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An Agricultural Investment Map Based on Geographic Information System and Multi-Criteria Method

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Abstract: The study aimed to produce an investment classification map, which shows the potential areas of investment in agriculture in Sinnar, Sudan. The spatial multi-criteria analysis was used to rank and display potential locations, while the analytical hierarchy process method was used to compute the priority weights of each criterion. The study attempted to explore the utilization of Geographic Information System (GIS) to map the potential investment areas, therefore, it did not cover a comprehensive analysis of all factors that influence investment in agriculture. In addition, the analysis was limited to criteria that had spatial reference. The investment criteria for spatial analysis were defined from the guidelines provided by the Ministry of Investment, Sudan. Even with the shortcomings of the data, it was found that the results obtained were very encouraging and provided clear indicative areas for agricultural investment in Sinnar. Government agencies can use GIS to access information regarding the potential areas of investment, and minimize investment risks. On the other hand, the economic development organizations will now have the ability to benefit from the Geographic Information System (GIS) solutions by leveraging on this technology to attract and retain business from worldwide sources. Thus, the model will serve as a decision support tool for investors and decision makers at various levels.

Key words: GIS, multi-criteria, spatial analysis, agriculture, investment

INTRODUCTION

Although, there is a great potential in the field of agriculture, developing and reaping maximum benefits from this sector need more effort in order to move the wheel of production towards improvement and progress. In 2003, the Ministry of Investment in Sudan commenced an investment map for Sudan, which is still in progress. The data related to the investment in GIS software are being gathered, but no analysis has yet been carried out on them to define which areas have greater potential for investment with minimum risk. Nevertheless, one of the ways to encourage investment is to provide the investors with good and high quality information because wrong information can be costly in investment activity. Hence, this study provides the potential areas for agricultural investment by evaluating them based on several types of criteria using Geographic Information System (GIS).

There are many factors contributing to the success of decision making in yielding the right investment, such as information and technology (Trull, 1966). In the past, potential investors wasted a lot of time and resources to search for answers to many questions, such as: Who is the owner of the land? Is the land suitable for agriculture? Besides, they were also faced with many problems, such as the lack of correct data when needed, as well as outdated maps and data. Needless to say, combining the data and maps for a study is time-consuming because different sets of data and maps have incompatible formats, definitions and scale (M-NCPPC, 1999).

The second issue deals with compatible technology and the right people who can use it to solve problems. GIS offers the potential to minimize the above-mentioned problems and to generate many benefits through its flexibility, speed, availability and processing power (M-NCPPC, 1999). Following this, GIS and Multi Criteria Evaluation are useful tools to support the decision makers in achieving greater effectiveness through the aggregation of geographical data and the decision-makers' preferences into one-dimensional values of alternative decisions (Malczewski, 1999). One approach of Multi Criteria Method is the pair-wise comparison method-a method developed by Satty (1980) in the context of the Analytical Hierarchy Process (AHP). This

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method involves pair-wise comparisons to create ratio matrix. It takes the input of pair-wise comparisons and produces the relative weights as output. There are GIS applications used in the construction industry, however, its usefulness in other areas like business and economics is still being explored (Cheng *et al*., 2007). In one of the earlier studies, the developed system was based on GIS and Multi criteria method. The system contained criterion definition, management, evaluation scenario and user interface. The purpose of the system was to develop and analyse the environment to support various investment researchers and investors, as well as to assist users to find the information about particular projects (Lin *et al*., 2008). Moreover, in a study done by Cheng *et al*. (2007) the researchers presented the utility for shopping mall location selection, which was one of the core business activities, or specifically, the improvement of investment in Hong Kong. In the study, the project was demonstrated to create the features associated with household incomes, demand points, etc. Nevertheless, the limitation of this study was that the results depended on one factor only without considering the selection of the best mall through the analysis of all factors which had different weights. Similarly, another study was done on the selection of shopping centre location, but it was based on combined MCDM methodology. In addition, a study was also conducted by Moldovanyi (2003), which performed a spatial multi-criteria analysis in order to rank and display the marketability of 32 pay pond businesses in West Virginia. The results of this study, as compared with the first one, were more reasonable because they depended on the criteria evaluation of spatial data and considered the factors that influenced marketability. On the other hand, by using the ranking method, it was difficult to get the accurate expression of relative preferences on the criteria due to the limitations of the 9-value scale of Saaty (Lin *et al*., 2008). To overcome this problem, Saaty proposed the Analytical Hierarchy Process (AHP). Fuzzy AHP (i.e., Analytical Hierarchy Process) was utilized for assigning weights of the criteria for site selection and fuzzy TOPSIS (i.e., a technique for ordering preference by similarity to ideal solution), and it was used to determine the most suitable alternative using these criteria weights (Onüt *et al*., 2009). Apparently, the study overcame the limitation in the previous one.

