

Original Research Article

GIS-Based Assessment of Land Suitability for Industrial crops (cotton, sesame and groundnut) in the Abyan Delta, Yemen

ABSTRACT

A Geographic Information System (GIS)-based method was used to assess land suitability ~~evaluation~~ in the Abyan ~~D~~delta for ~~the~~ industrial crops through simultaneous consideration of -physical features and current land use. The objective of the present study was ~~therefore carried out with the objective of to~~ investigate the potential and capability of Geographic Information System (GIS) as a modern technique ~~for to~~ integrating spatial and attribute data for producing land suitability ~~evaluation~~ maps of the main irrigated industrial crops (cotton, groundnut, and sesame) cultivated in the Abyan Delta, Yeman, study area under irrigation system based on an integration of land qualities and land characteristics as related to crop requirements_[TSW1]. ~~Our The~~ results reveal ~~the that~~ currently ~~the~~ total land area of ~~the~~ Abyan delta is 53600 ha of which only 14862 ha (27.6 percent) is unsuitable land for these industrial crops (N1 & N2)_[TSW2]. Suitability classes include 12075 ha (22.5 percent) of Hhighly suitable land units (S1) for the selected industrial crops, (i.e. cotton, sesame and groundnut)_[TSW3] are 12075 ha (22.5 percent), 19877 ha (37.1 percent) of mModerately Ssuitable (S2) is 19877 ha (37.1 land, 18 percent) and 6787 ha (12.7 percent) of mMarginally Ssuitable land(S3) is 6787 ha (12.7 percent). This study provides an approach to identify and rate ~~parametric rating of the land qualities and overall insight into the integration of land qualities~~ in relation to the suitability of land 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 ~~to~~ align future development projects towards with the concurrent goal of improving long-term agricultural productivity.

Keywords: Geographic Information System -(GIS), land suitability evaluation, crop requirements, soil, climate, spatial and attribute data,

1. INTRODUCTION

Land suitability evaluation as defined by Sys et al. (1991); Van Diepen et al. (1991) and Rossiter (1996a), is the process of making predictions of land performance over time based on specific types of land uses. ~~The~~ Land suitability evaluation is forms a pre--requisite for land use planning, especially for agricultural cropland (REFERENCE)_[TSW4]. Each cropland plant species requires specific soil_[TSW5] and climatic conditions for ~~its~~ optimal growth. (Sys et al., 1991). The land suitability is determined, based on integration of land qualities and land characteristics and is widely accepted_[TSW6]. FAO guideline on the land evaluation (1976) areis well known worldwide for land suitability evaluation method_[TSW7]. In addition a number of recent

reports provide

35 methodologies on the Geographic Information System (GIS) applications ~~of GIS to the~~ for land evaluation
(Mongkolsawat et al, 1999; Thavone, 1999; [TSW8]

36 Paiboonsak et al, 2004; Maleki et al, 2006). ~~Hence, t~~The ability of GIS ~~(Geographic Information System)~~ to
37 record, store, and retrieve location and elevation data from many soil observations ~~including their~~
~~location and elevation on the~~

38 ~~ground (i.e., the exact location of a soil profile observation was rarely recorded in many early surveys)~~ has
39 paved the way for studies ~~on~~ the spatial variation of soil properties within ~~the~~ subjectively delineated
40 landscape units (Burrough, 1991). This is a vast improvement over earlier soil surveys which lacked soil
profile location information (REFERENCE [TSW9]). The ever increasing demands for increasing food grain
production could

41 be met through systematic soil surveys ~~of the soils~~, evaluating their potentials for a wide range of land uses
~~options~~

42 and formulating economically viable, socially acceptable and environmentally

43 sound, land use plans. ~~which were economically viable, socially acceptable and environmentally~~

43 ~~sound~~. The traditional surveying methods ~~of survey~~ are time consuming, labour intensive, and expensive ~~to~~
~~generate~~

44 ~~data~~. With the advent of remote sensing the database generation became fast, cost effective and reliable
45 (Sathish, & Niranjana, 2010). Thus remotely sensed soil information can be generated ~~data is~~
integrated in a GIS to obtain different thematic

46 information for use ~~ing~~ in land evaluation techniques .

