

Geospatial information system land evaluation analysis for rainfed farming using multi-criteria decision analysis approach

Basuti Bolo¹, Dimane Mpoeleng², Irina Zlotnikova³

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ABSTRACT

This paper aims to develop a geospatial information system based land evaluation method for rainfed farming. To produce geospatial information of potential areas for sorghum using Multi-Criteria Decision Analysis (MCDA) approach. The land suitability is based on the biophysical and soil factors. The analysis aimed at the production of geospatial information displayed in maps and a graph showing potential areas that are suitable for rainfed farming. A fuzzy modeling decision analysis tool integrated with map algebra expression ADD (+) Geographical Information System (GIS) analysis operation was used to combine the information from several criteria to form a single suitability map. The results showed the land parcels that are suitable, marginal suitable and non-suitable for sorghum. The suitability map was overlaid with the existing land use to identify areas that are plowed for sorghum that are on suitable areas.

1. Introduction

In this study, the focus was on the development of geospatial information system land evaluation analysis for sorghum crops. The study produced geospatial information of potential areas in maps that are suitable for sorghum crops under rainfed farming conditions using the Geographical Information System (GIS) tools and Multi-Criteria Decision Analysis (MCDA) approach. A wide range of geospatial information on maps is needed for planning, management, and operational decision making. Geospatial information is one of the important kinds of information that can be used for land suitability analysis and land use planning. This study focused on the land suitability of sorghum under rainfed farming in Botswana. The research investigated both areas of cultivated and uncultivated areas based on the current suitability which is the suitability based on the present climatic condition.

Geographical Information System (GIS) is a computer-based system of storage and manipulation of data which is organized by area or location (FAO 1996); (Prakash 2003). Research by (Leingsakul, Mekpaiboonwatana, Pramojane, Bronsveld & Huizing 1993) had shown that the integration of GIS and Remote Sensing technology could locate land for a new location to plant crops (Prakash 2003). GIS has the power to integrate a large number of complex data in maps, graphs, charts or in statistical format, to make decisions. In the multi-criteria evaluation of many factors, GIS has the power to analyze and produce results for decision making.

2. General Background

Research has been carried out on spatial information using GIS and Multi-Criteria Decision Analysis, and it has been used to assess the suitability of different crops for different areas and

¹ Basuti Bolo

Botswana International University of Science and Technology
Basuti.bolo@studentmail.biust.ac.bw

² Dimane Mpoeleng

Botswana International University of Science and Technology
mpoelengd@biust.ac.bw

³ Irina Zlotnikova

Botswana International University of Science and Technology
zlotnikovai@biust.ac.bw

agricultural land resources. GIS, Remote Sensing, and Multi-Criteria Evaluation were integrated to provide decision of evaluation suitability of rice (Perveen, Nagasawa, Uddin & Delowar 2003). The biophysical and topography of the soils were considered for suitability analysis. Multi-Criteria Evaluation: Analytic Hierarchy Process (MCE: AHP) Analysis was used for decision making. The research provided suitability areas for rice.

In the western part of the Nile Delta in Egypt research was done to decide on the best agricultural use of uncultivated land (El-Kawy, Ismail, Rod & Sulumana 2010). The developed as a result Agricultural Land Evaluation System for Arid and Semi-arid Regions (ALESarid) used a GIS-based Multi-Criteria Decision Analysis (MCDA) to assess the agricultural land capability and suitability.

In 2012 a GIS Multi-Criteria Evaluation was used in modeling future land use for resources planning and management using physical parameters to find the best spatial allocation of land for future agriculture and forest development in the lower Aswa basin of Uganda (Nyeko 2012). GIS Multi-Criteria Evaluation Analysis based on land characteristics physical parameters were used. The results showed high potential areas to be used. Similarly, the land suitability evaluation for sorghum based on Boolean and fuzzy Multi-Criteria Decision Analysis method was also carried out in Lybia (Elaalem 2012). The study was based only on four biophysical criteria.

