**Crop-land Suitability Analysis for Major crops in Koga irrigation scheme: A Multi Criteria Decision Making Approach using GIS and Remote Sensing. Upper Blue Nile Basin, Ethiopia**

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**Abstract**

Land suitability analysis is a prerequisite in achieving optimum utilization of the available land resources. Lack of knowledge on best combination of factors that suit production of crops has contributed to the low production. The aim of this study was to develop a suitability map for maize, wheat and onion crops based on physical, chemical and climatic factors of production using a Multi-Criteria Evaluation (MCE) & GIS approach. The study was carried out in Koga irrigation project in Ethiopia. Biophysical and chemical variables of soil, climate and topography were considered for suitability analysis. All data were stored in ArcGIS 10.1 environment and the factor maps were generated. For MCE, Pair wise Comparison Matrix was applied and the suitable areas for maize, wheat and onion crops were g identified. Currently the project area is dominantly covered by **wheat**. However the crop-land evaluation results of this study showed that, **92.5**% of total area is moderately suitable and 7.5% is marginally suitable for onion. However, of this irrigated farm land 24% and 14% of the total area is moderately suitable for wheat and maize respectively and the remaining 76% and 86% of the total is marginally suitable for wheat and maize. The result showed that the Koga irrigation crop land is moderately suitable for onion production than the current dominantly (100%) covered by wheat. This research provided information at local level that could be used by farmers to select cropping patterns and suitability.

**Keywords**: Upper Blue Nile Basin, Multi-criteria, GIS, Land evaluation, Land suitability analysis.

**Introduction**

Ethiopia, situated in the Horn of Africa, has a population of close to 90 million and a surface area of 1.2 million square kilometers, of which 65% is suitable for arable farming. Agriculture is the main stay of the country’s economy, contributing about 47.7% of the country's GDP and employing more than 85% of the working population (World Bank, 2005). The production system is dominated by smallholder farming under rain fed conditions. Agriculture is traditional and it is characterized by subsistence mixed farming with crop cultivation and livestock husbandry practiced on most farms. Agriculture is highly dependent on rainfall, and hence the onset, duration, amount and distribution of the rainfall determines the performance of the agriculture sectors in particular and the economy of the country in general. More than 95% of the country’s agricultural output is generated by subsistence farmers who, on average, own less than 1 ha of cultivated land with poor fertility as a result of continuous cropping and low input application.

Though agriculture is the dominant sector, most of Ethiopia’s cultivated land is under rain fed agriculture. Due to lack of water storage and large spatial and temporal variations in rainfall, there is no enough water for most farmers to produce more than one crop per year and hence there are frequent crop failures due to dry spells and droughts which have resulted in a chronic food shortage currently facing the country. Since the mid-1980s, the Ethiopian government has responded to drought and famine through promoting and construction of irrigation infrastructure aimed at increasing agricultural production. These are traditional, small, medium and large-scale irrigation schemes performing at different levels. Irrigation development has positive socio-economic and some negative environmental impacts. Formally accounted overall irrigation development is estimated at some 5 – 6 percent of the developable potential of 3.7 million ha (Awulachew et al. 2007)

Thus, this study project is one of the large scale irrigation schemes developed in northern part of the country. To make the project productive and to boost crop yield we intended to know the most suitable crop to be adapted by the smallholder farmers.

Land suitability assessment in a Geographic Information System (GIS) environment is formulated as a multi-criteria decision making (MCDM) problem. Different MCDM approaches are developed to combine factors in a suitability analysis of land for potential land uses. These MCDM approaches are used to develop a generic suitability index. Approaches include both qualitative and quantitative techniques. Results from the MCDM analysis are then linked to a GIS for more detailed spatial analysis.

Optimizing crop production can be achieved through sustainable agriculture or farming. The concept of sustainable agriculture or farming involves producing quality products in an environmentally friendly, socially acceptable and economically efficient way (Addeo *et al,*.2001), ensuring optimum utilization of the available natural resource for efficient agricultural production. In order to comply with these principles of sustainable agriculture, one has to grow the crops where they suit best and for which first and the foremost requirement is to carry out land suitability analysis (Nisar Ahamed *et al,*.2000). Suitability is a function of crop requirements and land characteristics (Mustafa et al.2011).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). Land suitability analysis has to be carried out in such a way that local needs and conditions are reflected well in the final decisions (Prakash 2003).