47 According to Burrough (1991) soil survey applications were among the first uses of GIS. ~~Also,~~ GIS is now
 48 firmly established tool in modern soil survey ~~analysis practice and are used~~ for map production, deriving
 49 suitability maps to meet users' requests for special purpose information, and -for visualizing modelling environmental
 49 processes. Based
 50 ~~on the literature review, it has been realized that, the Many~~ problems associated with soil data
 50 ~~can~~ could be
 51 properly dealt with if the potentials of GIS are tapped into [TSW10]. Despite the large amount of work
 51 published on
 52 GIS applications in literature, little has been published in terms of digital soil mapping using GIS for
 53 crop land suitability analysis. Kalogirou (2002) modeled a geographic information technology in
 54 conjunction with expert systems [TSW11] called LEIGIS software to implement a land suitability evaluation
 54 model.
 55 The model used wasis based on the Food and Agriculture Organisation's (FAO) land classification for crops
 55 and
 56 data which describes an agriculture area in terms of soil mechanics and environment. The software
 57 ~~developed model?~~ allows the evaluation and presentation of any equivalent spatial dataset and does not
 57 require
 58 special computer skills [TSW12].
 59 In a study carried out by Ramakrishnan et al (2009), it was observed that if spatial soil information wasis
 59 available, in
 60 GIS ~~then many~~ professionals could assess the soil information for developmental purposes,
 60 effective
 61 agricultural research, and in advisory programs. Behrens and Scholten (2006) also developed a digital soil
 62 map as a tool to generate spatial soil information which provided solutions for the growing demand for
 63 high resolution soil maps worldwide. Their paper summarized the present state of global? soil survey
 63 in terms of [TSW13]
 64 digitally data availability type soil data, applied digital soil mapping. Similarly, Behrens et al (2005) developed
 64 digital soil
 65 mapping using artificial neural networks.

This [TSW14] study focused on the development of a methodology based
 66 ~~on overly of thematic digital maps that is able to spatially predict soil units. Therefore, IL~~ and evaluation is
 67 considered as robust one of the approaches that to assist in considering the best outcomes of land use
 67 under certain
 68 conditions and specific situations [TSW15]. This [TSW16] study focused on the development of a methodology
 68 based
 69 on overlaying thematic digital maps to spatially predict soil suitability units for evaluating agricultural
 69 land suitability in Abyan Delta, Yemen. Therefore, [TSW17] insights gained from this land evaluation are certainly
 69 expected to
 70 enhance our understanding about potential improvements the role of land evaluation in enhancing the in
 70 agricultural productivity in
 71 Yemen through proper planning (Al-Mashreki 2010). Our The land suitability evaluation for the main industrial
 71 crops (i.e. cotton, groundnut and sesame) grown in the Abyan
 71 Delta was conducted with the objective of to investigate the potential and capability of GIS Geographic
 71 Information
 72 System (GIS) as a tool modern technique to integrate spatial and attribute data for producing
 72 irrigated cropland and suitability
 73 evaluation maps, of the main industrial crops (cotton, groundnut and sesame) cultivated in the study area

~~74 under irrigation system. Cropland suitability was measured based on crop specific requirements including an integration of soil characteristics, topographic variables, and climate data land qualities, soil characteristics???? and land characteristics as related to crop~~
~~75 requirements.~~ [TSW18]

76

772. MATERIALS AND METHODS

78

79 2.1 Study area

80 The Abyan ~~De~~lta is located in an arid to sub-tropical zone in the southwest of the Abyan governorate
~~alongt~~ the
 81 coast of the Aden Gulf, approximately between latitudes 13°04' to 13°18' N, and longitudes 45°08' to
 45°30' E.

82 ~~The regionand~~ has a total land area of 53,600 hectares and is situated far away [TSW19] about 55
 km east of Aden city (Figure1). It is

83 considered as one of the potential cultivated areas [TSW20] in Yemen's Southern Coastal plains ~~in Yemen~~. All
 crops (cereals,

84 vegetables and fruits) ~~are~~ cultivated in this area ~~are under~~ irrigated ~~edion system~~ from spate water and tube
 wells.