The use of GIS, following the Multi Criteria Analysis, has become popular in site selection (Hossain and Das, 2009; Zucca *et al*., 2008). The application of GIS technique in combination with a multi-criteria approach is not restricted only to finding potential places for agricultural investment or development (Hossian *et al*., 2007), but it goes beyond to analyze land suitability for different crops. There are many studies covering this area such as the ones done by Chuong (2008) and Liu *et al*. (2006).

In this study, the suitable area for agriculture was determined by the Ministry of Agriculture, and the analysis provided the areas that have high potential of investment in agriculture.

MATERIALS AND METHODS

The selection of criteria was restricted by the available data. The principle supporting the data for this study was provided in 2003. The criteria that had spatial reference were land use, road, railways and water resources. The stability of results was tested using the sensitivity analysis and trade-off method, which assisted in producing significant results. The flow chart of the methodology is shown in Fig. 1.

GIS model: Buffer Wizard was created for road, railway and water resources. On the other hand, land use was classified to replace the values based on new information.

Analytical Hierarchy Process (AHP): In AHP method, every criterion under consideration was ranked in the order of the decision maker's preference. The square pair-wise comparison matrix is presented in Table 1. To

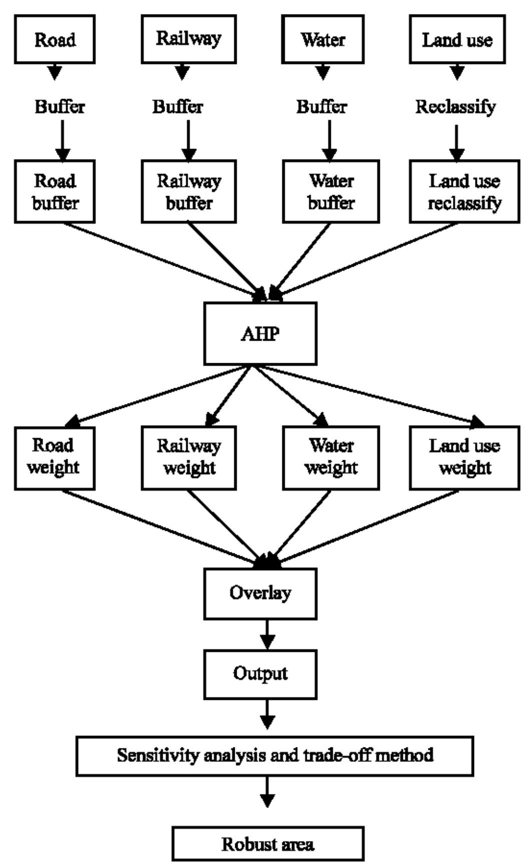

Fig. 1: Flow chart of methodology

Table 1: Specify square pairwise comparison matrix (A)

	C1	C2	C3	C4	Priority vector
C1	1.0	2.0	2	2.0	0.387337662
C2	0.5	1.0	2	0.5	0.198133117
C3	0.5	0.5	1	0.5	0.139691558
C4	0.5	2.0	2	1.0	0.274837662
Total	2.5	5.5	7	4.0	

C1: Landuse, C2: Water, C3: Road and C4: Railway

Table 2: Normalize matrix A by dividing each column entry by the sum in the column

	C1	C2	C3	C4	Priority vector
C1	0.4	0.36	0.29	0.50	0.387337662
C2	0.2	0.18	0.29	0.125	0.198133117
C3	0.2	0.09	0.14	0.125	0.139691558
C4	0.2	0.36	0.29	0.25	0.274837662
Total	1.00	1.00	1.00	1.00	1

