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Review Article

Geographic Information Systems for Egyptian Agricultural land evaluation

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ABSTRACT
Evaluating the Egyptian agricultural lands in terms of their capability and suitability for cultivation with different crops is necessary to reach the best benefit. Therefore, many researchers and specialists in the field of land evaluation follow several methodologies and apply different models to reach the most accurate results. Among those used methods, mathematical and statistical models are deal with many layers of data. On the other hand, computerized and automated models developed by software packages save time, effort and deal with a huge amount of data at one time. One of the most important tools currently used in presenting the results of land evaluation is the Geographic Information System (GIS) tools. These tools deal with spatial and soil attributes in the multiple sites to be evaluated. The main advantages of these tools are that they display data over a wide geographical scale in the form of spatial distribution maps. These maps are very important for decision makers in achieving better agricultural practices and optimal utilization of land resources. With the use of these tools, future planning for reclamation and cultivation of lands becomes clear and simple, in addition to saving costs significantly.
Keywords: GIS, Egypt, Land Evaluation

INTRODUCTION

Continuous agricultural lands evaluation for the purpose of maximizing their use is very necessary. Especially at the present time, good planning is mandatory to achieve the optimal utilization of all environmental resources. Many agricultural lands around the world are exposed due to major problems such as desertification, urban sprawl, degradation, pollution, and others. With the continuous climatic changes causing a change in the conditions of agricultural production in those areas, it was necessary to discuss the issue of continuous agricultural land evaluation. It is difficult to conduct continuous evaluation of agricultural lands for a particular area using traditional methods. These conventional routine methods require time, effort and cost, in addition to the inaccuracy in some cases. Therefore, it is necessary to use modern methods and models that can match soil spatial and attributes' data to conduct the evaluation on a wider geographical scale. Based on these reasons, GIS has proven highly efficiency in producing spatial distribution maps for different land uses, as well as evaluating agricultural lands and classify their data into different orders and classes. Moreover, Ibrahim et al. (2013) mentioned that the integration of GIS and remote sensing was found to be an effective tool for sustainable land use planning. Sayed and Khalafalla (2021) concluded that GIS technique with geostatistical tools is a valuable approach for capability and suitability evaluation of land. For land suitability evaluation, there many layers of data related to soil parameters, climatic conditions, social and environmental impacts of a specific land use that planned to be evaluated. However, land suitability evaluation includes questions of (where, why and when) the crops grow (Sekiyama and Nagashima 2019). To answer these questions, many different methods of land suitability analysis are followed. That meant, there is no universal or a standard methodology or a protocol for this process. The main output of the process of land suitability analysis is to judge the land (Suitable or unsuitable) for specific use. With these data, possibility to answer questions (when and why) will be there. Using these outputs, land suitability mapping using different spatial variability distribution and geostatistical analysis can be used to answer the question (where) depending on spatial and soil attributes (Mugiyo et al., 2021). Because of big data included in the evaluation, Multi-Criteria Evaluation (MCE) is used. Therefore, Geographical Information Systems (GIS) found to be an effective approach for land evaluation. It is capable to investigate multiple geospatial data. Moreover, integration of remote sensing, GIS, and machine learning techniques could enhance the accuracy and the predictability of land evaluations' outputs. Decision-makers must have a sufficient knowledge about land evaluation used techniques whereas many factors should be included in the applied criteria. Not only soil attributes are used, but also climate data as well as socio-economic factors should be included in the criteria of land evaluation (Atoyebi et al., 2017). In Egypt, with the dramatic increasing of population and with agricultural land challenges such as urban sprawl, salinization, degradation and climate change, land evaluation should be done for better agricultural management.

Therefore, and based on what has been mentioned previously - the aim of this review is to clarify the importance of modern methods, especially geographic information systems, in evaluating land globally, and to know the extent of its application on Egyptian lands.