85 Climatically, the study area is located in agr-climatic zone 12, which t1he representative agro-meteorology
 86 station for zone 12 is Al-Kod at 20 m altitude (REFERENCE) [TSW21]. ~~However, the m~~ Mean monthly
 temperatures range ing from 25 °C

87 in January and February to over 31.6 °eC in June. The average maximum temperature in summer season is
 88 around 35 °C (June to September) and wide monthly?? variation in rainfall from 200-700 mm ~~to~~
 depending on

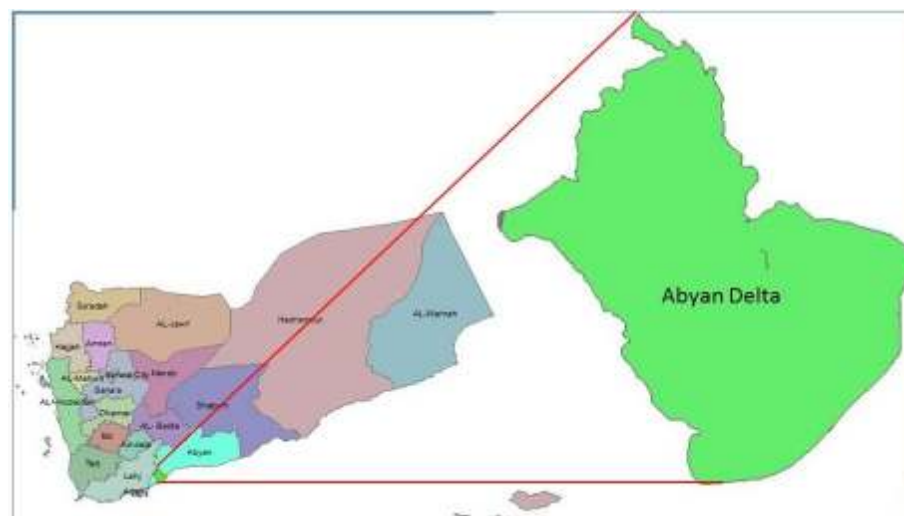
89 geographical location and time of year. ~~The m~~ Mean monthly evapotranspiration varies from 119.7
mm? (unit??) in

90 December to 176.7 [TSW22] mm -in May, while the total annual evapotranspiration is about 1795 mm.
 Average monthly

91 relative humidity varies between 69% and 73%. [TSW23] The mean monthly run of wind [TSW24] at 2m above
 ground in the

92 studyproject area varies from 119 in November to 174 km/day in March.

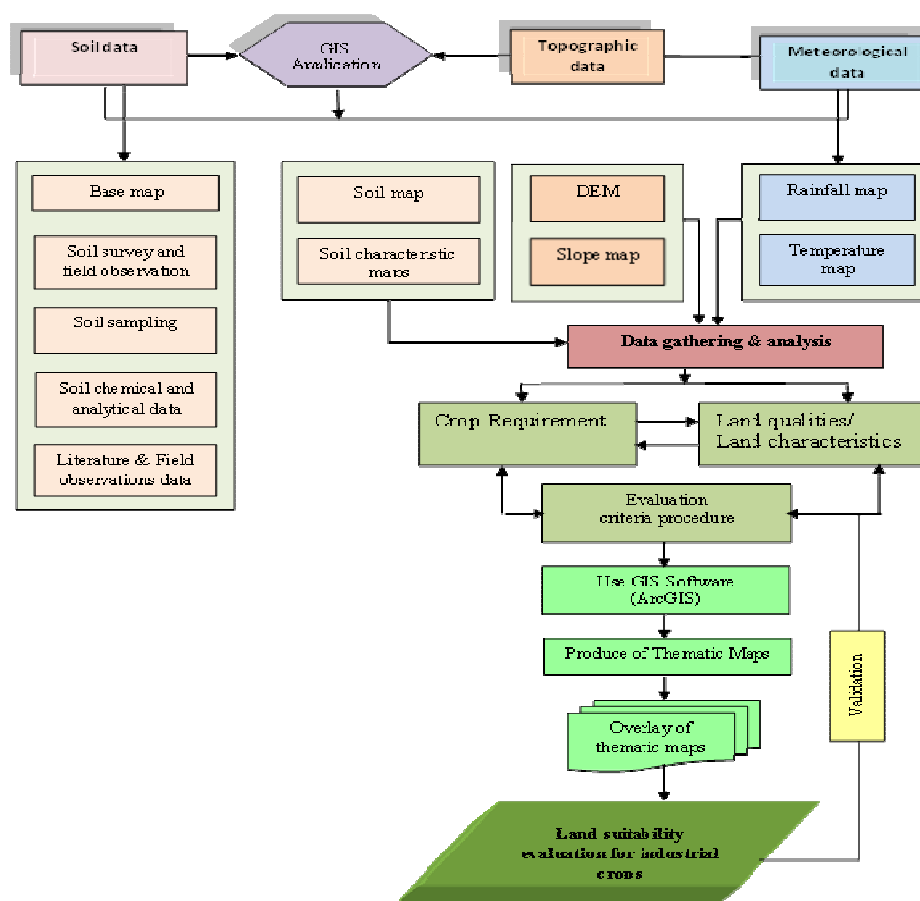
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[TSW25] Figure 1: Location Diagram of the Abyan Delta study area in Yemen.