C1: Landuse, C2: Water, C3: Road and C4: Railway

Table 3: Random indices for matrices of various sizes

N	R1
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.40
9	1.00
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

generate the criterion values for each evaluation unit, each factor was weighted according to the estimated significance for agricultural investment project. The normalized matrix is shown in Table 2. Meanwhile, the individual judgment, which never agreed perfectly with the degree of consistency achieved in the ratings, was measured by using Consistency Ratio (CR), indicating the probability that the matrix ratings were randomly generated. The Random Indices for matrices are listed in Table 3. The rule of thumb is that a CR less than or equal to 0.1 indicates an acceptable reciprocal matrix, while a ratio over 0.1 indicates that the matrix should be revised. Revising the matrix entails finding inconsistent judgments regarding the importance of criteria, and revising these judgments by re-comparing the pairs of criteria which are judged inconsistently.

Using the above method, the weight of the following criteria can be calculated:

Calculating Consistency Ratio (CR):

$$CR = CI/RI$$

Where:

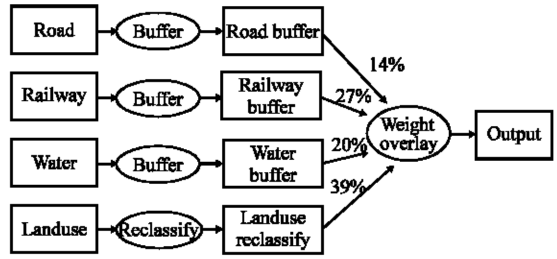

Fig. 2: Model builder

$$CI = \lambda_{max}\text{-}n/n\text{-}1$$

RI = Random consistency index
n = No. of criteria
λ_{max} = The priority vector multiplied by each column total
λ_{max} = 4.13526786
CI = 0.04508929
CR = 0.05009921

The significant findings from the study showed the Consistency Ratio (CR) value of 0.0500992, which fell much below the threshold value of 0.1 and it indicated a high level of consistency, as shown below. Hence, the weights can be accepted.

Map calculator: The data was converted to raster format, then the linear weightage combination using the map calculator and the final weights were used to provide the final results.

Model builder: A model was created for retrieving significant results in order to summarize all the important steps that were carried out in designing the model builder, as shown in Fig. 2.

Classification map: Finally, the classification map, which shows the potential investment in agricultural field, was produced. This map will help the investors to choose between the alternatives and reduce the doubts around them.

Sensitivity analysis: Subsequent to obtaining ranking of alternatives, the sensitivity analysis was performed to determine the robustness. This was to identify the effects of changing the inputs (i.e., weight and criterion scores).

Trade-off method: This method was based on the identification of goal in the criterion space by examining the trade-offs among the criteria. In addition, it also helped to determine the consistency of the available solutions of the criteria.

Case study: In this study, the agricultural investment opportunities in Sinnar were taken as the case study.

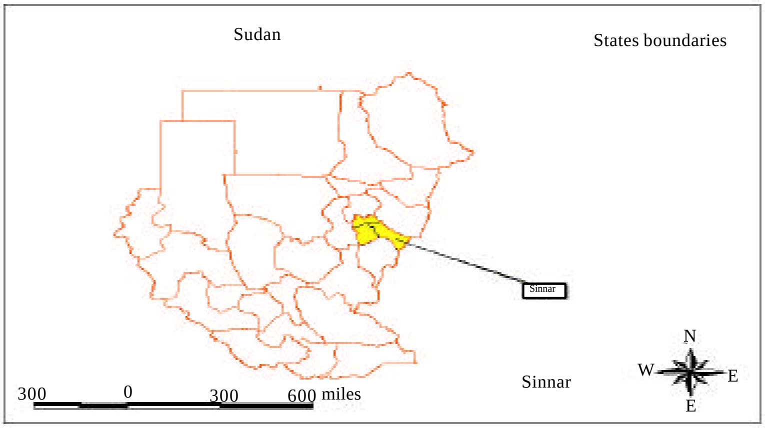

Fig. 3: Sinnar-location of the study area

Sinnar extends over most of the Eastern part of the present Sudan, forming a triangular-shaped territory between the White and Blue Niles. Figure 3 shows the location of the study area. The soil, mainly alluvial, is very fertile, and wherever cultivated, yields abundant crops.

