



## **GIS-Based Assessment of Land Suitability for Industrial Crops (Cotton, Sesame and Groundnut) in the Abyan Delta, Yemen**

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### **Authors' contributions**

*This work was carried out in collaboration between all authors. Author MHM designed the study, wrote the protocol and wrote the first draft of the manuscript. Author KBA reviewed the experimental design and all drafts of the manuscript. Authors AAM and NAO managed the analyses of the study. Author KC identified the plants and performed the statistical analysis. All authors read and approved the final manuscript.*

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### **ABSTRACT**

We investigated the potential and capability of GIS as a technique for integrating spatial and biophysical attribute data to produce land suitability maps of the main industrial irrigated cropland (cotton, groundnut, and sesame) cultivated in the Abyan, Yemen Delta, In order to improve decision-maker strategies. We collected 64 soil samples in a systematic, georeferenced soil survey. Spatial overlay of detailed soil site characteristics, physical site qualities, and crop specific requirements was performed to reveal areas suitable for crop production. Our results of the land suitability classification for cotton, sesame and groundnut indicated that the highly suitable class (S1) accounts 22.2%, 22.6% and 22.8%, while moderately suitable (S2) constitutes 36.7%, 37.2% and 37.4% and the marginally

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suitable (S3) are 13.1%, 13.1% and 12.5% respectively. Whereas, currently not suitable (N1) accounts 1.9%, 1.7% and 1.3% and the permanently not suitable constitutes 26.1%, 26.1% and 26.1% respectively. However, our results also reveal the total land suitability for the mentioned crops comprise 14862 ha (27.7%) is unsuitable (N1 & N2) and 38739 ha (72.3%) represent S1, S2 and S3 of the total land area. This study provides an approach to identify and classify land in relation to the suitability to support selected industrial cropland. It also provides insights for proper land use planning and appropriate management, which could help policy makers, planners, and decision-makers align development projects with the concurrent goal of improving long-term agricultural productivity. A GIS based approach for evaluating land is useful for sustainable agricultural planning.

*Keywords: Geographic Information System (GIS); land suitability evaluation; land characteristics; crop requirements; soil; climate; spatial and attribute data.*

## 1. INTRODUCTION

Land suitability evaluation as defined by Sys [1], Van Diepen [2] and Rossiter [3], is the process of making predictions of land performance over time based on specific types of uses. Land suitability evaluation is a pre-requisite for land use planning, especially for agricultural cropland [4]. Each plant species requires specific soil and climatic conditions for its optimal growth [1]. The land suitability is based on integration of land qualities and land characteristics [5]. Food and Agriculture Organisation (FAO) [6] are well known worldwide as the standard method for land suitability evaluation. In addition a number of reports provide methodologies on GIS applications for land evaluation [7,8]. The ability of GIS to record, store and retrieve location and elevation data from many soil observations has paved the way for studies on the spatial variation of soil properties within subjectively delineated landscape units [9]. This is a vast improvement over earlier soil surveys which lacked soil profile location information [10]. The ever increasing demands for increasing food grain production could be met through systematic soils survey, evaluating their potentials for wide range of land uses and formulating economically viable, socially acceptable and environmentally sound [11]. The traditional surveying methods are time consuming, labour intensive and expensive. With the advent of remote sensing, the datageneration became fast, cost effective and reliable [12]. Thus remotely sensed soil information can be integrated in a GIS to obtain different thematic information for use in land evaluation techniques. According to Burrough [9] soil survey applications were among the first uses of GIS. GIS is now a firmly established tool in modern soil survey analysis for map production, deriving suitability maps to meet users' requests for special purpose information and for visualizing environmental processes. Many problems

associated with soil data can be properly dealt with if the potentials of GIS are tapped into [13]. Despite the large amount of work published on GIS applications in the literature, little has been published in terms of digital soil mapping using GIS for crop land suitability analysis. Kalogirou [14] modeled a geographic information technology in conjunction with expert systems called LEIGIS software to implement a land suitability evaluation model. The LEIGES model is based on the FAO [6] and data which describes an agriculture area in terms of soil mechanics and physical environment.

In a study carried out by Ramakrishnan and Guruswamy [15], it was observed that if spatial soil information was available, GIS professionals could assess site suitability for developmental purposes, effective agricultural research, and advisory programs. Behrens and Scholten [16] also developed a digital soil map as a tool to generate spatial soil information which provided solutions for the growing demand for high resolution soil maps worldwide. Their paper summarized the present state of global soil survey, digital data availability, applied digital soil mapping. Similarly, Behrens et al. [17] developed digital soil mapping using artificial neural networks.

This study focused on the development of a methodology based on overlay of thematic maps to spatially predict soil units for evaluating agricultural land suitability in Abyan Delta, Yemen.

Insights gained from land evaluation are expected to enhance our understanding about potential improvements in agricultural productivity through proper planning [18]. Our land suitability evaluation for the main industrial crops (cotton, groundnut and sesame) grown in the Abyan Delta was conducted to investigate the

potential capability of GIS as a tool to integrate spatial and attribute data for producing land suitability maps. Cropland suitability was measured based on crop requirements and land characteristics. Accordingly, we created thematic maps such as Digital Elevation Model (DEM), slope, climate zones and soil characteristics maps (pH, electric conductivity, organic matter, cation exchange capacity, soil texture, calcium carbonate, available phosphorus, and total nitrogen) and other layers such as road distance, drainage density to determine which factors influence cropland suitability. Each thematic maps was produced in a digital format and stored in a geodatabase of land resources characterization of the study area and classified into 5 land suitability classes ranging from lowest to highest cropland suitability.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The Abyan Delta is located in an arid to sub-tropical zone in the southwest of the Abyan governorate in the coast of Aden Gulf, between latitudes 13°04' to 13°18' N, and longitudes 45°08' to 45°30' E. It has a total land area of 53,600 hectares (Fig. 1). It is considered as one of the most prime farmland areas in Yemen's southern coastal plains. All crops (cereals, vegetables and fruits) cultivated in this area are irrigated from spate water and tube wells. Climatically, the study area is located in agro-climatic zones 10 and 12 (Fig. 2), which the representative agro-meteorology station for these zones is Al-Kod at 20 m altitude [19]. Mean monthly temperatures range from 25°C in January and February to over 31.6°C in June. The average maximum temperature in summer season is around 35°C (June to September) and wide variation in rainfall from 200 to 700 mm / year depending on geographical location and time of year. Mean monthly evapotranspiration varies from 119.7 mm in December to 176.7 mm in May, while the total annual evapotranspiration is about 1,795 mm. Average monthly relative humidity varies between 69% and 73%. The mean monthly wind speed at 2 m above ground in the project area varies from 119 in November to 174 km/day in March. The normal length of the growing period (LGP) for the study area lasts 120-200 days between April and October with sometimes a relatively dry interval in June recorded across two decades of meteorological data.

### 2.2 Data and Methodology

Our study identified the kinds of data input into a GIS and how this data can be used to create useful interpretive maps for cropland suitability testing. The data needed in the current research included climatic, topographic, and edaphic spatial data. Data gathering included field surveys of soil site characteristics and laboratory analysis,

The semi-detailed soil survey was conducted to investigate soil across the study area, where numerous ground observations were carried out to map the soils, identify their main properties and distribution. In this stage, the survey used soil pits and minipits were normally dig down up to 70-100 cm depth. Auger observations were done to check the boundary of soil mapping units as well. Data sheets were used for recording the information based on FAO guidelines for soil description [20]. Actually 80 soil pits and minipits and about 30 auger observations were done during this work. The soil observations were made at regular intervals along east to west and south to north to investigate soils on the different land units. At each soil site, a GPS reading was used to pinpoint the locations (Fig. 3). A total number of 64 soil samples were collected and delivered to the laboratory of Renewable Natural Resources Research Center at Yemeni Agricultural Research and Extension Authority for physical and chemical analysis. The methods used for the analysis of water extracts of soil obtained at saturation based on FAO [21]. The samples were analyzed for Soil Reaction (pH), Organic carbon content (OC), Cation Exchange Capacity (CEC), Electrical Conductivity (EC), Calcium carbonate (CaCO<sub>3</sub>), Texture or particle size distribution, Exchangeable Cations and Anions as well as Soluble Cations and Anions if the EC >1 mS/cm (milisimins/cm). The soil samples were air dried, passed through a 2 mm sieve and stored in plastic bags ready for laboratory analyses. The soil analytical data shown in Table 5 (Appendix 1).

Based on the spatial distribution of the soil site data, it was possible to produce soil characteristics maps using Kriging methods. According to Harasheh [22] the use of GIS allows the construction of models from which a new thematic map (e.g. land suitability map) can be produced from a set of thematic maps.

The conceptual framework for assessing suitable land is the Crop and Land Suitability Assessment

(CLSA), which is based on an agro-ecological zoning approach developed and used by FAO [23]. The edaphic suitability assessment is input-specific and for this preliminary assessment was based on:

- (i) matching the soil requirements of crop with the soil conditions of the soil units.

- (ii) modification of the soil unit evaluation by limitation imposed by texture and slope.

