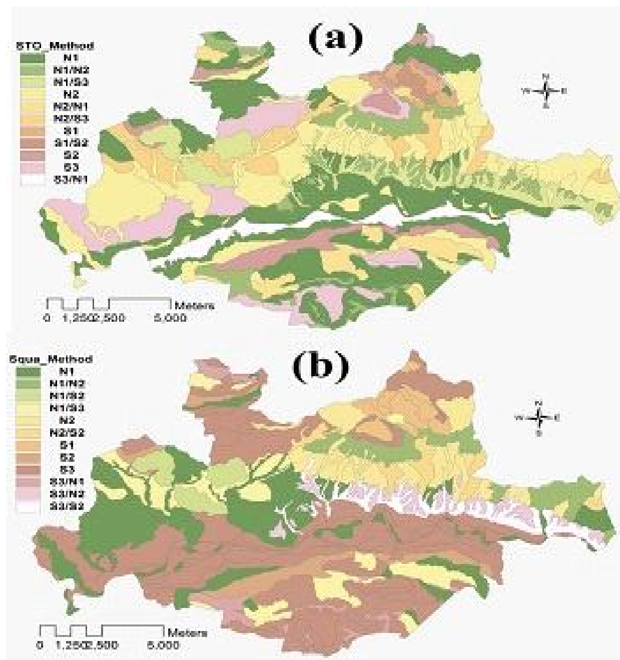

Fig 5: Wheat land suitability maps for the two parametric methods (a): Storie method, (b): Square root method in Valle Telesina, Italy (Rabia and Terribile, 2013)

Multi-Criteria Evaluation (MCE) with GIS, RS, AHP, Boolean, ideal vector approach and Fuzzy AHP: This group is more powerful integration technology for the agricultural land suitability analysis in recent trends of sustainable agricultural programme. AHP, ideal vector approach and fuzzy AHP for agricultural land suitability analysis were used in Dehradun district, Uttaraanchal, India, based on following evaluation criteria-soil, climate, irrigation, market and infrastructure, socio-economic population (Prakash, 2003).

AHP integrating MCE with GIS to delineate the suitable areas for rice crop using the relevant variables of soil and topographic database and distribution derived from RS image and integrating biophysical and socio-economic data for land use suitability evaluation of irrigated wheat cultivation in relation with its suitability level in Haripur, Bangladesh (Perveen *et al.,* 2008). Bio-physical, socio-economical and environmental factors were used in Iran for rice cultivation along with this method (Moddahi *et al.,* 2014), and in Kenya, Jafari and Zaredar (2013) used this approach for suitability analysis of rice growing sites. MCDM with GIS, AHP, weighted linear combination techniques were used to integrate fuzzy suitability criteria maps of land suitability for pineapple. The data were multi-disciplinary and included climatic (annual mean rainfall), topographic (slope), pedological (soil texture), hydrological (rivers and streams), demographic (population), transportation (roads) and land cover data in Eastern Region of Ghana (Attua *et al.,* 2010).

Indian Scenarios: Land suitability evaluation for various agricultural crops has been carried out at different research centres in India (Raju, 2015; Prakash, 2003). Remote sensing can provide us the information like land use and land cover, drainage density, topography etc. (Das, 2000). A multi criteria decision making approach using remote sensing and GIS technique with remote sensing (RS) was used (Mustafa *et al.,* 2011, Fig. 6) for multiple crops land suitability in Agra district, UP, India. *Kharif* and *rabi* season cropping patterns maps were developed by integrating crop suitability maps for the winter and summer seasons separately. Results indicated that about 55 % is highly suitable (S_1) for sugarcane and 60%, 54% and 48 % of the area are moderately suitable (S_2) for cultivation pearl millet, mustard and rice respectively (Mustafa *et al.,* 2011).

Das and Sudhakar (2014) followed the land evaluation procedure given by FAO for soil site suitability under rainfed agriculture to assess the land suitability for Khasi mandarin orange and pineapple in East Khasi Hills District of Meghalaya. The study revealed that highly suitable areas for orange are found in the Cherapunjee and Mawsynram area that covers 34.5 sq. km areas. Moderately suitable (37% of TGA) and marginally suitable (24% of TGA) areas are found only because of slope constraint (8% - 30% slope). The hills with deep gorges and ravines on the southern portion of the district is found not suitable for orange plantation because of steep slopes (>30%) and stoniness (Das and Sudhakar, 2014).

CONCLUSION

Land suitability for agriculture is a very important piece of information in agriculture development and future planning. Based on that, a land suitability assessment for Agriculture purpose has been conducted in order to help decision makers, agriculture development planners and determine how proper or appropriate it is for a particular use of the land in a particular location which are more suitable for certain agriculture use. Its major objective is to find out places which are most suitable for certain agricultural use. Land suitability tools have been extensively applied to identify better management Practices in agricultural areas. These tools evaluate the suitability of an agricultural Land to a specific practice or land use. Soil and landscape properties are essential in this type of evaluation, fact that

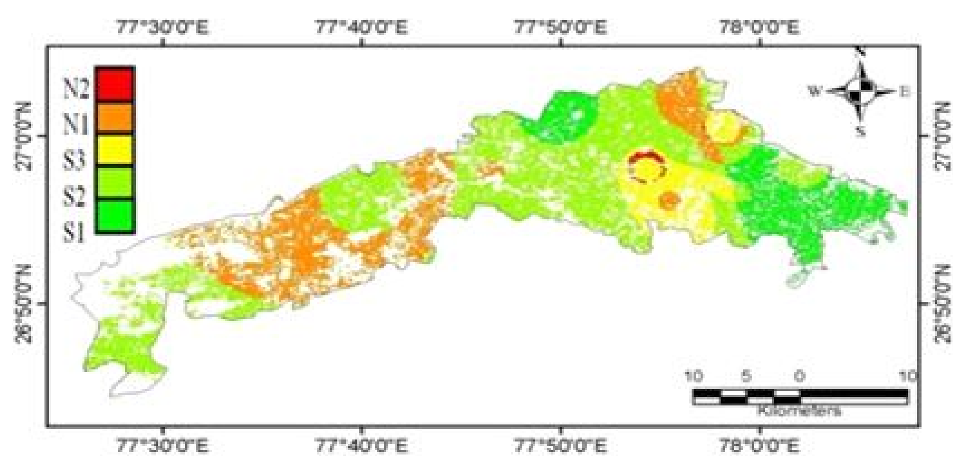

Fig 6: Suitability map of rice based a multi criteria decision making approach using remote sensing and GIS in Kheragarh tehsil of Agra district, UP, India (Mustafa *et al.,* 2014)

makes especially interesting the coupling of this type of model with Geographic Information Systems (GIS). The integration of RS-GIS, Fuzzy-logic and application of Multi-Criteria Evaluation using AHP could provide a superior database and guide map for decision makers considering crop land substitution in order to achieve better agricultural production.

So, GIS has contributed to the speed and efficiency of overall planning process in agricultural land use suitability because quick and efficient access to large amount of information was enabled by GIS, exhibiting relationships, patterns, and trends that are useful in combining soil survey information to monitor land use suitability evaluation.

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