In Kenya, (Kihoro, Bosco & Murage 2013) carried research on suitability analysis for rice growing sites using Multi-Criteria Evaluation and GIS approach. The research was based on physical soil characteristics, climatic and topography consisting of six criteria. Similarly to previous research, in Lybia, (Abushnafa, Spenceb & Rotherhama 2013) developed a Land Evaluation Model using a Geographic Information System and Multi-Criteria Analysis. The soil characteristics factors were used as input factors.

In Ethiopia, GIS-based Multi-Criteria Decision Analysis was applied and focused on land suitability analysis to identify permissible areas suitable for rice crop production in west-central highlands of Amhara Region (Ayehu & Besufekad 2015). This research was based on topography, physical and chemical properties of soil and climate.

This research used the Multi-Criteria Decision Analysis (MCDA) approach, Remote Sensing and Global Positioning systems (GPS) geospatial information tools and systems to improve the methods that were used in past studies. Multi-Criteria Decision Analysis (MCDA) approach was used to evaluate the factors. This research produced digital geospatial information and databases for potential agricultural crop production under rainfed farming that could be used by the farmers.

3. General and Specific Objectives

The general objective of this study was to develop a geospatial information system based land evaluation analysis for crops under rainfed agriculture using Multi-Criteria Decision Analysis approach.

The specific objectives of the study were as follows;

1. To identify advanced geospatial information system tools that can be used in the development of geospatial information system land evaluation analysis.
2. To develop methods of assessment and evaluation of land that is suitable for agricultural crop using Multi-Criteria Decision Analysis.
3. To collect spatial data and information on soil and land use.
4. To analyze the data and transform it into geospatial information using GIS tools.
5. To produce agricultural land suitability geospatial information and databases of the study area.

4. Methodology

Multi-Criteria Evaluation Decision Analysis was used for the suitability decision. Global Positioning System (GPS) was used for positioning locations and picking the reference points. Remote sensing

ortho-photographs were used mapping the land use of the study area. The research used land and crop suitability indicators designed for the specific sorghum crop. The methodology is led by specific objectives (see Section 3).

4.1 Advanced Geospatial Information System Tools for Land Evaluation Analysis

This part describes new technologies and tools that can be used to develop geospatial information system land evaluation and analysis methods for land suitability for crops under rainfed farming. The tools that were used to develop geospatial information system methods for land evaluation and analysis were identified as follows;

- Remote sensing for providing land covers images
- Global Positioning System (GPS) for positioning the locations
- Multi-Criteria Decision Analysis for land assessment
- Geographical Information system for analysis, producing geospatial information, geospatial databases, and for producing maps for visualization and decision making.

4.2 Methods for Development of Methods for Assessment and Evaluation of Land Suitability for Agricultural Crops

The land is assessed and evaluated to match land use with land (FAO 1996). In this study agricultural land was assessed based on the requirements of crops under rainfed farming. The procedures were as follows; Firstly, it was the selection of study area to be evaluated and the agricultural land use that area, secondly, it was the description and identification of the requirements of the selected crop, and thirdly, it was the description of land units and their quality within the areas selected.

In this study agricultural land was evaluated for easy agro-climatological and ecologically zoning to match the land with its use to increase production as well as the management and conservation of agricultural land. The evaluation process was the next to be operated after the land assessment. Multi-Criteria Decision Making (MCDM) was used in the evaluation.

4.2.1 Multi-Criteria Decision Making (MCDM)

Land suitability is a multi-decision approach that involves the selection of major land use using many factors. All the factors (criteria) are not equally important and have different results. Multi-Criteria Evaluation (MCE) is primarily concerned with how to combine information from several criteria to form a single index of evaluation. It provides a collection of techniques and procedures for structuring decision problems, designing, evaluating and prioritizing alternative decisions. Multi-Criteria Decision Making (MCDM) is defined as a process that combines and transforms some geographic data inputs into a resultant decision output (Ayehu & Besufekad 2015). It involves input data, decision makers and the manipulation of data and information using specified decision rules. Evaluation is divided into steps. Step one is the decision on input datasets/criteria, step two is the creation of new data from the input, the third step is a reclassification of suitability, and the fourth step is to apply multi-criteria decision analysis method.