2.2 Data and methodology

The study was identifying the kinds of data input into a GIS and how this data can be used to create useful interpretive maps. The data layers needed in the current analysis include research is about the climate, topography, soils, and land use????.[TSW26] Data[TSW27] gathering included field surveys, laboratory analysis and secondary data collected from various organizations and individuals. [TSW28]The materials used in this research were considered as the sources and input data for the Geographic Information System (GIS) as a vital step for land evaluation. The steps and processes which have been [TSW29]followed will be described in details. Furthermore, integration and modeling applied for analyzing and weighting values of subclasses of thematic maps have been given. Basically, the research methodology consists of office study (pre and post fieldwork) and actual fieldwork survey for investigation and data collection. The pre fieldwork phase involved a review of published literature such as books, technical reports and journals[TSW30].[TSW31] Internet explorer was used to look for relevant data to consolidate land resource themes, besides visiting the concerned institutions and all stakeholders involved with land resources issues[TSW32]. The fieldwork survey was carried out to investigate soil characteristics land resources across the study area. Its current situation is, then, evaluated to formulate the main findings and conclusions and recommendations. For the production of the thematic maps, the methodology used consists of: (a) analysis of soil lab. data (b) use of available GIS program (c) preparation of topo layers, and (d) calculation of area under different mapping units and suitability classes. The post-fieldwork phase involves analyzing all the collected data and information. However, the topographic characteristics, the climatic conditions and the soil quality of an area are the most important determinant parameters of the land suitability evaluations. According to Harasheh (1994) 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 of the overall methodology followed in the current research is illustrated in Figure 2[TSW33].[TSW34][TSW35]



[TSW36][TSW37]Figure 2: Conceptual framework of the research methodology

Source: compiled by the authors

According to Rasheed & Venugopal (2009), land evaluation for assessing its suitability ~~for maximum yield to~~ ~~for different crop types for maximum yield~~ from unit land resources ~~requires~~ ~~needs~~ knowledge of climate ~~ie~~ ~~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~~[TSW38]-

2.3 Soil Samples Treatment and Laboratory Analysis

Analyses of soil samples collected from the study area were conducted based on the methods used in the laboratory of Renewable Natural Resources Research Center (RNRRC) at Yemeni Agricultural Research and Extension Authority [TSW39](AREA[TSW40])(REFERENCE). The methods used are those essentially used for the analysis of water extracts of soil obtained at saturation[TSW41]. The methods are described in (FAO, 1988) Bulletin No. 10 "Physical and Chemical Methods of Soil and Water Analysis". The samples were taken to the laboratory and the soil was analyzed for Soil Reaction (pH), Organic Matter Content (OM[TSW42] or OC???), Cation Exchange Capacity (CEC), Electrical Conductivity (EC), Calcium carbonate (CaCO₃), Soil Texture or particle size distribution, Exchangeable Cations and Anions, as well as Soluble Cations and Anions if the EC > 1 dS/cm[TSW43]. The soil samples were air dried, passed through a 2 mm sieve and stored in plastic bags ~~ready~~ for laboratory analysis. The sampling design [TSW44]yielded a total of 103 samples. The soil analytical data is given in Table 5 (ANNEX 1[TSW45]) .

2.4 Suitability Evaluation Procedure

The present method We assessed the suitability of land for the industrial crops (i.e. cotton, sesame and groundnut) cultivated in the Abyan Delta based on the parametric approach defined by the of FAO (1976) and on the basis of a matching exercise between the growth and production requirements of each the crop, s and the soil parameters. 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 at the primary level [TSW46] as [TSW47] well as. There were a different number of sub-variables under each category at the secondary level. The evaluation was done using several parameters, wherein every soil mapping unit was rated as per limitation technique using the criteria [TSW48]. For each soil sample site, the variables Tables 1, 2, and 3 adopted from Wen (1997) shows criteria used in assessing soil suitability for the industrial crops cultivated in Abyan Delta. In these tables, the average of the two values [TSW49] defining a suitability class in the rating scale (i.e., 40–60 for suitability class S3, 60–85 for S2, and 85–100 for S1) was assigned to each climate, topography, soil and topography parameters according to its suitability class. The five land suitability classes of land suitability maps have been given such as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently unsuitable (N1) and permanently unsuitable (N2) with the area covered by each class shown as hectare and percentage. They were all adapted from the FAO system.