In order to assess suitability of soils for crop production the soil requirements of individual crop types must be known. Further, these requirements must be understood within the context of limitations imposed by landforms and

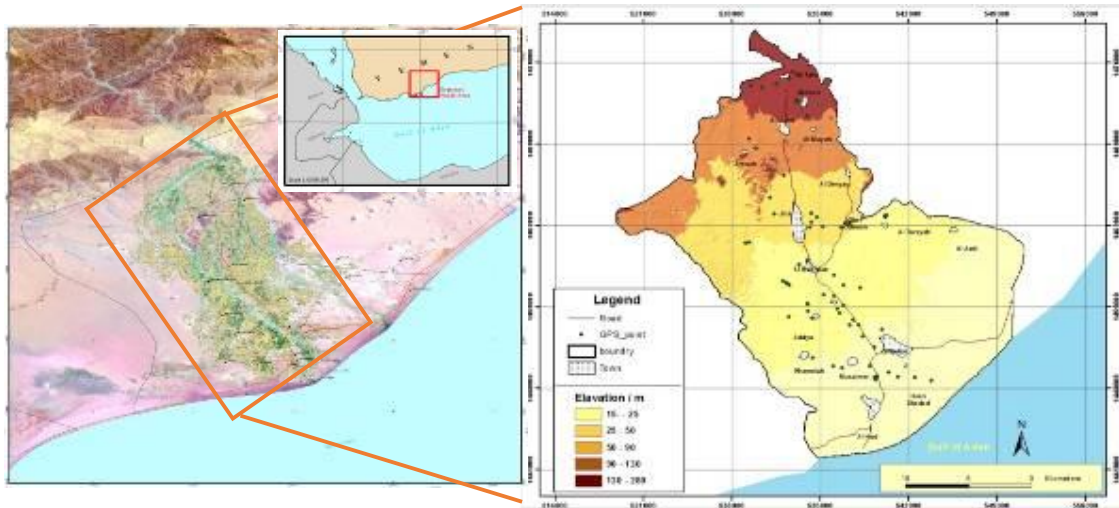


Fig. 1. Location diagram of the study area

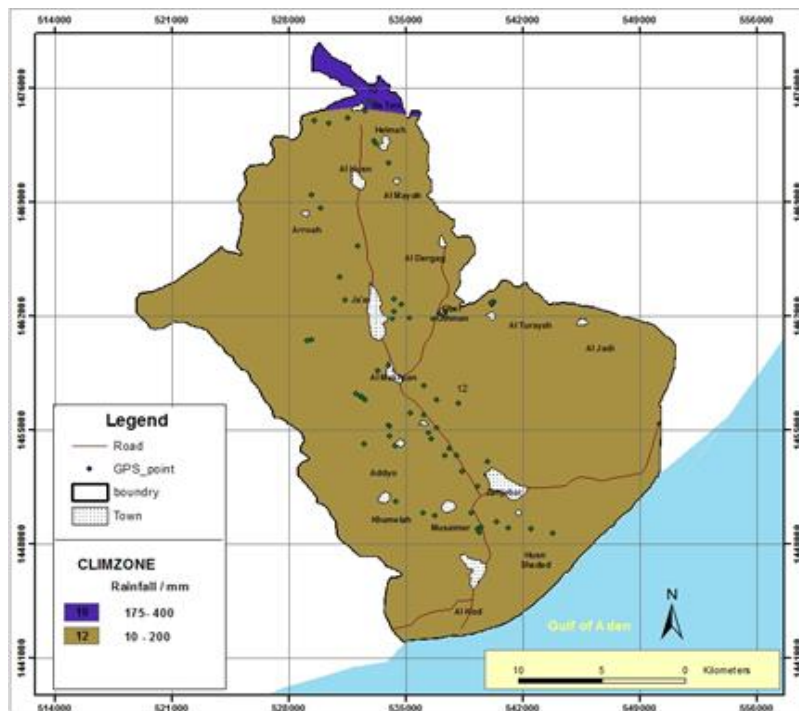
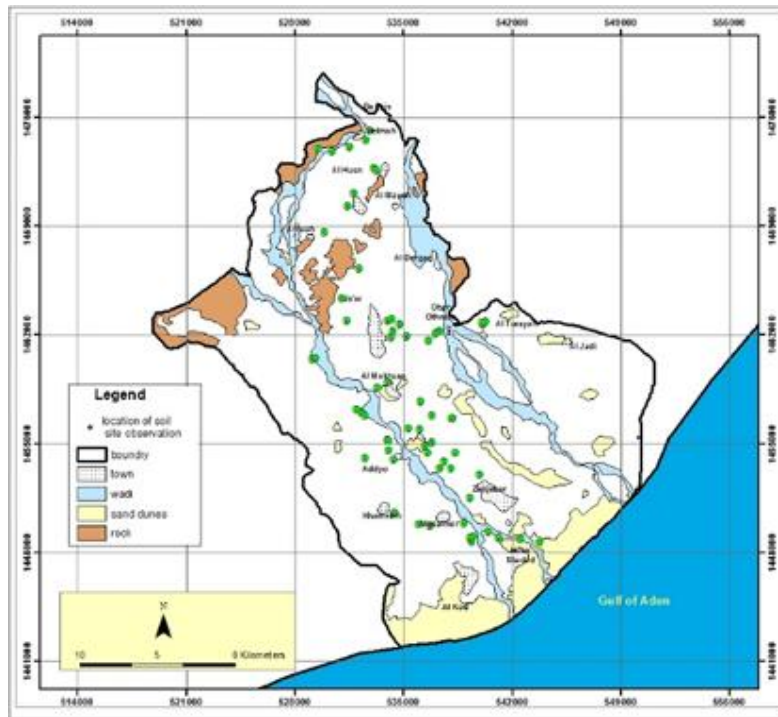


Fig. 2. Agro-climatic zones map of the study area



**Fig. 3. Location of soil samples sites**

other features, which do not constitute the soil unit but may have a significant influence on the potential soil use [24].

A spatial database was created in ArcGIS (ESRI, 2010, version 10.0) for the study area, using the spatial reference UTM Zone 38N projection. The vector data were stored in a feature dataset within the database to retain a standard of data management and easy identification. The purpose of this geodatabase is to permit the whole work flow to be tracked, as well as for efficient data management. The database can store both spatial data and non-spatial database tables to support the modelling procedures in producing final outputs.

However, climatic zones, soil characteristics, DEM and slope maps well prepared to be considered for the case of built-up area. Spatial analysis was used for generating various types of thematic maps. All mentioned variables\thematic maps were integrated in the ArcGIS environment through an index overlay to produce land suitability maps for industrial crops. The conceptual framework of the overall methodology is illustrated in Fig. 4.

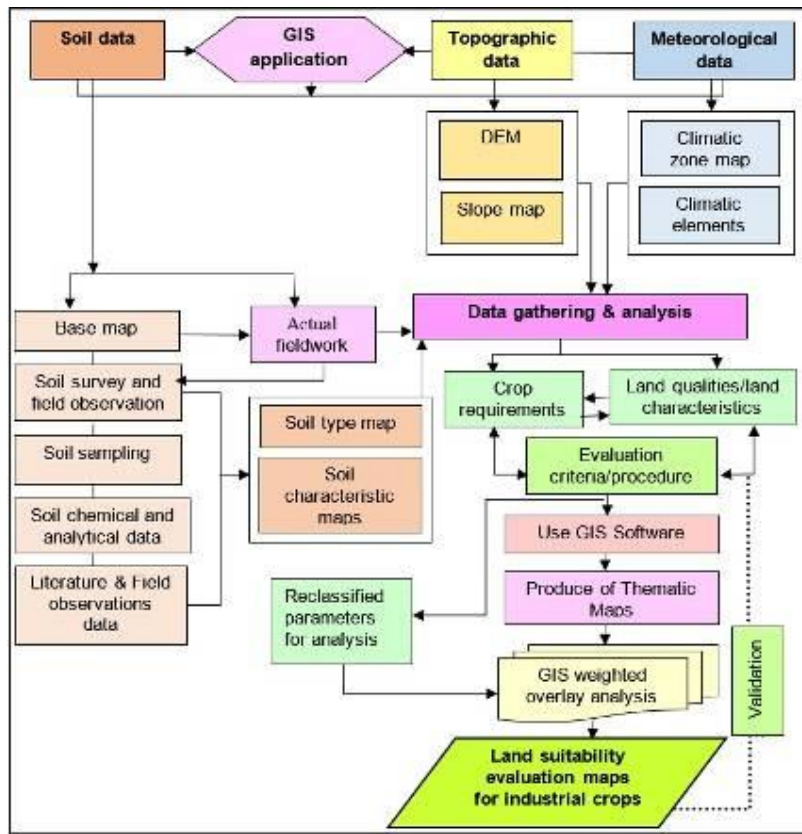
According to Rasheed [25], land evaluation for assessing its suitability to different crops for

maximum yield from unit land resources needs knowledge of climatic parameters, topographical characteristics, and details of soil site characteristics. Hence, it is necessary to evaluate the soil in a given agroecological unit for crop production under defined management system.