This study used the MCDM based on the spatial geographic data of land characteristics with large numbers of factors identified and considered to come out with the final suitability map of sorghum, five factors were used namely; soil Potential Hydrogen (PH), soil depth, slope, salinity and water holding capacity. These were used based on the crop requirements to match land with its use to increase sorghum production. Map algebra expression ADD (+), a GIS analysis operation was used. This operation was used to integrate, calculate and analyze the raster maps to produce a single suitability map using fuzzy overlay analysis.

The land evaluators and experts can define the ideal requirements of land use but are often unsure about the boundaries between classes; this has given the fuzzy operation a chance. Fuzzy operation method is the decision-making method to address the imprecision and uncertainty. The fuzzy logic

operation makes it possible to improve analysis and simplification of the soil characteristics that are characterized by vague conception (Prakash 2003).

4.3 Methods for Collection of Spatial Data and Information on Soil and Land use

The data was collected from different data types sources. The spatial and non-spatial data was collected in different formats such as digital data, analog and fieldwork data, and reports. The secondary land digital data on soil characteristics in the form of Geographical Information System files were used. The aerial ortho-photographs of the 1m resolution was digitized to produce existing land use maps. The data were combined with the data collected from the field. A survey was carried out to collect, survey, assess, ground truthing and map the environment. The data was collected using a GPS device taking the x and y coordinates of locations that were used to reference the data and transform it into real-world geospatial information, including the attributes data for the study area.

4.4 Methods for Data Analysis and Transformation

This study used a Computer Assisted Overlay mapping techniques integrated with Multi-Criteria Decision Analysis (MCDA) methods. It allowed the evaluation criteria map layers to be combined in order to determine the composite map layer. The map overlay approach was used in the form of Map algebra and raster calculator operation. Different maps were overlaid for suitability. GIS Statistical and mathematical operations such as Map algebra operations were used for analysis. The data was analyzed using GIS and other supporting software.

In this study, GIS Computer Aided Overlay (CAO) analysis was used for analyzing the data for land suitability using soil physiological characteristics parameters of sorghum. Overlay analysis is a tool for applying weights to many inputs that can then be combined into a single output map (Abushnafa, Spenceb & Rotherhama 2013).

4.5 Methods for Producing Agricultural Land Suitability Geospatial Information and Databases

The process of land suitability classification is the evaluation and grouping of specific areas of land in terms of their suitability for a defined use (Prakash 2003). There are four categories of generalization of the land suitability classes. These are orders, classes, sub-classes, and units. This study used two orders being suitable (S) and non-suitable (N). The suitable order S was a combination of S1 (highly suitable), S2 (moderately suitable) and S3 (marginally suitable). The order categorized as non-suitable was a combination of N1 (currently unsuitable) and N2 (permanently unsuitable land). This was done because, from the economic point of view, growing crops on very marginally suitable lands is very risky. Even if farmers managed to grow these crops, the production would be very low and expensive. There are lands in Botswana where currently are not in use where the crops would be much easier to grow. It differs Botswana from European countries where ministries of agriculture and individual farmers could consider using very marginally suitable (S4) and even currently unsuitable lands (N1). The reason for that is that in Europe there might exist agricultural technologies not available currently in Botswana, and governments could afford investments into improving land quality and melioration for other use such as fruit tree production. European countries are small and densely populated (Olesen & Bindi 2008), so almost all agricultural land is in use.

Suitable classes on the maps were coded as (1), marginally suitable (2), non-suitable areas (3) while areas without any data were coded (4). The maps were then integrated together to produce a single map showing agricultural potential areas for a sorghum crop.

5. Results

The major problem today is to produce and provide accurate agricultural information to increase food production on scarce agricultural land and on difficult, unreliable climate change conditions. Global Positioning System (GPS) and Geographical Information System (GIS) are two examples of advanced Information and Communications Technologies able to increase production through land evaluation.