RESULTS AND DISCUSSION

The AHP method was used to evaluate the criteria. The first result depended on the four types of spatial criteria (i.e., road, landuse, railway and water recourses). The results of analysis indicated that nearly 37% of the study area presented with the darkest area, as shown in Fig. 4 was the most suitable place for investment. However, the suitability for investment decreased as the areas became lighter, giving the results 32, 23 and 8%, respectively. The evaluation results concluded that the closer the agricultural project was to a major road, railway and water sources, the greater was its investment potential. Areas which were less or not suitable for agricultural projects (such as bare rocks and shifting sands), conversely, had the lowest potential for investment. The sensitivity analysis indicated that the change did not significantly affect the outputs, thus ranking was considered to be robust. The trade-off method results (Fig. 5) indicated the best alternative, which had the highest stability among all criteria.

The results presented were in agreement with the earlier studies conducted using the multi-criteria analysis. Multi Criteria Evaluation (MCE) method was used to analyze and find the flood vulnerable areas in the west of Black Sea of Northern Turkey (Yalcin, 2002). In this study, GIS was integrated with MCE, whereby seven spatial criteria were used. Each criterion was presented and stored in layer by using Arc View 8.2, and the criterion values were generated. The criterion maps were converted into grids and the mathematical processes were applied to the criteria utilizing the Map Calculator. In addition, Ranking Method was used to rank every criterion under consideration in the order of the decision maker's preference and Pair-wise Comparison Method (PCM), which was designed as a user interface to calculate the weights from the input preferences using the Visual Basic Application (VBA) programme embedded in ArcGIS 9.1. At the end of the application, the composite maps were created using Boolean Approach, Ranking Method and Pair-wise Method. There were three different results produced from the methods used. Following this, the difference between the three methods was analyzed. In addition, this study also conducted the sensitivity analysis. The purpose was to examine how sensitive the choices were to the changes in criteria weights. This was useful in situations, such as where uncertainties existed in the definition of the importance of different factors.

Another study in Singapore presented a GIS-based multi-criteria analysis approach to assess the accessibility of housing development. It applied the multi-criteria analysis framework to incorporate the buyers' opinions into accessibility assessment with GIS in order to determine the overall attractiveness of an area for housing development from a demand-side perspective. In the past, the accessibility analysis for housing development focused on the supply-side perspective. Hence, the approach proposed here will allow the planners and housing developers to examine the accessibility requirements from the demand-side perspective, so that demand and supply issues can be better managed (Zhu *et al*., 2005).