In this study all thematic maps already mentioned have been combined through an index overlay with multi-class maps and summing of each pixel 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 [TSW50] 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 [TSW51]. The suitability classes were then used in ArcGIS software to generate land suitability maps and area statistics.

Table1: Criteria used in assessing soil suitability for Cotton (*Gossypium hirsutum*) in the Abyan

Delta SI Soil site [TSW52] No characteristics	Class and degree of limitations									
	S1			S2			S3		N	
1 Climate	100	95	85	85	60	60	40 [TSW53]	40	25	25

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162

3	Rainfall (mm)	900-1200	750-999	625-749	625-500	SS	< 500	-	VS
	Mean Temperature (°C)								
	LGP								
	[TSW54]								
	(Day s)								
	Topography (%)								
	Slope (%)								
4	Soil								
	Depth (cm)	0-3	1-5	5-10	10-20		>20		
	Texture	M	-	H	L		-	-	
	Coarse fragments (%)	0-3	3-15	15-35	35-50		-	-	
	pH (H2O)	6.4-7.0	7.0-7.6	7.6-8.0	8.0-8.5		< 20	-	
	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	120-200	90-120	< 90	20-30		-	Relative humidity (%)	
	CaCO ₃ (%)	0-10	10-20	20-30	30-40		-	> 40	
1	Gypsum (%)	0-3	3-6	6-10	10-15		-	> 15	
	Drainage class	WE	-	MW	IM		Pod	PO	
	Table2: Criteria used in assessing soil suitability for Sesame (<i>Sesamum indicum</i>) in the Abyan Delta								
	SI Soil site								
	No characteristics								
1	Climate								
	Rainfall (mm)	400-500	350-400	250-350	175-250		-	< 175	
	Mean Temperature (°C)	24-26	24-26	20-24	18-20		16-18	< 16	
				27-28	28-30		30-38	> 38	

	LGP (Days)	80-100	70-80	<70	-	-	-
	Relative humidity (%)	VL, LL, MM	-	MH	-	-	VH
2	Topography (%)						
	Slope (%)	0-3	1-5	5-10	10-20	-	>20
3	Soil						
	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
4	Drainage class	WE	MW	-	IM, POa	Pod	PO

Table3: Criteria used in assessing soil suitability for groundnut (*Arachis hypogaea*) in the Abyan Delta

SI No	Soil site characteristics	Class and degree of limitations ^[TSW55]									
		S1		S2		S3		N			
		100	95	85	85	60	60	40	40	25	25
1	Climate										
	Rainfall (mm)	400-900	400-500	300-400	200-300	-	-	-	-	< 200	< 10
	Mean Temperature (°C)	22-32	18-22	14-18	10-14	-	-	-	-	< 10	< 10
	LGP (Days)	90-150	70-90	<70	-	-	-	-	-	-	-
	Relative humidity (%)	MM	MH, ML, VL	VH	-	-	-	-	-	-	-
2	Topography (%)										
	Slope (%)	0-3	1-5	5-10	10-20	-	-	-	-	>20	>20
3	Soil										
	Depth (cm)	WE	-	MW	IM	Pod	PO	Pod	PO	Pod	PO
		DD	MD	MS-	SS	-	VS	-	VS	-	VS
	Texture	M	-	H	L	-	-	-	-	-	-
	Coarse fragments (%)	0-1	1-3	3-15	15-35	-	> 35	-	> 35	-	> 35
	pH (H2O)	6.8-7.5	7.0-7.5	7.5-8.0	8.0-8.2	-	> 8.2	-	> 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	-	> 12	-	> 12
	ESP	0-8	8-10	10-15	15-20	-	>20	-	>20	-	>20
	CaCO3 (%)	0-12	12-25	25-35	35-50	-	>15	-	>15	-	>15
	Gypsum (%)	0-2	2-4	4-10	10-20	-	-	-	-	-	-
4	Drainage class	WE	-	MW	IM	Pod	PO	Pod	PO	Pod	PO