### 2.3 Suitability Evaluation Procedure

We assess the suitability of land for the industrial crops (cotton, sesame and groundnut) cultivated in the Abyan Delta based on the parametric approach of FAO [6] and on the basis of growth and production requirements of each crop. A comprehensive analysis of the physical settings for the study area revealed major environmental variables such as climate, soil, hydrology and topography for land suitability assessment. These variables outlined in Tables 1, 2, and 3 adopted from Wen [26] shows criteria used in assessing soil suitability for the industrial crops. In these tables, the range of the two values defining a suitability class in the rating scale (i.e. 0-25 for N2, 25-40 for N1, 40-60 for suitability class S3, 60-85 for S2, and 85-100 for S1) was assigned to each climate, topography and soil parameters according to its suitability class.





**Fig. 4. Conceptual framework of the research methodology**

Source: compiled by the authors

The potential land classification model was selected as 1) Its outputs closely match the information requested by decision-makers, as well as data available for calibration; 2) It is extensively used worldwide at similar scales; 3) The required input data were feasible to obtain including the highest and lowest realistic parameter limitations for mapping the inputs change according to possible variability in the study area (e.g. soil group, hydrologic conditions, organic matter contents, textural classes and management practices). In order to assess the relationship between the topography shape and land suitability for crop production, the data set were downloaded from CGIAR-CS [27] website (<http://srtm.csi.cgiar.org/>).

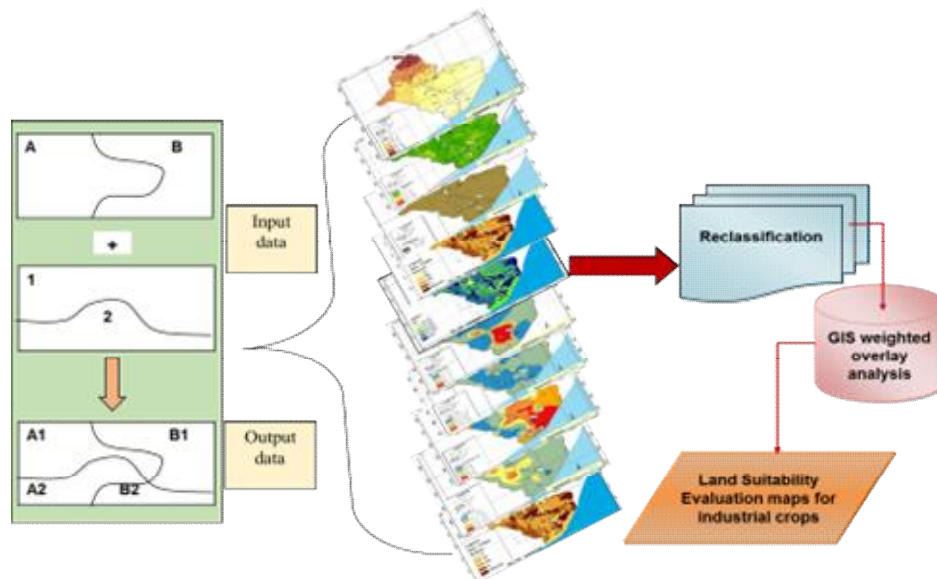
A weighted sum overlay technique was applied for producing the land suitability maps for each the industrial crops. The approach applies a common scale of values to diverse and dissimilar input variables to create an integrated analysis. The weighted overlay process provides the researcher with opportunities to analyze multiple variables in a spatial environment as to

determine the variables associated with crop land suitability analysis [7]. Since the importance of of each variable is not likely to be equal, the weighted overlay applies different weights to different thematic layers. Such an approach also makes the application of different weights to different thematic layers by weighting the value of each subclass within each thematic map. A weighted overlay was used to combine all variables layer maps into new raster map layer containing an individual value for each pixel to produce a land suitability maps for each crop. The weighting values used in the overlay operations were only performed on the following thematic raster maps such as soil chemical and physical characteristics maps (soil Texture, pH, ECe, CEC, OM, TN, CaCO<sub>3</sub>), DEM, slope and climate zones. The weighting value was given based on the influence of every subclass. Spatial data were converted into raster layers and projected to UTM Zone38 in ArcGIS 10.0. It should be noted that the heuristic value for subclass is given between 1 to 5 in this study, where value of 1 indicates the influence of the given subclass is very low while value 5 is very

high. Then a suitability level is assigned to each variables maps based on expert knowledge and bibliography revision. Next, weights for each variables maps are established, where the value between 0 and 1 is assigned to each variable layer according to Burrough [9] and Al-Mashreki [7]. Lastly, variables thematic maps are integrated in the GIS environment [28,29]. All these thematic maps were produced in digital format as a geodatabase of land resource characterization of the study area and ranked. The output data is expressed as a raster (grid) file of suitability class per cell. Based on the findings of the current study, it was found that there is a good potential land in the study area for producing the selected crops under irrigated system in a condition that the requirement of water is met. The concept of overlay model, which contains major steps of the weighting values is schematically shown in Fig. 5.

However, thematic maps were combined through an index overlay with multi- class maps and summing of each pixels values, to produce the land suitability maps at 1: 25.000 scales to show the potential of the area for main crops production based on the influence of relative factors and their weighted values. The overall suitability of the soil was determined based on the degree of agreement on site characteristics and the number of limitations for a particular soil unit. The final soil suitability was based on the number and degree of limitations (e.g. slope, coarse texture, soil nutrient availability, soil

organic matter content, soil moisture content, temperature and rainfall conditions etc.). A rating of S1 indicates that there are no or only minor limitations to production of the crop, provided climatic conditions are suitable. The rating of S2 indicates that limitations are such that they would markedly affect production of the crop, yet not to the extent of making the land completely unsuitable for that crop. The N1 rating means that the limitations appear to be severe or is at best very limited for crop production due to economic cost. The N2 rating means that the limitations are very severe and crop production is not possible. The land evaluation is expressed in terms of suitability ratings based on how far the soil conditions of a soil unit meet the crop requirements under a specified level of inputs. Soil unit ratings remain unchanged where textures are medium and fine. In all other cases, i.e. soil units with coarse textures – i.e. sand (S), loamy coarse sand (LCS), fine sand (FS), loamy fine sand (LFS), and loamy sand (LS) – the soil unit rating was lowered by 25 percent for all crops. The slope rating of S1 means that the soil unit ratings, remain unchanged. All ratings of soils with S2 slope rating are decreased or downgraded by one class, i.e. S1 soil rating changes to S2 if the slope rating is S2; S2 soil rating changes to N if the slope rating is S2; and all soil ratings of soils with N slope rating are downgraded to N. The suitability classes were then used in ArcGIS software version 10.1 to generate land suitability maps and area statistics.



**Fig. 5. Concept of the model of thematic maps for the study area**  
*ESRI ArcGIS version 10.0 was used for this model*

**Table 1. Criteria used in assessing soil suitability for cotton in Abyan Delta**

Land characteristics	Class and degree of limitations											
	S1		S2		S3		N1		N2		0	
	100	95	95	85	85	60	60	40	40	25		25
<b>1 Climate</b>												
Rainfall (mm)	900-1200	750-900		625-750		625-500		300-500		< 300		
Mean Temp(°C)	< 26	24-26		22-24		20-22		-		< 20		
LGP (Days)	120-200	90-120		<90		-		-		-		
Relative humidity (%)	MM	-		MH		-		-		HH		
<b>2 Topography (%)</b>												
Slope (%)	0-3	1-5		5-10		10-20		-		>20		
<b>3 Soil</b>												
Depth (cm)	DD	MD		MS		SS		-		VS		
Texture	M	-		H		L		-		-		
Coarse fragments	0-3	3-15		15-35		35-50		-		> 50		
pH (H2O)	6.4-7.0	7.0-7.6		7.6-8.0		8.0-8.5		-		> 8.5		
CEC (cmol/kg)	> 24	16-24		-		< 16		-		-		
OC (%)	> 0.8	0.4-0.8		< 0,4		-		-		-		
ECe (dS/m)	0-8	8-10		10-12		12-16		16-22		> 22		
ESP	0-15	15-20		20-30		30-40		-		> 40		
CaCO <sub>3</sub> (%)	0-10	10-20		20-30		30-40		-		> 40		
Gypsum (%)	0-3	3-6		6-10		10-15		-		> 15		
<b>4 Drainage class</b>	WE	-		MW		IM		POd		PO		

**Table 2. Criteria used in assessing soil suitability for sesame in Abyan Delta**

Land characteristics	Class and degree of limitations											
	S1		S2		S3		N1		N2		0	
	100	95	95	85	85	60	60	40	40	25		25
<b>1 Climate</b>												
Rainfall (mm)	400-500	350-400		250-350		175-250		-		< 175		
Mean Temp.(°C)	24-26	24-26		20-24		18-20		16-18		< 16		
LGP (Days)	80-100	70-80		<70		-		-		-		
Relative humidity (%)	VL, LL, MM	-		MH		-		-		VH		
<b>2 Topography (%)</b>												
Slope (%)	0-3	1-5		5-10		10-20		-		>20		
<b>3 Soil</b>												
Depth (cm)	DD	MD		MS		SS		-		VS		
Texture	M	-		L		H		-		-		
Coarse fragments	0-3	3-15		15-35		35-50		-		> 50		
pH (H2O)	6.2-6.5	6.5-7.0		7.0-7.5		7.5-8.2		-		> 8.2		
CEC (cmol/kg)	> 24	16-24		< 16		-		-		-		
OC (%)	> 2	1.2-2.0		0.8-1.2		< 0.8		-		-		
ECe (dS/m)	0-2	2-4		4-6		6-8		-		> 8		
<b>4 Drainage class</b>	WE	MW		-		IM, POa		Pod		PO		