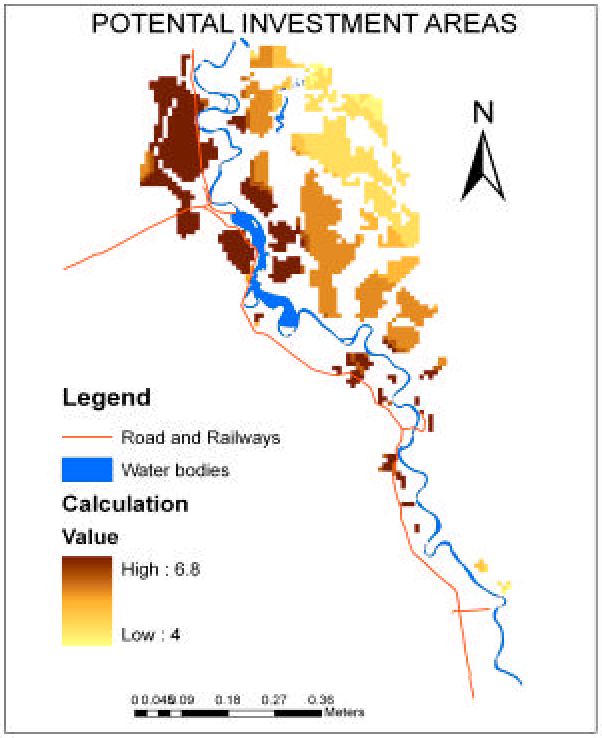

Fig. 4: Potential projects with road and water resources

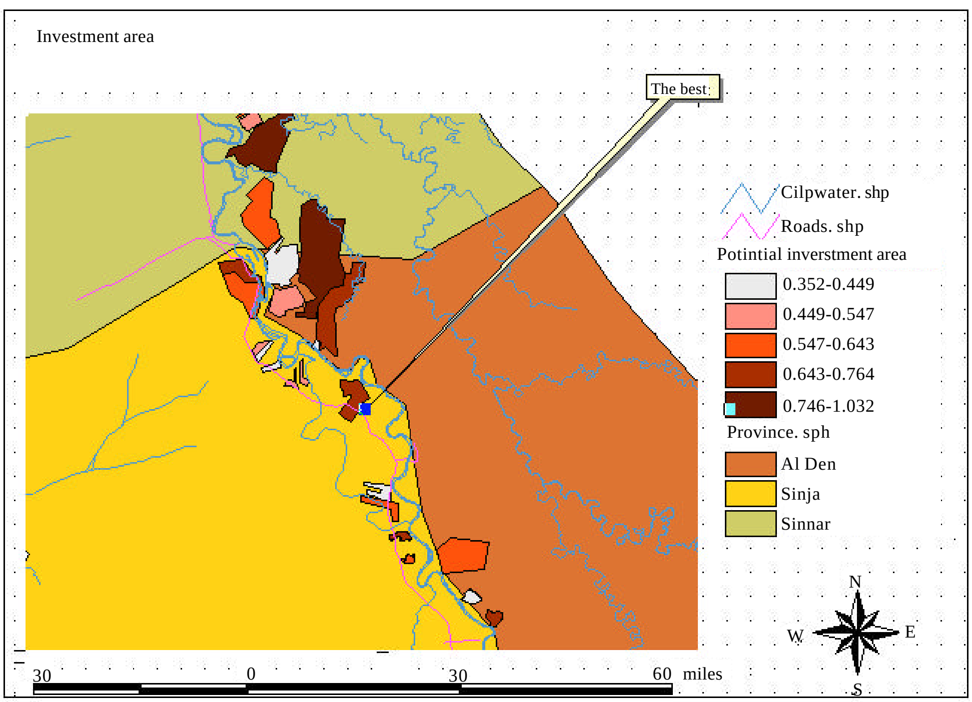

Fig. 5: Trade-off evaluation results

Lin *et al.* (1997) presented GIS-based multi-criteria evaluation for investment environment to provide the investors and local government decision makers with more specific information on investment location. Thus, the aim of this study was to explain how to develop an analysis environment to support various investment researchers and investors. Furthermore, Antonie *et al.* (1997) presented an example application on the integration of multi-criteria evaluation technique with GIS for sustainable land use in Kenya by maximizing revenues from crop and livestock production, food output, district self-reliance in agricultural production and minimizing environmental damages from erosion.

Other studies used the multi-criteria analysis to find the best location for the purpose of planning, such as the best places to build hospitals (Malczewski and Ogryczak, 1990; Malczewski, 1991), a solid waste transfer station (Gil and Kellerman, 1993), or more generally, any type of public facility (Joerin, 1995; Yeh and Hong, 1996).

Another study was also performed utilising the spatial multi-criteria analysis in order to rank and display the marketability of 32 pay pond businesses in West Virginia (Aurora, 2003).

CONCLUSIONS

This study deals with one important application of GIS technology, i.e. investment mapping, and provides a clear idea for the third world countries (who are dealing with a real problem pertaining to advance technology) in order to encourage the investment there. It integrates GIS and Multi Criteria Method to evaluate the different alternatives. Besides, this study also provides clear indicative areas for agricultural investment. The potential areas of agricultural investment in the study area were evaluated into four classes. The subjective numbers in the weights and values of the criteria can be changed according to the study area characteristics and experts' opinions.

From this study, several conclusions were made. When performing the sensitivity analysis on all the criteria, it revealed that the accuracy in estimating weights needed to be examined carefully. In addition, the sensitivity analysis helped to see the roles of attribute and weight, while the trade-off method assisted in determining the consistency of the available solutions of the criteria that could lead to the best solution. The classification map of agricultural investment projects could be produced by using GIS and multi-criteria techniques. Finally, this map could give planners and investors the tool for assessing and minimizing investment risks.

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