2.5 Weighted overlay and Model Construction

The use of the A weighted sum overlay technique was applied for the purpose of producing the land suitability maps for each industrial crops grown in Abyan Delta (e.i. Cotton, Sesame and Groundnut^[TSW56]). The It is an approach applied in a common scale of values to diverse and dissimilar input variables with the aim of creating an integrated analysis. It is indicated that this The weighted overlay process provides the researcher with opportunities to put into analyze multiple variables in a spatial environment consideration the geographic problems often demanding the analysis of different factors such is the case with as to determining the variables associated with crop-land suitability analysis [REFERENCE]. Since the importance of each variable these factors is not likely probable to be equal, the weighted overlay-

~~Such an~~
~~approach~~
~~also makes~~
~~the~~
~~application~~
~~of~~applies
different
weights to
different
thematic
layers
~~possible.~~
~~An overlay~~
~~operation is~~

part of spatial analysis processes based on the by weighting the value of each variable subclass within each thematic map [TSW57]. A weighted overlay was used to combine all factor [TSW58] layer maps into new information to produce an individual value for each pixel to produce a and a new maps were produced (in our case land suitability classification maps for each the selected crops). The weighting values used in the overlay operations were only performed on the following thematic raster maps [TSW59] such as soil chemical and physical characteristics maps (soil Texture, pH, EC_e, CEC, OM, TN, CaCO₃), Digital Elevation Model (DEM), slope and climate zones. The weighting value was given based on the influence of every subclass [TSW60]. Spatial data were converted into raster layers and projected to UTM Zone38 in ArcGIS 9.2. [TSW61] It should be noted that the heuristic value for factor and classification is given between 1 to 5 in this study, where value of 1 indicates that the influence of the given variable (factor, subclass or whatever standardized term you settle upon or result towards is very low while value 5 is very high. In this study all thematic maps already mentioned have been were combined through an index overlay with multi-class maps and summing of each pixel values, to produce the land suitability maps at 1: 25,000 scale to showing the potential of the area for the main crop land areas production based on the relative influence of each weighted relative factors and their weighted values. All these thematic maps were produced in digital format as a geodatabase of land resource characterization of the study area and ranked [TSW62]. The output data is expressed as a raster (grid) file which contains the of suitability class per celles. So that each cell in a grid is considered as a numerical storage of suitability classes for that 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 Figures 3 and 4. (REFERENCE ESRI ArcGIS version you are using for this figure.