Land Evaluation

Land evaluation is considered as a tool for systematic and strategic land-use planning for a specific purpose. Moreover, it can be expressed as a knowledge-based that requires different conditions to be included and achieved. Land evaluation can be automatically done by the use of different models such as agricultural land evaluation system (ALES), land evaluation for capability (LECS) and geographic information system (GIS) as Ganzorig and Adyasuren (1995) description. Evaluation of land is an interpretation of the soil attributes, cropping cover, climatic conditions and other data layers related to the specific purpose of land-use to characterize and diagnose the optimal land-use among these alternatives (Sayed, 2006). Therefore, using a suitable approach to deal with these multiple data layers is needed. Geographic information system (GIS) is an important tool for land evaluation mapping and these outputs can be utilized for sustainable planning of land resources (George, 2015). Land evaluation is also the process of assessing land performance for specific purposes or to estimate and predict the use of land (van Diepen et al., 1991). Agricultural land evaluation includes two major types (capability and suitability evaluation). For the agricultural lands in Egypt, the situation is difficult because of many challenges that face the Egyptian Government. The increase of population and urban sprawl on the Nile Valley agricultural lands are the main problems. Furthermore, climate change is a vital factor controls the sustainability especially for agricultural sector in Egypt. Food security is targeted from the government to achieve better life for Egyptian people. Therefore, agricultural land evaluation is strongly needed for better utilization of lands and for achieving optimal income.

Land Capability

Land capability could be defined as the use of the land in specified way or management practices (Dent and Young, 1981). Land capability classes refer to the use of a piece of land for a targeted reason such as building, cropping, woodland, or wildlife (Mohamed, 2002). Capability class means the degree of goodness for land-use (For example, Agricultural activities). These classes can be subdivided into sub-classes based on limitations or conservation required. Manikandan et al. (2013) explained that these subclasses present limitations of the land under evaluation (such as erosion hazards, stones, shallowness, salinity, low fertility, excess water, and climatic limitations). Land capability could be includes in four classes (excellent, good, moderate, and not capable). There is a big number of studies were carried out regarding agricultural land evaluation either for capability or suitability evaluation in Egypt. These studies used several techniques and followed different approaches for agricultural land evaluation. There are methodologies depend on soil data only, while others used multiple evaluation criteria whereas soil attributes integrated with climatic data, socio-economic factors' data as well as spatial information. Many of previous studies done for agricultural lands' evaluation in Egypt depend on using GIS techniques and tools combined with machine learning and geostatistical analysis. These studies proved that the integration of remote sensing, GIS, and soil multiple layers were found to be as an important tool for land evaluation.

Land Suitability

Land suitability classification aims to fit the land for a specific use. Land suitability evaluation is based on soil survey; socio-economic information and the aim of land-use. There are two main suitability orders (suitable and non-suitable). Suitability classes refer to land limitations and they are (highly suitable, moderately suitable and marginally suitable). Moreover, classes are divided to sub-classes vary in management requirements (Manikandan et al., 2013). Elnaggar (2017) defined Land suitability as how the land is fitted with the requirements of a specific target of the land-use either in actual land-use or after improvement as estimated potential suitability. Moreover, it is a matching between land attributes and crop requirements to estimate land quality for a spcific land use (Mustafa et al., 2011). There are many studies done in Egypt for evaluating land suitability and capability. For Example, in El-Dakhla Oasis, Ibrahim et al. (2013) evaluated land capability and suitability for different 16 crops where a part of the area was having a good capability while other parts was under fair capability condition. They also found that the study area was moderately suitable for cultivating Alfalfa, Olive, Mango, groundnut, potato, wheat, and Sorghum while highly suitable for Barley. They used remote sensing and GIS tools for mapping their results successfully. Abosafia et al. (2022) found that GIS tools capable to evaluate the capability and suitability of Kafr El-Sheikh soils whereas they used ASLE model for evaluation. Their results indicated that, the land varied between very poor and fair capability. They also found that the land was highly suitable for wheat, barley and date palm, moderately suitable for growing Maize, and not suitable for Onion and Citrus.

Soil Fertility

Soil fertility evaluation is a part of land capability evaluation but for specific physico-chemical properties. Soil fertility was defined by Food and Agricultural Organization (FAO) as ability of soil to sustain of required nutrients by growing crops in sufficient quantities and correct utilities (Jin et al., 2011). Fertility status of the soil is the most important component that control the productivity potentials which strongly influenced by management activities (Johnson et al., 2000). Moreover, nutrient index (available P, available K and OC) and the soil reaction index are used for evaluation. With these inputs, soil fertility is evaluated under different classes (poor, medium and high) fertility (Abah and Petja 2015).