**3. RESULTS AND DISCUSSION**

**3.1 Production of Thematic Maps**

For the production of the thematic maps at 1:25,000 scale, the methodology used consists

of: (a) analysis of soil characteristic data in the lab, (b) use of available GIS program, (c) preparation of topographic map layers, and (d) calculation of area under different mapping units and suitability classes. The post-fieldwork phase involved analyzing all the collected soil



**Table 3. Criteria used in assessing soil suitability for groundnut in Abyan Delta**

Land characteristics	Class and degree of limitations										
	S1		S2		S3		N1		N2		
	100	95	85	85	60	60	40	40	25	25	0
<b>1 Climate</b>											
Rainfall (mm)	400-900	400-500		300-400		200-300		-			< 200
Mean Temp. (°C)	22-32	18-22		14-18		10-14		-			< 10
		32-34		34-38		>38					
LGP (Days)	90-150	70-90		<70		-		-			-
Relative humidity (%)	MM	MH, ML, VL		VH		-		-			-
<b>2 Topography (%)</b>											
Slope (%)	0-3	1-5		5-10		10-20		-			>20
<b>3 Soil</b>											
Depth (cm)	DD	MD		MS		SS		-			VS
Texture	M	-		H		L		-			-
Coarse fragments	0-1	1-3		3-15		15-35		-			> 35
pH (H2O)	6.8-7.5	7.0-7.5		7.5-8.0		8.0-8.2		-			> 8.2
CEC (cmol/kg)	> 16	-		< 16		-		-			-
OC (%)	> 0.8	0.4-0.8		> 0.4		-		-			-
ECe (dS/m)	0-2	2-4		4-6		6-8		8-12			> 12
ESP	0-8	8-10		10-15		15-20		-			>20
CaCO <sub>3</sub> (%)	0-12	12-25		25-35		35-50		-			>15
Gypsum (%)	0-2	2-4		4-10		10-20		-			-
<b>4 Drainage class</b>	WE	-		MW		IM		POd			PO

*Relative humidity (%): VL= very low, ML= moderately low, LL= low, MM= moderate, MH= moderately high, VH= very high. Depth (cm): DD= deep, MD= moderately deep, MS= moderately shallow, SS= slightly shallow, VS= very shallow, M= medium, H= heavy, L= light. Texture: WE= well, MW= moderately well, IM= imperfectly, POd= poor, PO= very poor*

data and information. However, the topographic characteristics, the climatic conditions, and the soil quality of the study area are the most important determinant parameters of the land suitability evaluations.

DEM of the study area has been produced where the area is classified into different elevation (Fig. 6). Based on the Digital Elevation Model (DEM) and the topographic map, the slope map of the study area has been produced (Fig. 7). However, the slope gradient has a range between 0 to over 40 percent across the study area. The steepest slope is the most susceptible location to soil erosion by both water and gravity and therefore not suitable for cropland. The slope map was classified into 5 classes using a slicing function. The most dominant zone is the slope located between the range of 0-10% followed by the slope located between the range of 10-20%.

According to our analysis, soil pH is the most important soil criterion in land suitability classification as it controls many chemical soil characteristics and some physical soil properties as well. Most of the soils in the study area have a

moderately alkaline reaction, where the majorities of soils have pH values in the range of 8.0-8.5. This range of values are moderately suitable for most crops production (Fig. 8). Electrical conductivity (EC) measurements are used as indications of total quantities of soluble salts in soils. General interpretation of EC value indicated that the range between 0-4 is considered salt free, 4-8 is slightly saline, 8-15 is moderately saline and >15 is strongly saline [30]. As measured by the electrical conductivity of saturation paste, the major salinity levels of the cultivated soils in the study area are very low (usually EC <4 mS/cm ) (Fig. 9).

With certain exceptions, levels of soil organic matter in the study area were very low, within the range of 0.4-1.3%. SOM values decreased with depth in all soil profile pits across the study area. So it can be concluded that the dominating soil fertility is very low (Fig. 10). The cation exchange capacity (CEC) lies in the range of less than 12 to 33 cmol/kg of soil, but most soils lie in the range of 16 to 22 cmol/kg followed by the range of 22-33 cmol/kg considering medium and high respectively (Fig. 11).

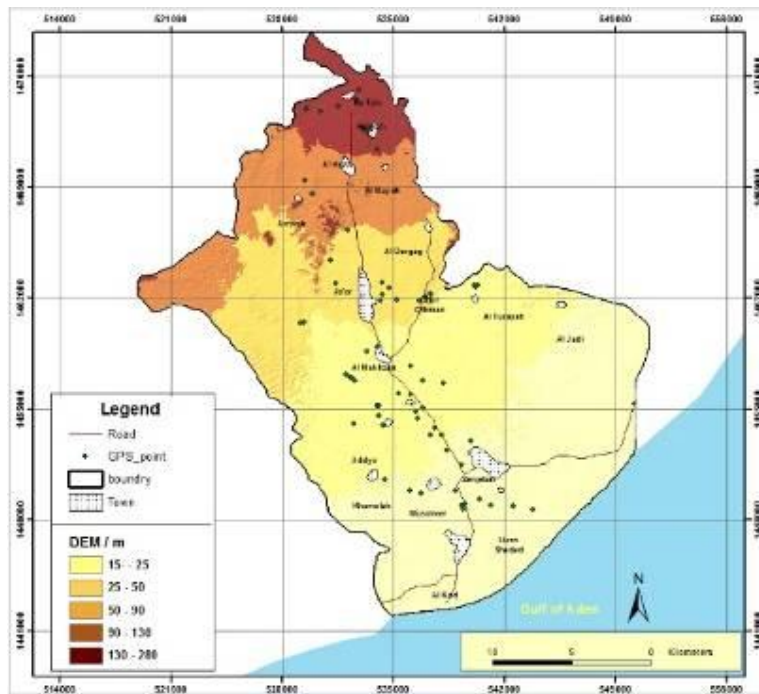


Fig. 6. DEM of the study area

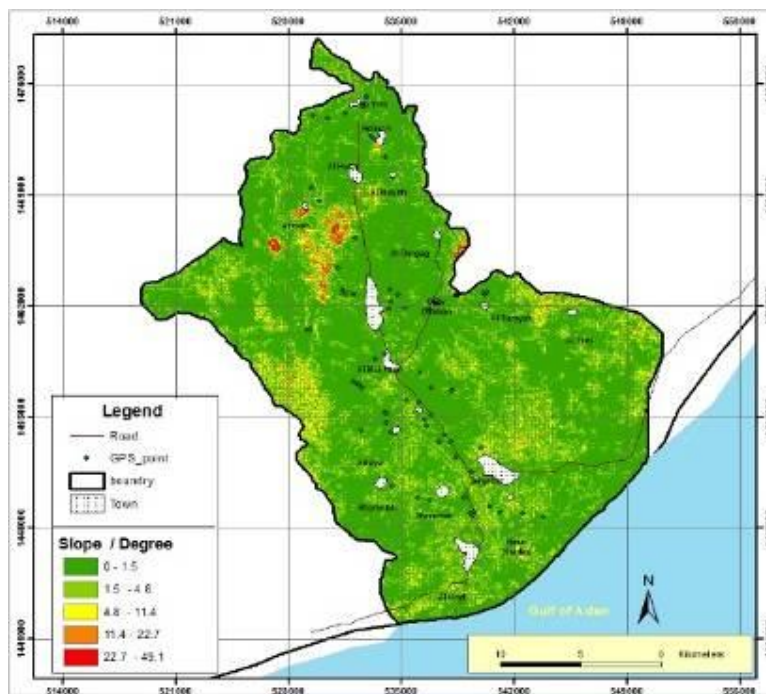


Fig. 7. Slope gradient map of the study area

Measurement of the percentage content of calcium carbonate ( $\text{CaCO}_3$ ) indicates that most soils in the study area lie in the range between

10 and 15% (moderate) (Fig. 12). The total nitrogen is very low as it is less than 0.05% and indicates high deficiencies (Fig. 13).