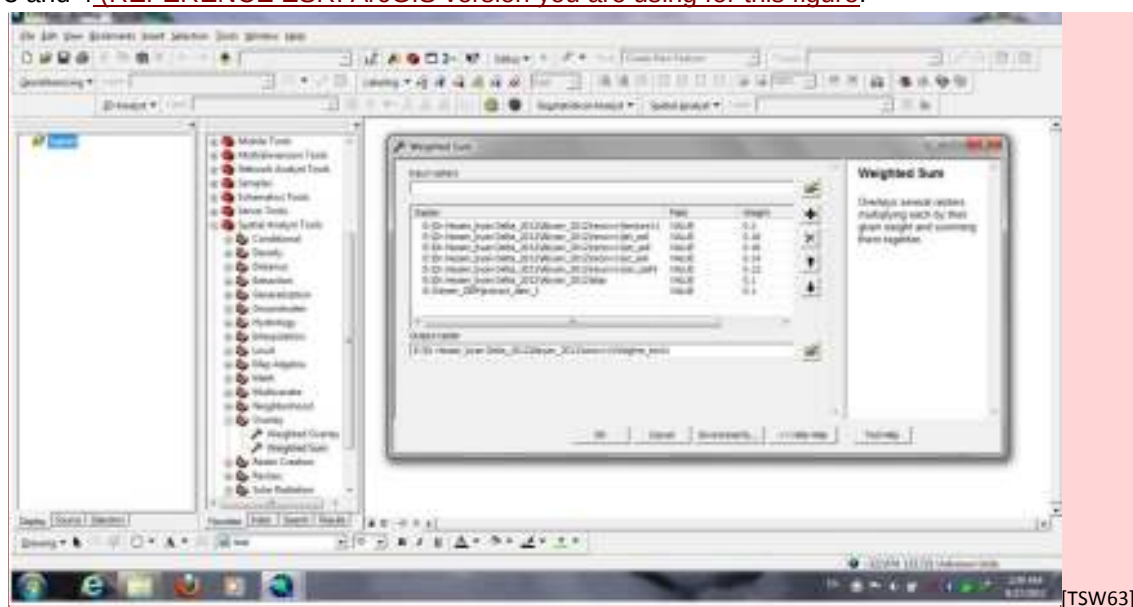
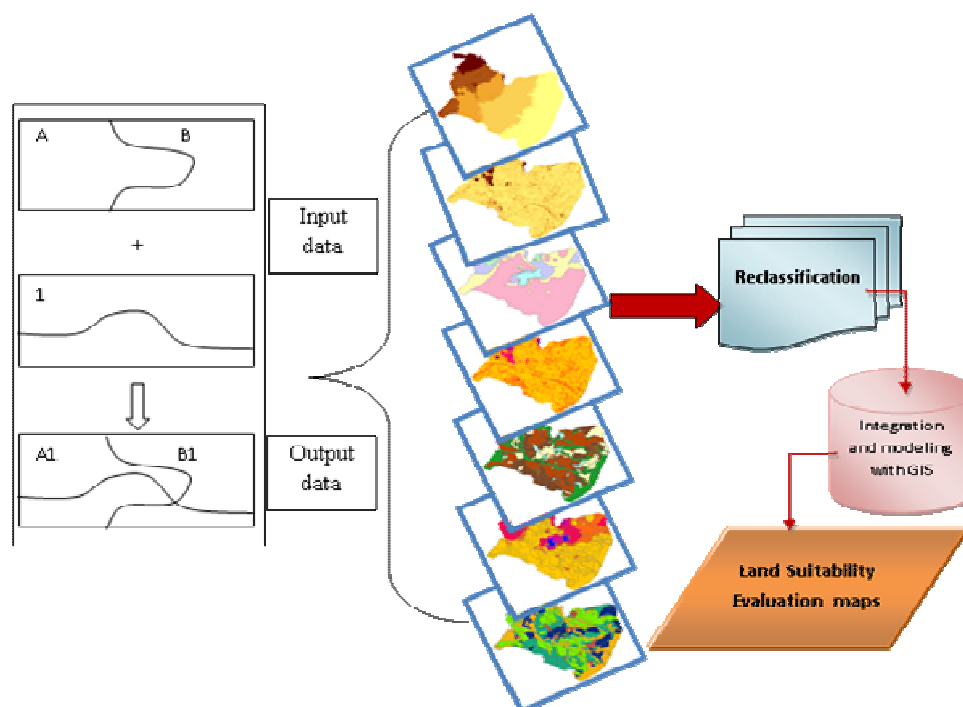


Figure 3: Overlay technique to generate land suitability evaluation map



[TSW64]Figure 4: Concept of the model of thematic maps for the study area

RESULTS AND DISCUSSION METHODS CONTINUED.....

3.1 Potential of GIS for land suitability evaluation

Classification of land suitability for sustainable use [TSW65] requires an understanding of conditions and processes controlling land characteristics and qualities in the study area. [TSW66] The main factors which could influence land suitability evaluation for the study area have been identified and analyzed and thematic maps such as Digital Elevation Model (DEM), slope, soil and land 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 [TSW67], drainage density [TSW68] have been produced to be overlaid. All these thematic maps were produced in a digital format as database of land resources characterization of the study area and ranked. [TSW69]

3.2 Modeling input data preparation

The potential land classification model [TSW70] was selected as due to the following reasons: 1) its outputs closely match the information requested by decision-makers, [TSW71] as well as data available for calibration; 2) it is extensively used worldwide in similar scales; 3) the required input data were seemed feasible to be obtained. Accordingly, the criterion and sources used are presented to establish the initial parameterization as input maps and single values respectively. This relies crucially on field experience with soil-water-land-use relations in the region where the model is to be applied. [TSW72] The highest and lowest realistic parameter limits [TSW73] for mapping the inputs change [TSW74] 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 the CGIAR-CSI (2008) website (<http://srtm.csi.cgiar.org/>). DEM of the study area has been produced where the area is classified into different elevation (Figure 5). Based on the Digital Elevation Model (DEM) and the topographic map, the slope map of the study area has been produced (Figure 6). However, the slope

gradient has a range between 0 to over 40 percent ~~across~~for the study area. Obviously, ~~t~~The steepest slope is the most susceptible location to soil erosion by both water and gravity ~~and therefore not suitable for cropland~~. ~~Based on this concept, the results show that t~~The slope map ~~washas been~~ classified into 5 classes using ~~a~~the 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%.