Agricultural Lands' Evaluation

Many decisions makers resort to evaluating agricultural lands to see how productive their lands are and also to make a decision about which crop is best grown on those lands. For example, in Egyptian agricultural lands, Fayed (2003) evaluated the land capability of El-Bostan region, West Nile Delta and classified it to moderate and marginal capability classes. the main limiting soil factors in the studied soils were soil texture, ESP, salinity and calcium carbonate content. Abd El-Khalek (2004) applied the soil capability index to Wadi El-Rayan soils and matched between the soil properties and rating of Storie index. He found that a half of investigated lands were non-agricultural while the other half is varied between poor and excellent soils. Some soils of Wadi El-Natrun area was studied using remote sensing and GIS techniques whereas FAO framework of land evaluation was applied Abd Al-Hamid et al. (2010). They pointed out that the study area was classified for capability to be under three classes (moderately suitable, whereas topography, soil texture and salinity were the limiting factors; temporary not suitable and permanently not suitable). They also estimated the potential capability of the land and their finding revealed that the limitations could be removed by enhancing some soil properties and the land could be cultivated with five main crops (wheat, barley, grapes, alfalfa and fodder beet). Mahmoud et al. (2009) used agricultural land evaluation system (ALES) for evaluating land capability in some Egyptian soils. They found that the current capability of the area ranged between high capability and moderate capability classes. After enhancement of soil parameters, soil could be moderately suitable for cultivating maize, olive, figs, wheat, sorghum and barley. They recommended using of GIS combined with modeling approaches for capability evaluation.

Some Used Methodologies and Models For Land Evaluation

For estimation of actual and potential land productivity, Riquier et al. (1970) approach is used. In this method, nine factors were considered for determining soil productivity, soil moisture content (H), drainage (D), depth (P), texture (T), soluble salts content (S), average nutrient content (N), organic matter content (O), soil cationic exchange capacity (A) and reserves of weatherable minerals (M). Each factor is rated on a scale from 0 to 100 and the actual percentages are multiplied by each other to calculate the productivity index (PI). The resultant index for productivity, also lying between 0 and 100, is set against a scale placing the soil in one or other of five productivity classes, namely excellent, good, average, poor, and extremely poor. The potentiality index (P`I) for the future land productivity estimation is also calculated after improving characterizations which considered as limitations of productivity.

Regarding evaluation and classification of land capability, several methods and approaches are applied. The most common used methods are Requier (1970), Storie index (1954), and Sys and Verheye (1975). Capability methods of evaluation depend on soil data (physical, chemical, and fertility) parameters. In some other methodologies, the climate data are also used as input data layer in the used model of evaluation.

The Sys et al. (1993) model is a parametric method which commonly utilized because of its comprehensiveness and ease of application. The Agricultural Land Suitability Evaluation (ALES) model (Ismail et al., 2001) has proven to be very fast, efficient, and easy for using.

The Storie index (Storie, 1954) is a mathematical model which can match many soil factors such as soil profile (A), the texture of surface soil (B), and a miscellaneous land factor including drainage, slope, and alkalinity (C). In addition, factor X can be considered related to miscellaneous soil parameters that can be modified by management. These parameters are nutrients status, alkali status, pH-level, soil erosion, and micro-relief. Each factor is scored as a percentage but multiplied as a decimal. The final index is expressed as a percentage. Where more than one property is considered, as in factor X, each is also scored as a percentage, and then all are multiplied together as decimals and expressed as the combined percentage of that factor. Soil grades of Storie Index were presented in table (1).

Sys and Verheye (1975) proposed the capability index (Ci) based on nine parameters for crop production in the arid and semi-arid regions (A: soil texture, B: calcium carbonate, C: gypsum, D: salinity, E: sodium saturation, F: drainage, G: soil depth, H: weathering stage, and I: profile development). Each factor is scored as a percentage but multiplied as a decimal. The final index is expressed as a percentage. Sys (1976) proposed the following scheme (table.2) for evaluating the degree of limitation. The limitation approach has been successfully used to provide a qualitative land evaluation based on general characteristics that are made available after a quality soil survey and general study of other soil resources in the area.

The parametric method was proposed by Sys et al. (1991); whereas soil-site parameters considered for land suitability evaluation are climatic data (i.e. available moisture or precipitation, temperature, and relative humidity), morphological characteristics of the soil profile (i.e. soil depth, slope, flooding, drainage and erosion level), Physical condition of the soil (i.e. soil texture, gravels, and Stoniness), and chemical parameters of soil (i.e. calcium carbonate, nutrient availability, gypsum, organic matter, cation exchange capacity, base saturation, salinity, alkalinity, and sodicity). Table (3) showed suitability classes and limitations of soils.

The Agricultural Land Evaluation of Suitability (ALES) model was developed by Ismail et al. (2001); whereas depe nds on using multi-criteria for evaluating the suitability of land. The same soil-site parameters mentioned above were used in the ALES model.