This research used GIS approach to identify areas suitable for sorghum crop based on the following five parameters: (1) slope, (2) soil depth, (3) soil PH, (4) salinity and (5) water holding capacity. The outputs were transformed into different maps of suitability for all factors used. The potential suitable areas for sorghum crops were based on five factors; (1) soil depth (50 cm - 200 cm), (2) slope (0 - 8%), (3) available water holding capacity (70 mm/m - >161 mm/m), (4) soil PH (5.2 - 8.5) and (5) salinity (0 - 10%). These factors were integrated using a Geographical Information System (GIS) Multi-Criteria Analysis to produce a single suitability map. A GIS analyst tool, Raster Calculator was used to overlying all the five factors together and produced unclassified maps with nine classes that were reclassified into two orders classified into four classes (coded 1,2,3,4 respectively) including Class 4 with no data.

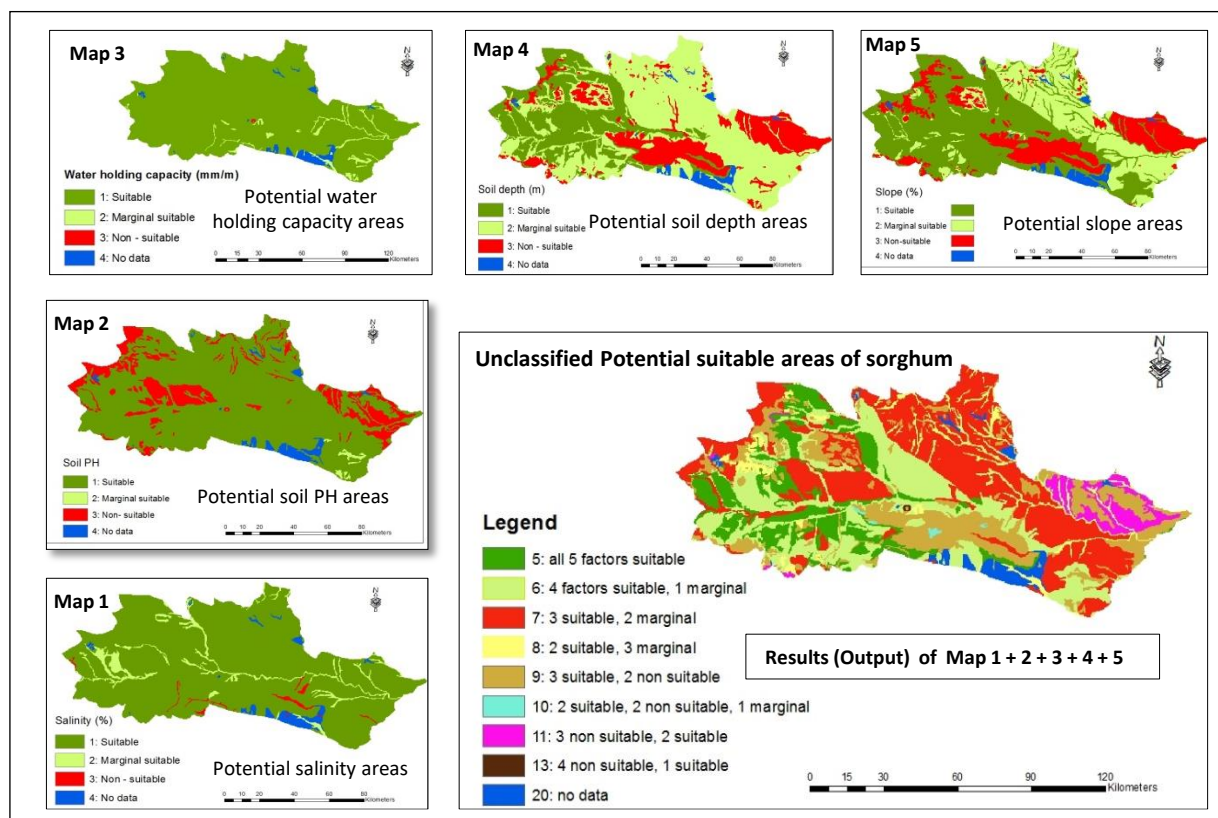


Figure 1: Unclassified potential areas of sorghum maps

The maps on Figure 1 show the results of unclassified land suitable areas and non-suitable areas of sorghum.