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. 2007). The objective of using MCE models is to find solutions to decision-making problems characterized by multiple alternatives, which can be evaluated by means of decision criteria (Jankowski et al. 2001).

In this study, we applied Analytical Hierarchy Process (AHP) in integrating MCE with GIS. The specific objectives of this research were to develop a suitability map for irrigated maize, wheat and onion based on physical and climatic factors of production.

**Materials and methods**

**Study area**

The study was conducted at Koga irrigation dam, near Bahir Dar, Ethiopia (110 10’N, 370 02’E). The impoundment is an instream system formed by the damming of Koga River, a second order stream flowing to Lake Tana. The Koga River that drains the 250km2 watershed is a tributary of Gigel Abay River in the head waters of the Blue Nile basin which flow into Lake Tana.

The reservoir has a capacity to impound a total volume of 83.1MCM of water at full supply level by inundating 18. 56km2 to irrigate 7,000ha command area. The project will affect seven Keble’s with the catchment area of 232km2

The overall objective is increasing agricultural production through three harvests per year instead of one. The Koga project area covers an extent of 10,000 ha of which 7,000ha is Irrigation area affecting 5000 households.

The area is generally hot, with average temperatures ranging between 23.55 and 23.75°C. The predominant soils are vertisols. These soils are characterized by imperfectly drained clays and prone to cracking (Sombroek *et al,*.1982).

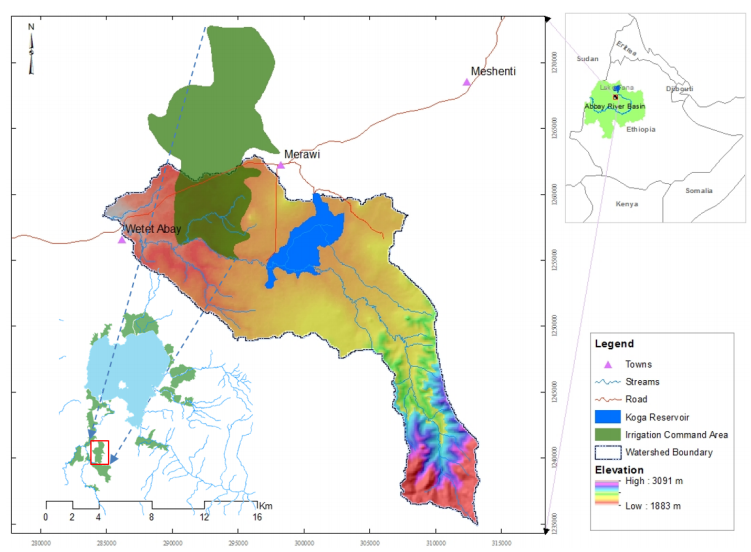


Figure1. The Koga watershed, reservoir and irrigation extent. The inset map shows the Koga irrigation scheme in the Tana sub basin.

**Data type and sources**

Point data of chemical properties (soil pH, OM, TN and available P) from composite samples were collected from the koga irrigation scheme. From 7000ha of command area we sampled 37 point samples for the lab analysis from representative sites of the area. Moreover, the topography (slope) and climatic (temperature) data were collected. The slope of the command area was prepared from DEM of the Tana basin using United States Geological Survey SRTM.The temperature data was collected from the nearby Merwi station.

**Parameters for suitability analysis**

Expert opinion of crop specialist was critical in this phase. Literature review of various references, interviews with local agronomists and researchers’ at Koga Irrigation and desk search of available data helped in identifying the critical requirements for suitable maize, wheat and onion growing areas. The factors identified were related to climate (temperature), soil (soil organic carbon, soil pH, soil phosphorus, Nitrogen) and topography (slope).