Geographic Information System (GIS)

A geographic information system (GIS) is an information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially-reference data, as well as a set of operations for working with data. In a sense, a GIS may be thought of as a higher order map (Azad, 2009). It is a powerful tool for data handling, processing and management, and solving environmental problems, but tools can do nothing without methods. (Panigrahy et al., 2006).

Importance of GIS

For such projects of agricultural land evaluation, huge number of soil samples should be collected and analyzed. In addition, a lot of effort is given for surveying and data collection. Therefore, fast and accurate technique should be found to be as an alternative for the conventional methods of soil surveying, sampling and analysis. For that, GIS is a cost-effective tool savings labor and analysis costs by about 75%. Routine methods are not able to get spatial data for all studied locations, but GIS is helpful for providing this data. GIS products such as mapping of soil properties as well as the land situation and classification of capability and suitability are considered as greatly assist for decision makers. These outputs can be easily shared among different teams, work-groups, departments, organizations, and all people. The main importance of GIS is visualizing the outputs in a larger geographic scale without extra cost. Furthermore, the integration of soil attributes, spatial data, machine learning algorithms, GIS and remote sensing is very necessary for getting an accurate situation for un-surveyed locations.

Components of GIS

The GIS environment consists mainly of Hardware, software, data, users and methodologies. Hardware includes laptop or computer system which GIS software packages run. These devices must be in a suitable condition to be matched with the used software. Some computers are connected with a scanner to scan a paper map and convert it to digitized one as in image format (TIFF, BMP, JPG etc.). The printers used as output device for a GIS work. The GIS software are used for their tools to store, analyze, and display data. Examples for GIS software are (MapInfo, ArcInfo, ArcView, ArcMap, etc.). There is free sourced software such as QGIS. Spatial data is other component of GIS used for generating soil maps. GIS users are technical specialists, operators, engineers or users.

Applications of GIS in Agriculture

Using GIS tools depend on the spatial data and target attributes. GIS is used in agricultural studies for detecting nutrient which can help in site specific nutrient management, reduce the cost of fertilization as well as increase nutrient use efficiency (Shanmugapriya et al., 2019). By application of some useful models such as NDVI integrated with remotely sensed data, Buttar et al. (2017) could map the healthy and non-healthy grown plants using GIS tools. Remote sensing and GIS tools of soil and crop can be an attractive alternative to the traditional methods of field scouting because of the capability of covering large areas rapidly and repeatedly providing spatial and temporal information necessary for sustainable soil and crop management (Basso et al., 2004).

Applications of GIS In Evaluating Some Egyptian Soils

There are many studies which carried out in Egyptian lands for different purposes using GIS tools. Among them, Darwish et al. (2006) evaluated Farafra Oasis soils as one of the newly reclaimed areas in Egypt using microleis model. They could classify land suitability to (highly suitable for wheat, potato and sunflower; and low suitable lands) with limitations of salinity, sodium saturation and texture. They also could map their results using GIS tools. Abdel Rahman et al. (2017) studied sixty soil profiles for land evaluation assessment purpose. They found that the soil could be classified depending on soil characteristics and physiographic units of the area. Their findings revealed that GIS generated maps of the study area could be categorized into several suitability classes. Shalaby and Moghanm (2015) studied the urban sprawl using GIS tools in Nile Delta. They showed that, a wide expansion of urban area on the account of fertile soils occurred during the study period 1984–2006. They could successfully utilized GIS for mapping their findings. Gad (2015) created a land resources database for Dakhla Oasis that aims to assess and map land capabilities based on FAO methodology. The researcher used soil attributed, remotely sensed satellite images, and climate and landscape data as layers of GIS model to classify land capability to (highly, moderately and non-capable soils). He mentioned that the use of GIS and Automated Land Evaluation System (ALES) is very useful to assess land capability and crop suitability. Belal et al. (2014) studied land degradation using GIS data. They demonstrated that about a half of the study area has undergone very high risk, whereas the rest area was under low risk of chemical degradation. Mahmoud et al. (2009) reported that the combination of GIS with modeling approaches such as ALES model is a quite evident proves the power of these tools for decision making in evaluating agricultural lands. Regarding land suitability evaluation, Belal et al. (2014) demonstrated that four land capability orders for agricultural land reclamation (i.e. good, moderate, weak and marginal) were found. Moreover, the evaluation model gives four limiting factors (topography, soils, erosion risks and bioclimatic deficiency). The researchers could map their results using GIS tools. Moursy et al. (2020) mentioned that the integration of soil surveying, sampling, laboratory analysis, and GIS technique found to be an effective tool for producing spatial information as well as land productivity data. Moreover, these data can be utilized for better land use management, planning for new lands reclamation, and enhancing agricultural productivity. Sayed and Khalafallah (2021) evaluated and mapped land capability and suitability in some parts of Assiut using ASLE and microLIES models. They could diagnose the soil limitations in the study area. El-Sayed et al. (2020) used geostatistical analysis tool in GIS to evaluate and map some soils in Sohag whereas they found that the study area included four capability classes ranged between Good, Fair, Poor and Non-agricultural lands.