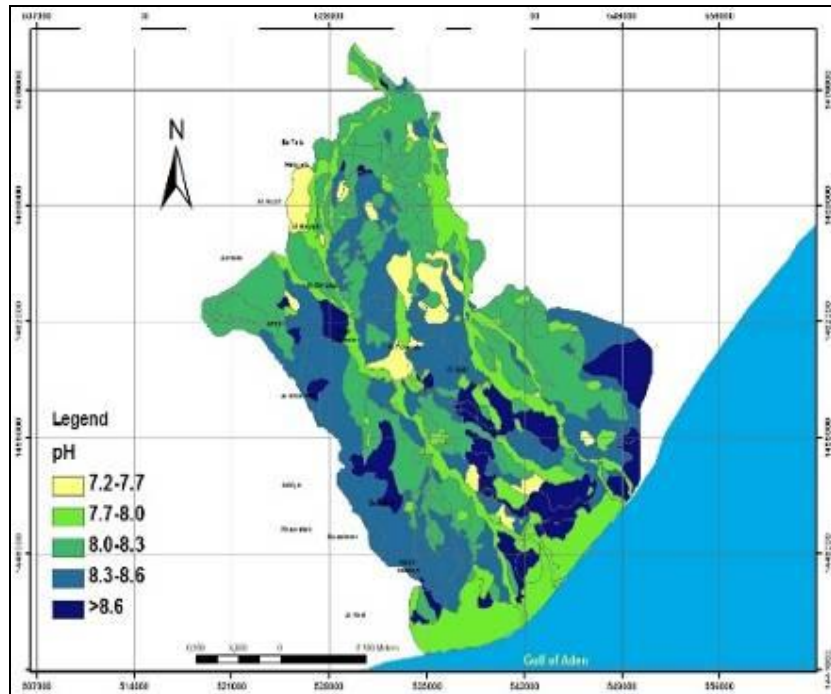


Fig. 8. pH values map of the study area

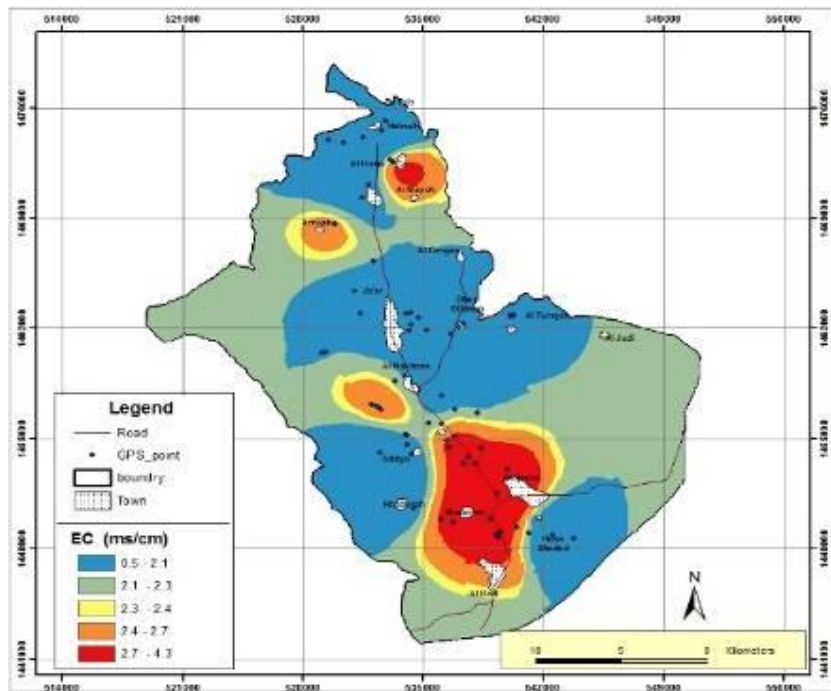


Fig. 9. EC map of the study area

The main soil textural classes are sand loam, loamy sand, loam, sand and sand clay loam/clay loam (Fig. 14). Available phosphorus levels are

very low in most soils at the northwestern and some of the southeastern parts of the study area, usually less than 10 ppm.

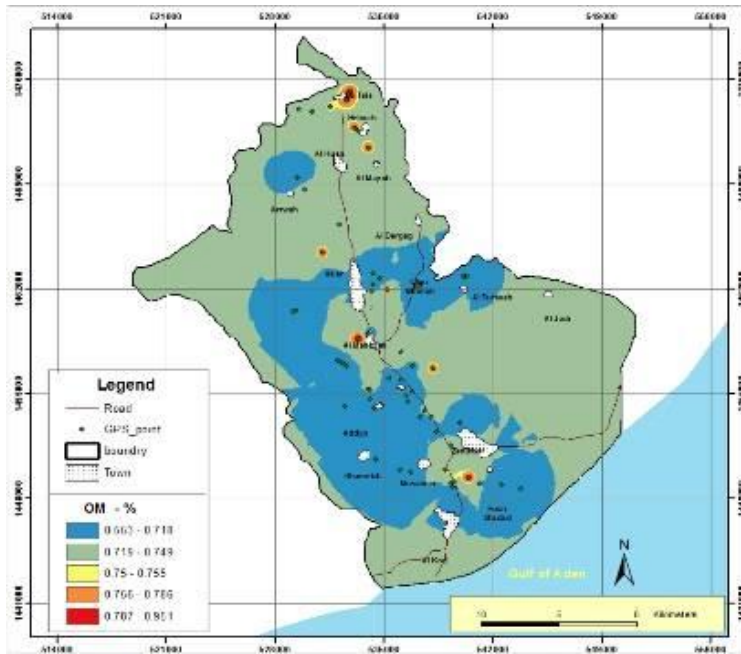


Fig. 10. OM values map of the study area

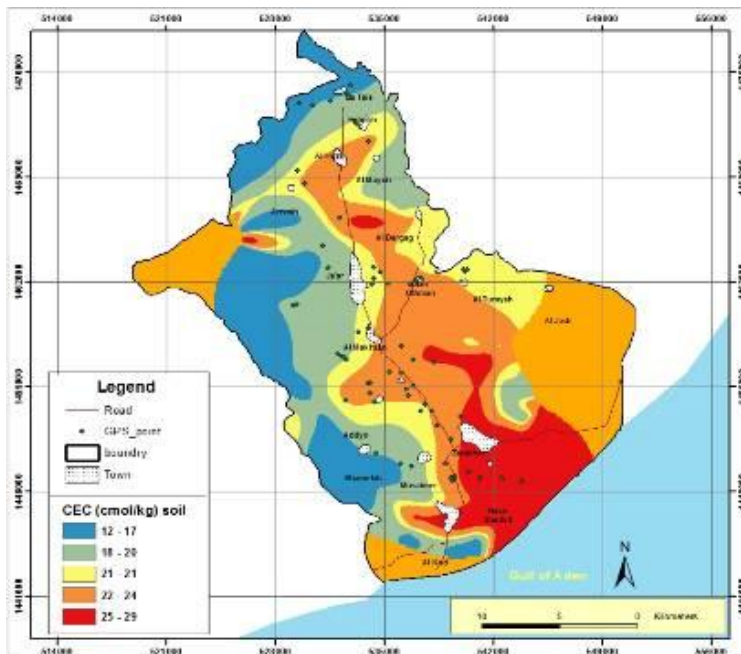


Fig. 11. CEC map of the study area

### 3.2 Land Suitability Model Outputs

The use of the weighted overlay technique was for the purpose of producing the land suitability for the main crops cultivated in the study area. It is an approach applied in a common scale of values to diverse and dissimilar input with the

aim of creating an integrated analysis. The importance of these factors is not probable to be equal. Such an approach also makes the application of different weights to different thematic layers possible. These overlay operations are only performed on raster maps.