Selection and description of crop land utilization types

The crop LUTs were selected through discussion with the informant farmers and development agents. When crop selection was carried out, area coverage, importance of the crops in the livelihood of the concerned community, physical observations of soils and agro-climatic conditions of the study area, etc were considered (FAO, 1998). Accordingly, a total of 3 different crop LUTs including maize (Zea mays), Wheat and onion produced under irrigation system were identified.

Climatic information on temperature was derived from the Ethiopian meteorology agency /EMA/.Data on soil properties was taken from the irrigated farm land and Amhara design and supervision works enter prize soil laboratory/ADSWE/ was used to examine the physical and chemical properties of the soil samples. 41composite soil samples were taken for examining the selected soil properties. The four soil properties Ph, organic carbon, total nitrogen and phosphorus contents were obtained from the laboratory result. The topographic information /slope/ was derived from our elevation GPS points taken from the study area. All the maps were geo-referenced to the Universal Transverse Mercator (UTM) coordinate system.) Using GIS software package Arc GIS 10.1.

Elevation

Temperatures

Organic matter

Soil Ph

Climate data

Nitrogen

Phosphorus

Slope

Reclassify

Apply MCE and pair wise comparison

Integrating MCE with GIS

Suitability map

Soil data

Step1

Step 2

Step 3

Step 4

Step 5 comparison

Step 6

**Figure 1: Work flow chart for methodology.**

Assigning weight of factors and multi-criteria evaluation (MCE)

The purpose of weighting is to express the importance or preference of each factor relative to other factors having influences on crop yield and growth rate. Factors established in this phase are not unique, but they are the most relevant. Expert opinion of crop specialization was very important in this phase. Local agronomists and researchers have identified the following variables as relevant to suitable maize, wheat and onion growing areas: soil Ph, soil organic matter, soil nitrogen, soil phosphorus, temperature, and slope as well as a relevant set of criterion. Suitability levels for each of the factors were defined; these levels were used as a base to construct the criteria maps (one for each factor).The suitability levels were: Highlysuitable-S1, Moderately suitable-S2, Marginally suitable-S3, Notsuitable-N based on the structure of FAO land suitability classification. According to the FAO guide line for irrigated crops and local expertise opinion, a specific suitability level per factor for each crop (irrigated) was defined.

The general procedure of MCE included several phases. First, the relevant criteria (factors and constraints; Eastmanetal. 1995) were established. Using the above mentioned factors/variables as criteria, a pair wise comparison matrix was constructed. Although a variety of techniques exist for the development of weight, one of the most promising technique is the Pair wise Comparison Matrix (PWCM) developed by Saaty T. (1980) in the context of a decision making process known as the Analytical Hierarchy Process (AHP) (Eastmanetal., 1995).The comparison concerns the relative importance of the two criteria involved in determining the suitability of the stated objective (Eastman et al., 1995).Ratings were provided on a nine-point continuous scale, which ranges from1 to 9. This method has been tested theoretically and empirically for a variety of decision making situations, including spatial decision making and has been incorporated into a GIS based decision making procedure (Malczewski,1999).In the procedure for MCE using weighted linear combination, it is necessary that the weights sum to 1.The MCE method used (weighted linear combination) requires that all factors must be standardized (Eastman,1999) or transformed into units that can subsequently be compared (Malczewski,1999).

Using pair wise comparison matrix, factor weights were calculated and 6 composite layers were constructed. Once the composite layers and their weights were obtained, the MCE procedure within Arc GIS10.1 was applied to produce the map of suitable areas. Finally, the suitability maps for the three crops (Figure 2) were identified by weighted overlay using spatial analyst tools in ArcGIS10.1.

**Result and discussions**

The point soil sample data for the soil chemical properties were analyzed by using Amhara design and supervision works enterprise (ADSWE) soil laboratory.