The classes displayed on the maps are as follows;

- 1) Class 5 (dark green): all five suitable factors;
- 2) Class 6 (light green): four suitable factors and one marginally suitable factor;
- 3) Class 7 (red): three suitable factors and two marginally suitable factors;
- 4) Class 8 (yellow): two suitable factors and three marginally suitable factors;
- 5) Class 9 (light brown): three suitable factors and two non-suitable factors;
- 6) Class 10 (light grey): two suitable factors, two non-suitable factors and one marginally suitable factor;
- 7) Class 11 (purple): three non-suitable factors, two suitable factors;
- 8) Class 13 (brown): four non-suitable factors and one suitable factor;
- 9) Class 20 (blue): no data.

The results of unclassified calculated raster layers of all the five factors used to produce a single layer of suitability map are summarized in Table 1.

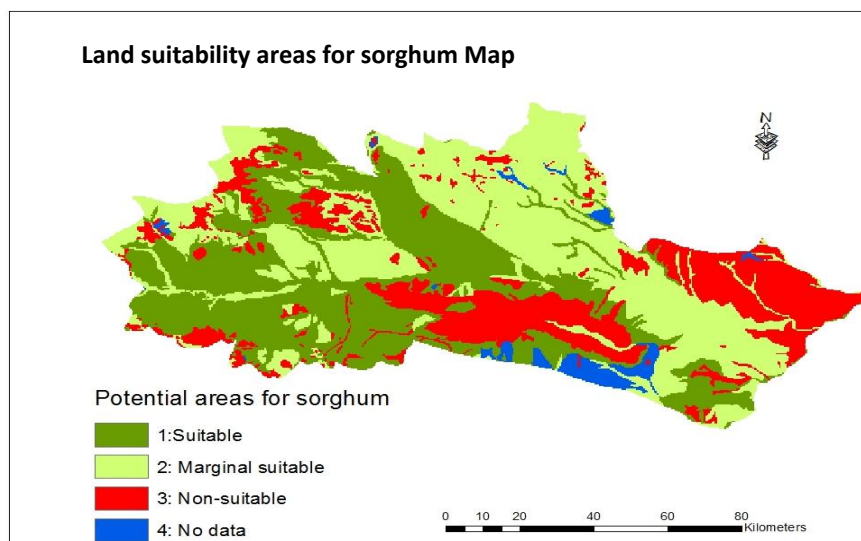
Table 1. Unclassified potentially suitable for sorghum areas.

Class	Slope	Soil PH	Salinity (ESP)	Soil Depth	Water Holding Capacity	Summary of Class	Reclassification
5	S	S	S	S	S	All 5 (S)	Suitable
6	S	S	S	MG	S	4S + 1MG	Suitable
7	MG	S	S	MG	S	3S + 2MG	Marginal
8	S	S	MG	MG	MG	2S + 3MG	Marginal
9	NS	S	S	NS	MG	3S + 2NS	Non-suitable
10	NS	S	S	NS	MG	2S + 2N + 1MG	Non-suitable
11	NS	NS	S	NS	S	3NS + 1S	Non-suitable
13	NS	NS	S	NS	NS	4NS + 1S	Non-suitable
20	ND	ND	ND	ND	ND	All ND	No data
<u>S = suitable</u>		<u>MG = Marginal suitable</u>		<u>NS = Non-suitable</u>		<u>ND = No data</u>	

Classes 5 and 6 were reclassified as suitable, Classes 7 and 8 as marginally suitable, Classes 9, 10, 11, and 13 as non-suitable and Class 20 as a class with no data. The reclassification is representing the final map of potential suitability map classified into four classes (“suitable”, “marginally suitable”, “non-suitable” and “no data”).