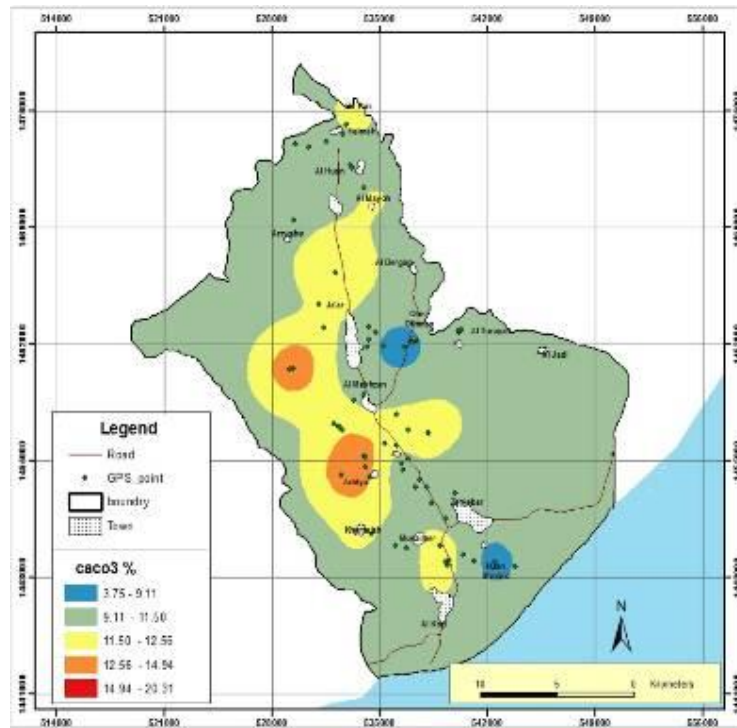


Fig. 12. CaCO<sub>3</sub> values map of the study area

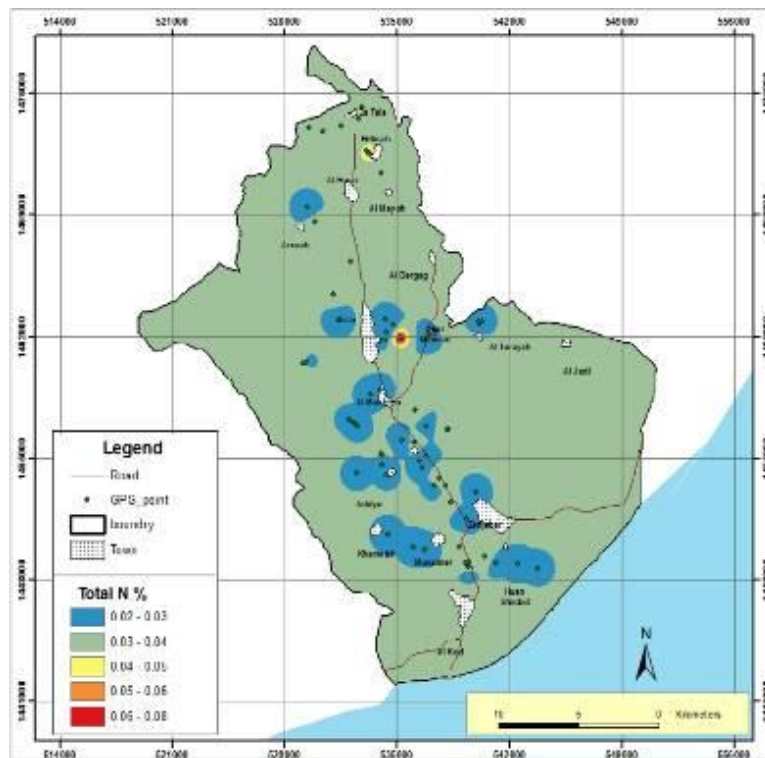
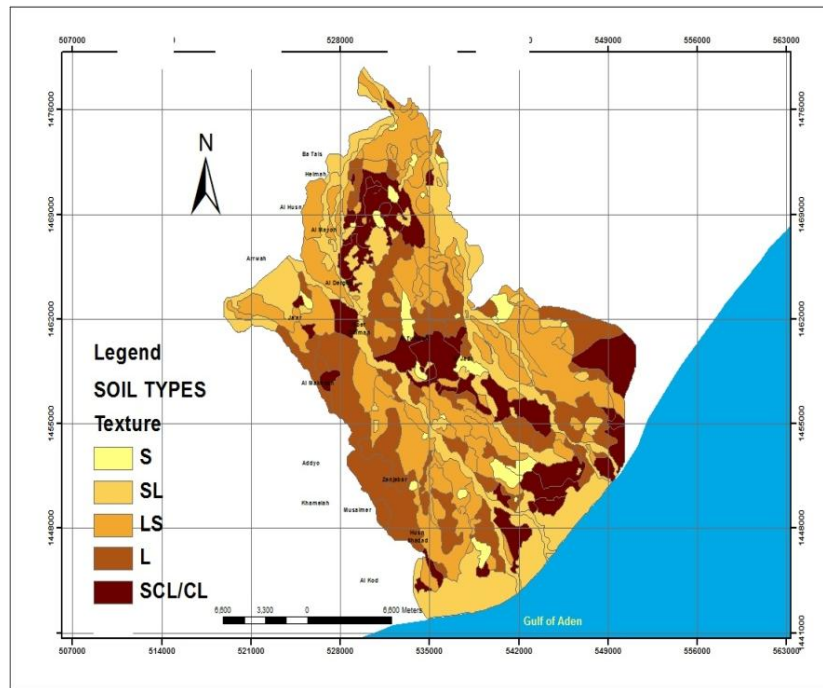


Fig. 13. Total N map of the study area





**Fig. 14. Soil type map of the study area**

The total land suitability results, as shown in Table 4 and Fig. 15, revealed that the total land suitability for the industrial crops (cotton, sesame and groundnut) comprise 14862 ha (27.7%) is unsuitable (N1 & N2) and 38739 (72.3%) represent S1, S2 and S3 of the total land area. However, the final suitability maps resulting from the spatial weighted overlay of biophysical (climate, topography and soil) suitability evaluation for each industrial crop are presented in Table (4) and Figs. (16 - 18).

### 3.3 Land Suitability for Industrial Crops (Cotton, Sesame and Groundnut)

The land suitability results for cotton indicated that the highly suitable class (S1) accounts for 22.2%, moderately suitable (S2) constitutes 36.7%, marginally suitable (S3) comprise 13.1% and the remaining 1.9% and 26.1% represent currently not suitable (N1) and permanently not suitable (N2) respectively of the total area (Fig.16).

The land suitability results for sesame revealed that the highly suitable class (S1) accounts for 22.6%, moderately suitable (S2) constitutes 37.2%, marginally suitable (S3) comprise 13.1% and the remaining 1.7% and 26.1% are currently

not suitable (N1) and permanently not suitable (N2) respectively of the total area (Fig. 17).

The land suitability results for groundnut indicated that the highly suitable class (S1) accounts for 22.8%, moderately suitable (S2) constitutes 37.4%, marginally suitable (S3) comprise 12.5% and the remaining 1.3% and 26.1% are currently not suitable (N1) and permanently not suitable (N2) respectively of the total area (Fig. 18).

Based on the findings of the current study, it was found that there is a good potential land in the study area for producing the selected crops under irrigation system in a condition that the requirement of water is met. If land condition is improved and updated from current physical suitability with appropriate management practices, increased potential land suitability could be achieved. The major limitations of both soil physical and chemical properties such as texture, soil depth, erosion, drainage, slope, organic carbon content, calcium carbonate, etc. inhibit successful cultivation. Therefore, improved soil conditions and inputs together with sustainable soil conservation are an important land management approaches to enhance sustainable productions in the study area.

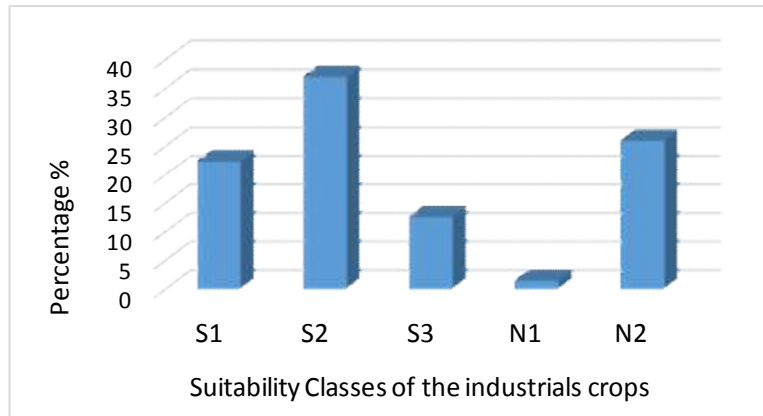


Fig. 15. Total land suitability classes for industrial crops crop in the study area