**Table:1 Soil chemical properties collected from the command area.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No | PH | Total nitrogen% | Av. P ppm | O/CARBON % | No | Ph | TN | AV.P ppm | o/carbon |
| 1 | 4.65 | 0.14 | 6.676 | 1.64 | 20 | 4.32 | 0.22 | 13.443 | 2.54 |
| 2 | 4.42 | 0.17 | 4.86 | 1.95 | 21 | 4.79 | 0.23 | 11.345 | 2.61 |
| 3 | 4.37 | 0.15 | 6.831 | 1.76 | 22 | 4.52 | 0.19 | 11.79 | 2.26 |
| 4 | 4.36 | 0.18 | 3.652 | 2.15 | 23 | 4.3 | 0.2 | 12.426 | 2.34 |
| 5 | 4.36 | 0.18 | 6.449 | 1.95 | 24 | 4.67 | 0.18 | 9.438 | 2.15 |
| 6 | 4.4 | 0.16 | 8.23 | 1.87 | 25 | 4.73 | 0.13 | 11.218 | 1.56 |
| 7 | 4.42 | 0.18 | 10.964 | 2.15 | 26 | 4.73 | 0.17 | 5.305 | 2.03 |
| 8 | 4.85 | 0.19 | 9.247 | 2.18 | 27 | 4.48 | 0.15 | 3.97 | 1.72 |
| 9 | 4.65 | 0.22 | 8.675 | 2.54 | 28 | 4.46 | 0.19 | 5.178 | 2.18 |
| 10 | 4.51 | 0.18 | 4.923 | 2.15 | 29 | 4.35 | 0.18 | 5.432 | 2.15 |
| 11 | 5 | 0.18 | 4.923 | 2.15 | 30 | 4.35 | 0.2 | 7.848 | 2.34 |
| 12 | 4.48 | 0.2 | 12.172 | 2.3 | 31 | 4.4 | 0.18 | 5.877 | 2.15 |
| 13 | 4.66 | 0.21 | 8.42 | 2.42 | 32 | 4.32 | 0.18 | 8.039 | 2.07 |
| 14 | 4.44 | 0.2 | 8.484 | 2.3 | 33 | 4.52 | 0.22 | 9.946 | 2.54 |
| 15 | 5.24 | 0.24 | 14.588 | 2.77 | 34 | 4.83 | 0.2 | 9.374 | 2.3 |
| 16 | 4.89 | 0.27 | 18.466 | 3.12 | 35 | 4.66 | 0.21 | 8.42 | 2.42 |
| 17 | 4.95 | 0.18 | 17.194 | 2.15 | 36 | 4.58 | 0.16 | 5.877 | 1.87 |
| 18 | 4.65 | 0.2 | 3.97 | 2.34 | 37 | 4.77 | 0.21 | 5.686 | 2.46 |
| 19 | 4.98 | 0.21 | 7.149 | 2.38 |  |  |  |  |  |

After the soil lab analysis land suitability evaluation, on basis of soil, climate and topographic conditions revealed that study irrigation farm land was classified into two land suitability classes as moderately suitable (S2), marginally suitable (S3) for the all selected three crops .Because of one or more limitation(s) of the land characteristics, none of the area in the study irrigation land falls in to highly suitable (S1) class for the selected crops (maize, wheat and onion).

The number of hectares available to each suitability class for each crop was as follows: moderately suitable (S2) 1018 ha, marginally suitable (S3) 5982 ha which represent 14.5% and 85% of land area for maize production, moderately suitable (S2) 1716ha**,** marginally suitable (S3) 5284 ha which represent 24.5% and 75.5% of land area for wheat production and , moderately suitable (S2) 6470 ha, marginally suitable (S3) 530 ha which represent 92.5% and 7.5% of land area for onion production. A study conducted by (Mekonen and Kebede 2011) indicated that no area is highly suitable for onion production.

The irrigation project area is moderately suitable for onion production for which farmers are interested in. In this study we tried to understand farmers’ perception against the moderately suitable crop (onion) and they explained their crop preference based on of the water availability and the crop demand. As per their explanation onion is water demanding crop. Though the study showed that 6470ha (92.5%) of the command area is moderately suitable for onion production farmers are producing wheat on more than 95% of their irrigable land with few coverage of maize in 20015. On the other hand the most important concern raised by farmers not to produce onion was the frequent occurrence of diseases. They were explaining this diseases the biggest challenge which is not yet solved by even if they reported repeatedly to the local and regional government.

The suitability map for wheat, onion and maize crops, identified by weighted overlay using spatial analyst tools in Arc GIS 10.1, for each crop in Figure2 reveals that the project area is neither highly suitable nor not suitable for all crops.