The land suitability analysis results were overlaid with the existing areas of plowed sorghum to match and observe similarities. The comparison of existing land use and suitability indicated the land suitable for sorghum but not used for its production.

The map in Figure 2 shows the potential suitability of sorghum after the reclassification of unclassified result map generated after the integration of all five factors. The results showed that suitable areas were distributed over the study area. The marginally suitable areas were found on the lower areas and non-suitable on hilly or high areas referring to the slope map (Figure 1).

**Figure 2:** Land suitability for sorghum map

The potential land suitability map for the sorghum crop was overlaid with the maps of the existing arable lands to compare the differences and similarities of the distribution of the existing arable land with the distribution of suitability. The land suitability and arable lands maps were also overlaid to identify potentially suitable areas which were not in use. The maps were overlaid to identify the arable lands that were on the suitable, marginally suitable and non-suitable areas. The map in Figure 3 shows the distribution of the existing areas plowed for sorghum in all classes.

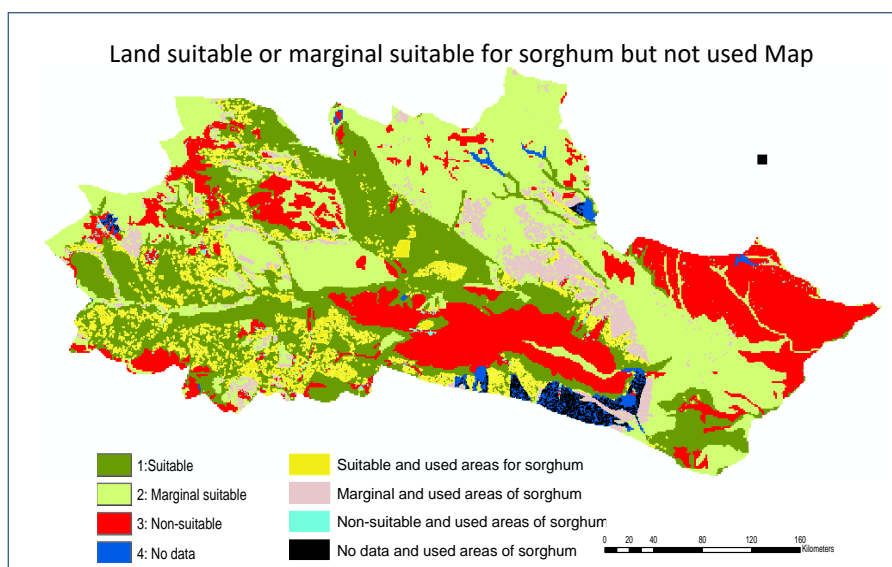


Figure 3: Overlaid maps of land suitable for sorghum and existing arable lands where sorghum was grown.

The results showed that there was no correlation between the existing sorghum areas and the land suitability areas as some areas of plowed sorghum were marginally suitable, non-suitable or those with no data.

According to Figure 4, the existing areas of sorghum located on suitable land comprised 64 704 hectares (18%) of the total suitable land that was estimated to be 368 366 hectares. The sorghum plowed areas on marginal suitable comprised 42 530 hectares (11%) of the total area of the marginal land estimated to be (388 035 hectares).