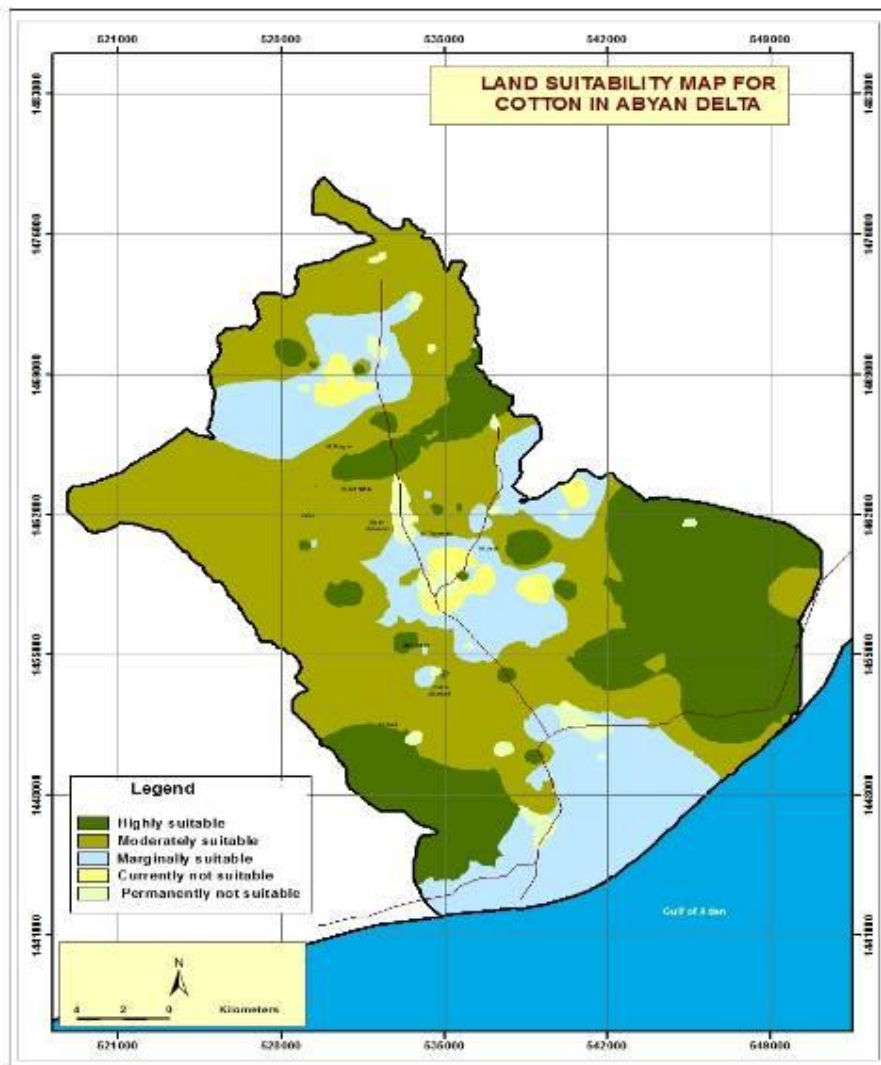


Fig. 16. Overall suitability map for cotton crop in Abyan Delta

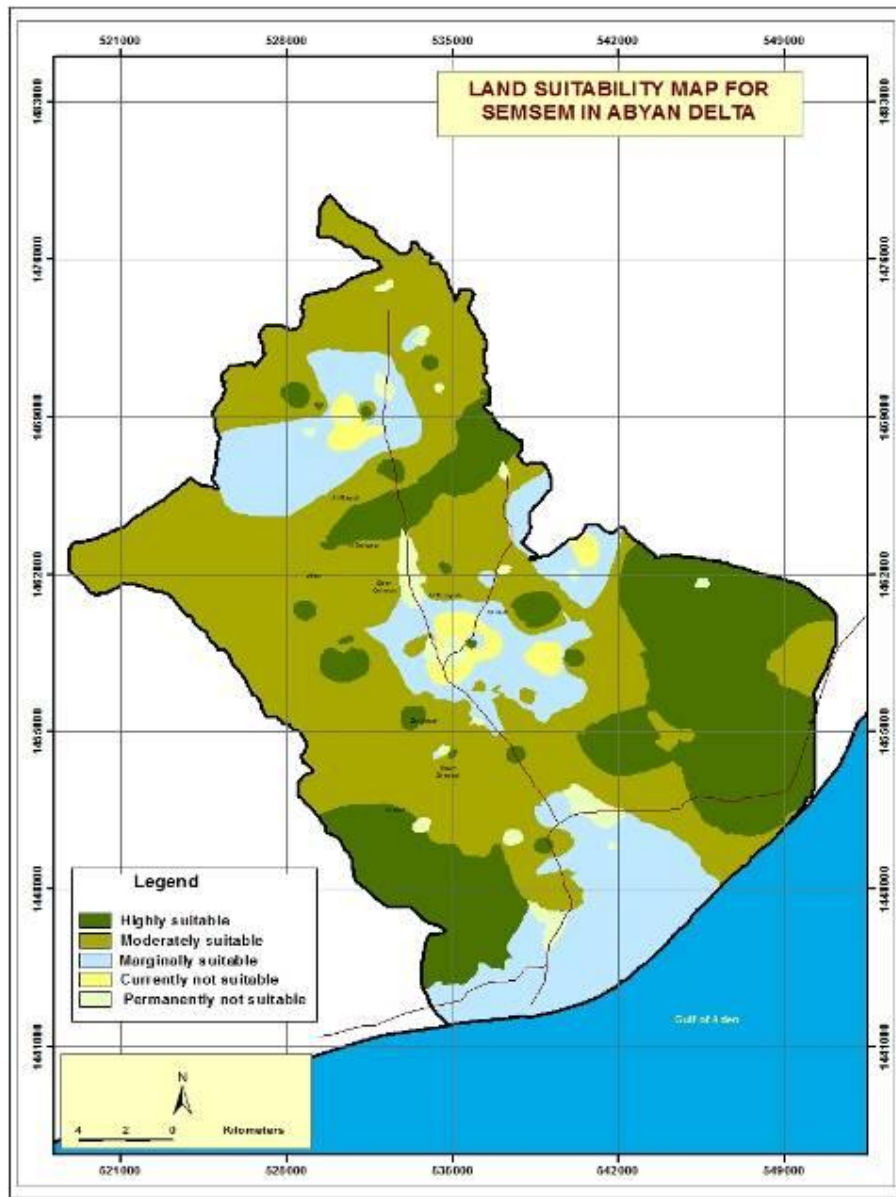
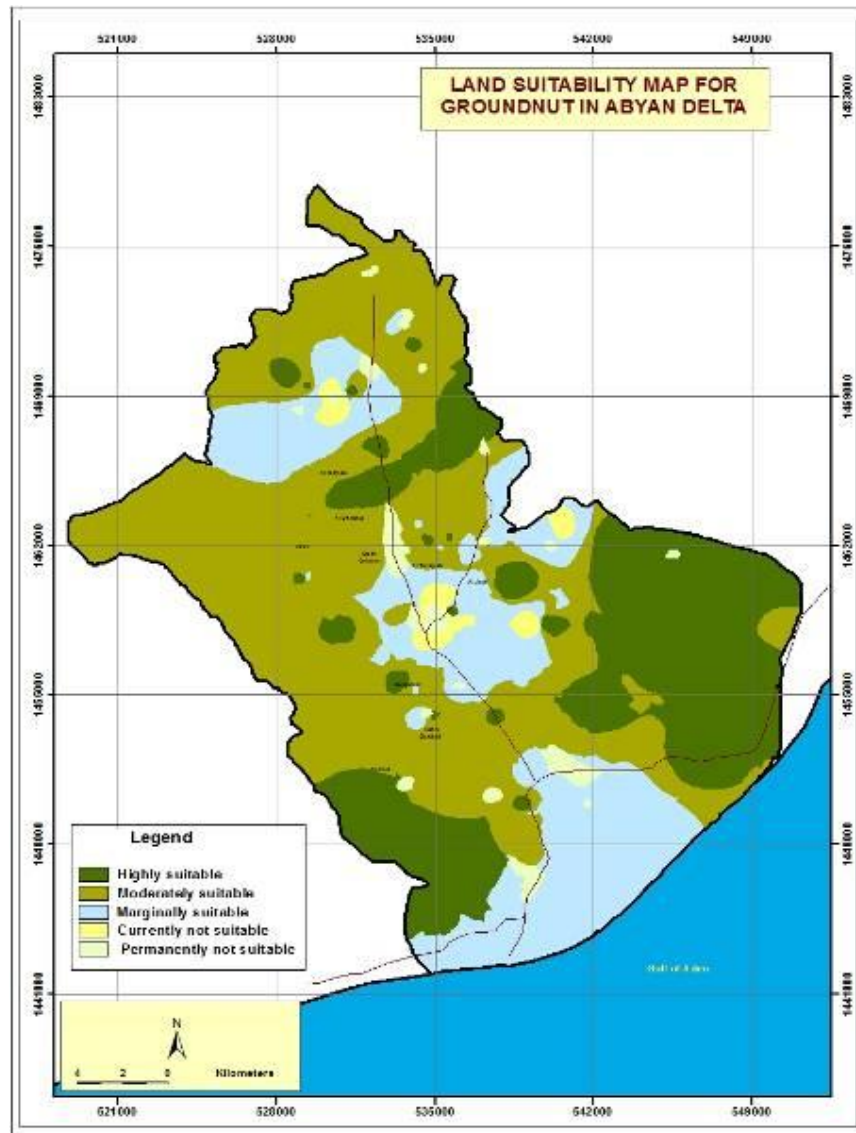


Fig. 17. Overall suitability map for sesame crop in Abyan Delta

Table 4. Summary of the results of the land suitability evaluation

Crops	Suitability classes in the study area					Total area (ha)
	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Currently not suitable N1	Permanently not suitable N2	
Cotton	11919.2	19681.9	7013.7	1002.2	13982.7	53600
Sesame	12111.6	19927.0	6647.2	931.4	13982.8	53600
Groundnut	12192.8	20022.5	6699.4	702.4	13982.9	53600
<b>Total mean</b>	<b>12075</b>	<b>19877</b>	<b>6787</b>	<b>879</b>	<b>13983</b>	<b>53600</b>



**Fig. 18. Overall suitability map for groundnut crop in Abyan Delta**

The findings of this study show the the adopted methodology can be further generalized and applied to any other area of interest.

#### 4. CONCLUSIONS

A GIS weighted sum overlay technique has the potential and capability to integrate spatial and attribute data for producing land suitability classification maps for the main industrial crops of the Abyan Delta. Our results of the land suitability classification for cotton, sesame and groundnut indicated that the highly suitable class (S1) accounts 22.2%, 22.6% and 22.8%, while

moderately suitable (S2) constitutes 36.7%, 37.2% and 37.4% and the marginally suitable (S3) are 13.1%, 13.1% and 12.5% respectively. Whereas, currently not suitable (N1) accounts 1.9%, 1.7% and 1.3% and the permanently not suitable constitutes 26.1%, 26.1% and 26.1% respectively. The major limitations include both soil physical and chemical properties such as texture, soil depth, erosion, drainage, slope, organic carbon content, calcium carbonate, etc. inhibit successful cultivation. Therefore, improved soil conditions and inputs together with sustainable soil conservation are an important land management approaches to enhance sustainable productions in the study area. This

study provides information about the suitability of cotton, sesame and groundnut in the study area and hence offers farmers alternative land uses to lessen the risk of crop failure. The suitability maps can be overlaid with the administrative map and be used to show specific locations where the three crops are at different suitability classes. The suitability maps could also be used by extension agents and farmers to make choice of appropriate uses for specific areas. Therefore, a GIS based approach cannot be overlooked in this study as a useful tool in land suitability assessment for agricultural planning.