**Identification of crop suitable area**

Multi criteria evaluation (MCE) was adapted in GIS environment by using weighted overlay in the spatial analyst tool. To determine the relative weight of each factor pair wise comparison technique was employed and each factor was compared to one another in head-to head fashion

Pair wise comparison matrix was arranged by comparing factors one to one based on pair wise comparison scale which is broken down from 1 to 9. The highest value indicates its practical important and the reciprocal kept in the transpose position indicating least important (Table 2). For example in Table 1 Nitrogen (on the left) is much more relevant compared to topography (on the top), then a value of 7 were assigned at the meeting point of the two. on the other hand, topography (on the left) of Table 2 is least essential than topography (on the top) therefore the reciprocal was assigned (i.e., 1/7). Among the major factors, topography was considered as the least important factor. The eigenvector was calculated for each factor (rows). According to Podvezko (2009), eigenvector is defined as the nth root of product of rows. The weights of factors were computed after normalizing the Eigen vector by its cumulative and multiplied by 100%. The reliabilities of weights were checked by computing the consistency of comparison matrix which was found consistent. The percent value of each factor was divided into four using equal interval method to assign value for each suitability classes (S1, S2, S3, S4).

Nitrogen is the most limiting nutrient in plant growth. It is constituent of chlorophyll, plant proteins, and nucleic acids. Phosphorus is the second most limiting nutrient next to nitrogen. It is essential component of Adenosine tri phosphate (ATP) which is the energy currency of the living cell; deoxyribonucleic acid (DNA) which is the seat of genetic inheritance; ribonucleic acid (RNA) which directs protein synthesis.

Table: 2 pair wise comparison matrix

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Factors** | Nitrogen | phosphorus | O-carbon | Ph | Temperature | Topography | weight % |
| Nitrogen | 1 | 2 | 3 | 3 | 3 | 7 | 43 |
| phosphorus | 1/2 | 1 | 2 | 4 | 3 | 7 | 29 |
| O-Carbon | 1/3 | 1/2 | 1 | 3 | 2 | 5 | 15 |
| Ph | 1/5 | 1/4 | 1/3 | 1 | 2 | 6 | 7 |
| Temperature | 1/4 | 1/3 | 1/2 | 1/2 | 1 | 3 | 4 |
| Topography | 1/7 | 1/7 | 1/5 | 1/6 | 1/3 | 1 | 2 |

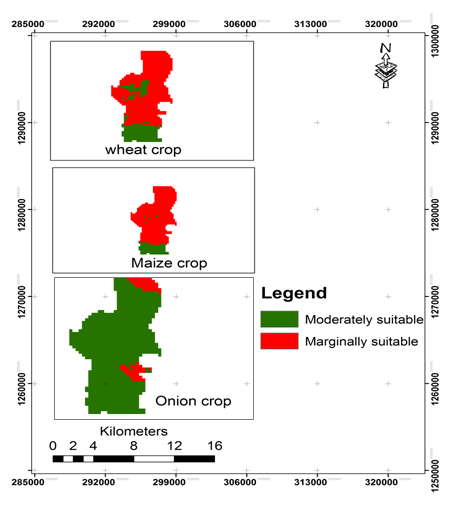


Figure2: Suitability map of wheat, Maize and Onion of Koga irrigation project

**Conclusions and recommendations**

In this study, we applied spatial analysis techniques to identify suitable areas for three crops maize, wheat and onion. The results obtained from this study indicate that the use of GIS and application of Multi-Criteria Evaluation using AHP could provide a superior database and guide map for decision makers considering crop substitution in order to achieve better agricultural production. This approach has been used in some studies in other countries. However, in Ethiopia this approach is a new and original application in agriculture, because it has not been used to identify suitable areas for major crops. This investigation is a biophysical evaluation that provides information at a local level that could be used by farmers to select their cropping pattern. Additionally, the results of this study are useful for other investigators who could use these results for diverse studies. For further study, we recommend to consider more number of factors like soil, climate, irrigation facilities and socio-economic factors which influence the sustainable use of the irrigation land.

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