GIS Mapping of Soil

Producing soil maps is absolutely essential. The importance of maps lies in the fact that they are a guide for decision makers and workers in agricultural lands to ensure a good use of these lands. Soil mapping depends on digital terrain model (DTM) to construct relation between landform and soil. Field work and laboratory analysis with special reference to soil constrains were the main targets to reach land evaluation and land suitability goals. Land capability and suitability maps are confirmed with the mapping units on the physiographic map for producing the productivity map using several automated models such as microLIES, ALSE, ALES and others. For example, ALES is used in arid and semi-arid regions to estimate the agriculture land evaluation whereas it is linked directly to its relational database and coupled indirectly with a GIS through the loosely coupled strategy.

There is a continuing demand for accurate and up-to date land use/land cover information for any kind of sustainable development program where land use/land cover serves as one of the major input criteria. As a result, the importance of properly mapping land use/land cover and its change as well as updating it through time has been acknowledged by various research workers for decision making activities; as for example, application of land cover change in urban environment by Deng et al., (2005).

Many researchers applied such mentioned models for evaluating agricultural lands in Egypt. For example, Moursy et al. (2020) used GIS tools to map land evaluation classes of Eastern part of Sohag, Egypt. They found that the investigated area was divided to six mapping units viz, Wad floor, Low elevated sand sheet, High elevated sand sheet, Table land, Bajada and Piedmont. Other study was conducted to generate soil maps of landuse/landcover of the soils adjacent to El-Manzala Lake east of the Nile Delta, Egypt using remote sensing and GIS tools. This area was found to be classified into flood plain, the lacustrine plain, and the marine plain. GIS could map the Water bodies and urban areas in the investigated area (Ali and Kotb 2010). The main physiographic units for some promising areas of El- Farafra Oasis. The physiographic point of view, the landscapes include two units (i.e. Plateau and depression floor) as described by Abdellatif et al., 2020. Yossif and Ebied (2016) measured the area of each land use in their study area using Arc-GIS software. Also they mapped the Change detection in the cultivated land area, Fish farms, and reclaimed areas. They could also evaluate the capability of the investigated area for the mentioned several land uses. Yousif (2018) applied GIS tools on the data of El-Tina plain soils to study land degradation between 2006 – 2014 periods. He found that the reason of land degradation is salinity caused by the rise of ground water level to < 50 cm from surface soil. However, he also used GIS tools to evaluate the investigated area where was classified into five main landforms (i.e. Piedmont, Foot Slope, Back Slope, Summit and Escarpment). In the same study, Yousif (2018) evaluated land capability by the modified Stori index. He reported that the studied soils were categorized in to grade 1, grade 2, grade 3, and grade 4 but grade 3 and 4 are the most common. According to land suitability assessment, the most suitable crops in the study area are alfalfa watermelon, barley, wheat, sorghum and olives. The evaluation results indicate that the main limiting factors for agriculture soil suitability in the studied area were soil texture, shallow soil depth, excess of salts and lime. Capability and suitability maps were generated using GIS tools. El-Sayed et al. (2020) successfully mapped capability and suitability of soils in Sohag using GIS-Geostatistical model while Sayed and Khalafalla (2021) recommended the same procedure for mapping land evaluation results. Abosafia et al. (2022) could map their outputs of land evaluation models for some parts of Kafr-Elsheikh using GIS tools.

CONCLUSION

From the review study, it became clear that GIS is very important and necessary in agricultural land assessment. The maps produced by GIS tools are considered as a guide for decision makers and planners for the optimal use of agricultural lands. Geographical information systems have proven highly efficient and competent in evaluating agricultural lands in Egypt. Therefore, it is strongly recommended to use GIS in evaluating agricultural lands in terms of their capability and suitability for cultivation with different crops.

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