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### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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## APPENDIX

Table 5. The soil analytical data

No.	UTM_E	UTM_N	E.Na (meq/100 g)	ESP	CEC (meq/l)	PH	EC (mS/cm)	CaCo <sub>3</sub> (%)	OC (%)	OM (%)	TN (%)	P (ppm)	Texture class
1	532809	1475192	1.3	8.125	16	8.1	0.47	13.75	0.939	1.274	0.074	7.75	LS
2	532590	1474582	1.5	8.33	18	8	0.6	12.5	0.689	1.2	0.068	4.75	SL
3	530381	1473825	1.3	6.5	20	8.4	0.4	11.875	0.37	0.637	0.057	4.5	SL
4	529514	1473997	1.2	7.491	16.5	8.4	0.84	10.938	0.455	0.872	0.043	3.5	S
5	531508	1474132	1.2	8.571	14	8.3	0.75	8.151	0.521	0.898	0.053	7.5	SCL
6	529888	1468627	3.9	12.581	31	8.5	2.5	12.5	0.504	0.87	0.039	8	L
7	529382	1469448	2.6	20	13	8.7	2.2	9.063	0.269	0.463	0.015	7.5	SL
8	533094	1472747	0.9	4.737	19	8.4	0.65	10.938	0.655	1.3	0.057	3.75	L
9	533232	1472574	2	4.074	27	8	6	7.813	0.37	0.64	0.26	7.75	SL
10	533990	1471400	0.8	4.444	18	8	0.45	14.063	0.722	1.245	0.067	12.25	L
11	531346	1462955	1.6	7.221	18	8.5	0.4	0	0.338	0.582	0.015	4.75	SL
12	531032	1464404	1	5.385	13	8.1	0.48	10.43	0.655	1.3	0.057	7.75	SL
13	534199	1461850	1.1	4.967	22	8.2	0.55	9.938	0.437	0.753	0.025	4.75	SL
14	534291	1463038	1.1	4.783	23	8.4	0.47	10	0.353	0.608	0.022	4.75	SL
15	534739	1462693	1.6	8	20	8.5	0.68	10.625	0.302	0.521	0.022	5.25	SL
16	534556	1469769	1.3	7.222	18	8.5	0.36	4.063	0.252	0.4234	0.008	2.75	SL
17	534307	1462259	0.7	3.82	22	7.7	0.22	9.375	0.302	0.463	0.007	5.75	SL
18	535213	1461911	0.7	3.333	21	8.3	0.93	6.875	0.722	1.245	0.79	2.65	S
19	532122	1466302	1.5	6.818	22	8.1	0.7	20.313	0.456	0.786	0.043	9	SL
20	536609	1461852	1.2	4.615	26	9	0.49	4.375	0.319	0.55	0.025	4	L
21	533339	1458652	1.1	5.5	20	8.2	1.66	13.438	1.126	1.94	0.013	20.25	L
22	533967	1458956	1.3	9.286	14	8.5	0.56	8.75	0.269	0.463	0.023	2.25	L
23	537317	1462285	1	4	25	8.1	0.38	8.438	0.386	0.666	0.034	11	S
24	537073	1462117	0.9	6	15	8.2	0.37	8.75	0.269	0.463	0.018	6	LS
25	532281	1457071	1.4	7	20	8.1	1.09	10.311	0.42	0.718	0.028	4.75	LS
26	532381	1456995	1.5	7.5	20	8	1.55	12.063	0.338	0.582	0.029	2.5	SL
27	532544	1456844	1.9	7.917	24	8.5	1.74	15.75	0.338	0.582	0.022	5.5	SL
28	536098	1457744	1.2	4	30	8.3	0.47	12.813	0.538	0.927	0.05	7.5	SL
29	538151	1456658	2	8.333	24	8.5	0.65	15.75	0.538	0.927	0.04	6.5	SL

No.	UTM_E	UTM_N	E.Na (meq/100 g)	ESP	CEC (meq/l)	PH	EC (mS/cm)	CaCO <sub>3</sub> (%)	OC (%)	OM (%)	TN (%)	P (ppm)	Texture class
30	531998	1457209	0.9	5.625	16	8.1	1.02	13.125	0.275	0.473	0.025	4	SL
31	536842	1456842	1.7	8.095	21	8.6	0.99	11.25	0.338	0.582	0.022	2.5	LS
32	540144	1462727	0.6	2.857	21	8	0.3	15.938	0.437	0.753	0.033	9	LS
33	540293	1462870	0.9	4.5	20	8.1	61	11.875	0.259	0.446	0.022	19	SL
34	540082	1462838	0.7	3.333	21	8	0.44	8.125	0.338	0.582	0.023	16	SL
35	529111	1460460	0.9	7.5	12	8.2	0.45	15.938	0.42	0.724	0.036	4.75	SL
36	529349	1460517	2.2	9.167	24	8.3	1.1	17.5	0.218	0.376	0.029	3.25	S
37	535302	1456008	1.3	6.5	20	8.3	0.4	12.5	0.37	0.637	0.015	4.5	S
38	543775	1448664	1.5	5.172	29	8	0.73	9.75	0.386	0.666	0.015	6	SL
39	542511	1448918	2.1	7.5	27	8.6	0.68	3.75	0.22	0.376	0.008	2.5	SL
40	539899	1453033	2	10.526	19	8.5	1.96	5.25	0.252	0.434	0.015	5.75	SL
41	539404	1448731	1.5	11.539	13	8	2.74	11.25	0.252	0.434	0.025	4.25	LS
42	536732	1449717	1.7	12	15	8	0.98	10	0.353	0.608	0.015	3.25	SL
43	536013	1449879	1.5	7.5	20	8.5	0.45	9.375	0.22	0.376	0.008	3.25	LS
44	534434	1450584	1.8	12	15	8.5	0.64	13.75	0.353	0.608	0.008	2.5	LS
45	539307	1451528	1.2	3.939	33	7.2	5.8	10.625	0.504	0.869	0.018	5.25	CL
46	538040	1453426	1.7	8.095	21	8.4	2	13.125	0.454	0.728	0.032	4.25	SL
47	537619	1453863	1.7	9.444	18	8.1	1.96	12.5	0.57	0.985	0.05	3	L
48	540441	1449367	1.7	6.8	25	8.3	0.86	10	0.86	1.48	0.057	7.75	SL
49	541134	1448987	1.7	6.296	27	8.2	1.34	9.75	0.37	0.64	0.025	4.75	LS
50	532506	1454110	0.8	3.81	21	8	0.36	17.88	0.252	0.434	0.019	4.75	SL
51	534054	1454626	1.3	5.909	22	8.1	0.36	13.75	0.386	0.666	0.019	3.25	SL
52	538358	1452455	1.3	7.222	18	8.3	1.3	10.313	0.37	0.637	0.035	6.75	SL
53	537327	1453412	1.7	10	17	8.3	1.6	12.188	0.252	0.434	0.026	2.5	SL
54	534353	1454002	0.9	3.215	28	8.5	0.34	13.75	0.286	0.492	0.025	2	SL
55	533974	1455249	1.4	9.334	15	8.3	0.86	13.875	0.42	0.724	0.034	3.5	SL
56	534050	1455234	1.4	4.667	30	8	2.15	12.813	0.42	0.724	0.036	8.5	L
57	536386	1454866	1.6	7.619	21	8.5	1.59	8.875	0.302	0.521	0.026	4.75	SL
58	536844	1455095	2.1	10	21	8.1	4.78	10	0.319	0.55	0.022	1.75	SL
59	536530	1454461	1.7	8.5	20	8.4	1.92	9.375	0.302	0.521	0.022	2	SL
60	539502	1449051	1.5	5.357	28	8.2	0.75	15	0.511	0.882	0.06	4	L
61	538900	1449900	1	7.692	13	8.3	1.29	14.688	0.519	0.895	0.043	3	L
62	539268	1448949	2	5.714	35	8.1	2.83	14.063	0.464	0.8	0.053	13	L

No.	UTM_E	UTM_N	E.Na (meq/100 g)	ESP	CEC (meq/l)	PH	EC (mS/cm)	CaCO <sub>3</sub> (%)	OC (%)	OM (%)	TN (%)	P (ppm)	Texture class
63	538142	1456649	1.3	5.417	24	8.3	0.96	12.813	0.701	1.208	0.064	11.5	L
64	536076	1455933	1.5	5.357	28	8.3	0.55	15.313	0.307	0.637	0.046	22	SL

LS= Loamy sand, SL= Sandy loam, S= Sand, SCL= Sandy clay loam, L= Loam, CL= Clay loam

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