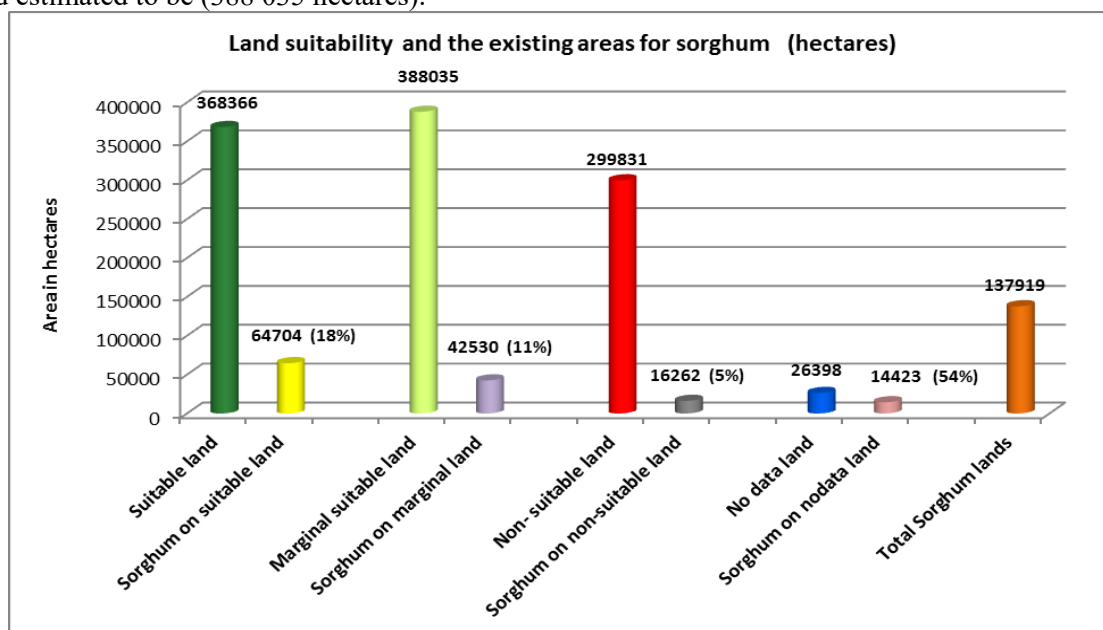


Figure 4: Land suitable for sorghum and existing arable lands

The sorghum plowed areas on non-suitable land comprised 16 262 hectares (5%) of the total non-suitable land (2 99 831 hectares). The sorghum plowed areas located on the land with no data comprised 14 423 (54%) of the total land with no data (26 398 hectares).

6. Discussion and Conclusion

This study achieved the objectives. The study improved the existing methods of land evaluation by developing a geospatial information system based land evaluation method. The existing methods that were improved are; methods for integration of complex dataset and information using GIS and GPS; methods for evaluation of land suitability Multi-Criteria Evaluation Analysis; and Spatial Multi-Criteria Decision Making Analysis methods integrated with fuzzy overlay. The method was improved using advanced GIS, MCEA, GPS, and Remote Sensing tools. These methods were used to process and transform data into land suitability information that was presented in maps of potential areas of sorghum.

The study proved the ability of GIS to integrate complex datasets and information using a variety of geographic technologies such as GPS to produce spatial information, spatial databases, and maps. The Multi-Criteria Evaluation Analysis methods based on geospatial information have the power to evaluate land suitability for rainfed farming. Spatial Multi-Criteria Decision Making Analysis methods, integrated with fuzzy overlay, have been proven to be the best methods that can be used to evaluate land use suitability.

This study concentrated only on sorghum, but the suitability of land for other crops, vegetables, and fruits could be evaluated using the same methods and techniques of GIS. The results of potentially suitable areas for sorghum showed that the suitable areas of rainfed farming (34%) could be easily doubled by improving the marginal land (36%). Thus there were substantial reserves for increasing the farming industry and reducing imports of food from other countries. Non-suitable lands are currently used for sorghum while suitable lands are not. This study was done for sorghum, but any other crop in other countries there might be a mismatch of land use, even in Europe.

This research helps to increase the area of crop production of sorghum as well as other crops in Botswana and other countries without waste resources on the non-suitable areas, or before plowing to improve the land. Even non-suitable lands can be improved. This helps reducing expenses, of waste resources on non-suitable lands. The land that is non-suitable can be converted for other suitability use. The marginally suitable and non-suitable lands can still be improved to be suitable for other crops in countries with a high population density. The spatial suitability information of the study area could improve the development of agro-climatological and ecological zoning. Land that is suitable for sorghum should be zoned for sorghum only same as other crops.

This research will act as a benchmark for future researchers and land use planners, monitors, and managers. Furthermore, the research can be used by other researchers as a reference to evaluate and identify the land quality for other land uses. Geospatial information system based land quality suitability analysis should be viewed as a process of converting geographic data into geospatial information that can be shared digital and online. The sharing of agricultural spatial information can be used by the farmers. Farmers need updated information about their farms for planning purposes. The spatial database created of the study area will contribute to the existing spatial information. It will help the decision makers to develop and implement policies, standards on digitized spatial data and information on land evaluation.

References

- Abushnafa FF, Spenceb KJ & Rotherhama ID 2013 “Developing a Land Evaluation Model for the Benghazi Region in Northeast Libya using a Geographic Information System and Multi-criteria Analysis,” ICESD 2013: January 19-20, Dubai, UAE.
- Ayehu GT & Besufekad SA 2015 “Land Suitability Analysis for Rice Production: A GIS Multi-Criteria Decision Approach”, *American Journal of Geographic Information System*, 2015, 4(3):95-104
DOI:10.5923/j.ajgis.20150403.02.

Elaalem M 2012 “Land Suitability Evaluation for Sorghum Based on Boolean and Fuzzy-Multi- Criteria Decision Analysis Methods,” *International Journal of Environmental Science and Development*, Vol. 3, No. 4, August 2012.

El-Kawy OR ABD, Ismail HA, Rod JK & Sulumana AS 2010 ”Developed GIS-based Land Evaluation Model for Agricultural Land Suitability Assessments in Arid and Semi-Arid Regions,” *Research Journal of Agriculture and Biological Sciences*, 6(5): 589-599, 2010.

FAO 1996 “Guidelines for land-use planning”. (FAO Development Series No. 1) ISBN 92-5-103282-3 1. Land use 2. Planning I. Title II. Series FAO code: 59 AGRIS: E11.

<https://www.mpl.ird.fr/crea/taller-colombia/FAO/AGLL/pdfdocs/guidelup.pdf>.

Kihoro J, Bosco NJ & Murage H 2013 “Suitability analysis for rice growing sites using multi-criteria evaluation and GIS approach in great Mwea region, Kenya,”. *SpringerPlus* 2013, 2:265. <https://doi.org/10.1186/2193-1801-2-265>

Malczewski J 2004 “GIS-based land-use suitability analysis: a critical overview”, *Progress in Planning* 62 (2004) 3–65. 2004.

Mustafa AA, M Singh M, Sahoo RN, Ahmed N, Khanna M, Sarangi A & Mishra AK 2011 “ Land Suitability Analysis for Different Crops: A Multi Criteria Decision Making Approach using Remote Sensing and GIS,” *Researcher*, 2011;3 (12).

Nyeko M 2012 “GIS and MCDA for land use resources planning”, Uganda, *Journal of Geographic Information system*, 2012, 4, 341 – 348. 2012. <https://doi.org/10.4236/jgis.2012.44039>

Olesen A & Bindi M 2002 ‘Consequences of climate change for European agricultural productivity, land use and policy’, *European Journal of Agronomy* 16 (2002) 239–262. [https://doi.org/10.1016/S1161-0301\(02\)00004-7](https://doi.org/10.1016/S1161-0301(02)00004-7)
http://www.ukm.my/ipi/wp-content/uploads/2013/07/70_2002_Consequences-of-climate-change-for-European-agricultural.pdf.

Perveen Mst F, Nagasawa R, Md. I. Uddin & Delowar HKM 2003 “Crop land suitability using MCE and GIS approach”, Japan.

<https://pdfs.semanticscholar.org/a1cf/ddc2bf49448871e9bcad5bd1a6c07306eb76.pdf>

Prakash TN 2003 “Land Suitability Analysis for Agricultural Crops : A Fuzzy Multicriteria Decision Making Approach,” pp. 1–68, 2003.