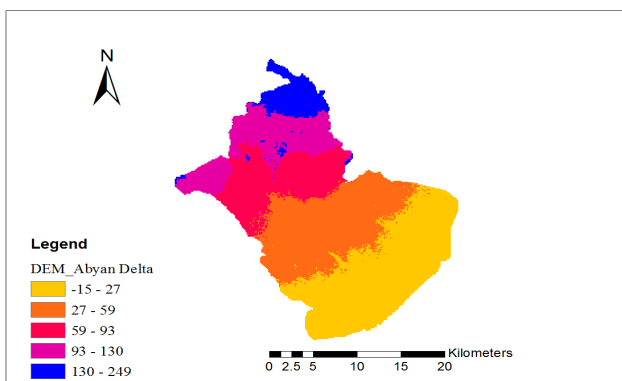


Figure 5: Digital Elevation Model (DEM)

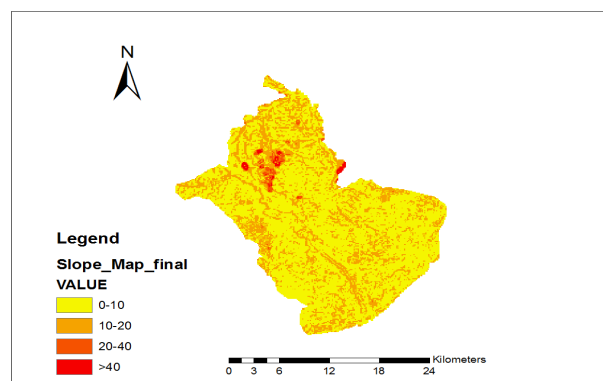


Figure 6: Slope (%) gradient map of the study area

Soil pH is the most important soil criterion in land suitability classification ~~asand~~ it controls many chemical soil characteristics and some physical soil properties ~~as well~~. ~~According to the analytical data of the soils samples, m~~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 7.5-8.5 followed by the range of 6.5-7.5 (Figure 7[TSW75]). 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 (Landon 1991). 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[TSW76]) (Figure 8).

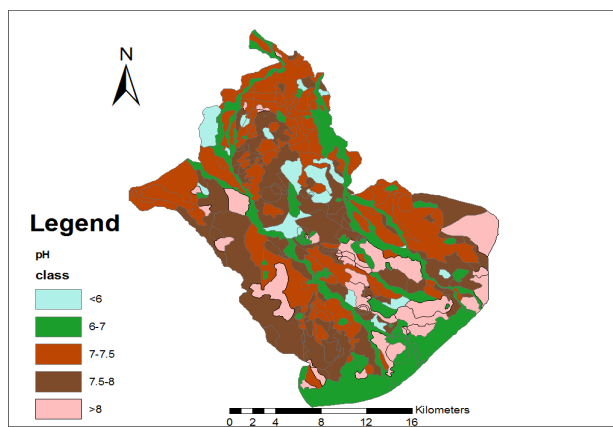


Figure 7: pH values map of the study area of the study area

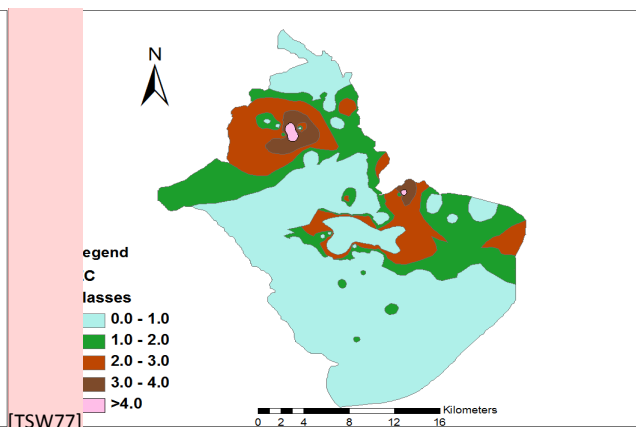


Figure 8: Electrical Conductivity soil map of the study area

With certain exceptions, levels of soil organic matter in the study area, ~~calculated from determinations of organic carbon arewere~~ very low, ~~being~~ within the range of 0.1-1.0%. ~~SOM~~its values decreased with depth in all soil profile pits ~~acrossef~~ the study area. So it can be concluded that the dominating soil fertility is very

low
(Figure 9).
The cation
exchange
capacity
(CEC) lies
in the range
of less than
5 to 35
cmol/kg of
soil, but
most soils
lie in the
range of 5
to 15
cmol/kg
followed by
the range of
15-25
cmol/kg
considering
low and
medium
respectively
(Figure
10).

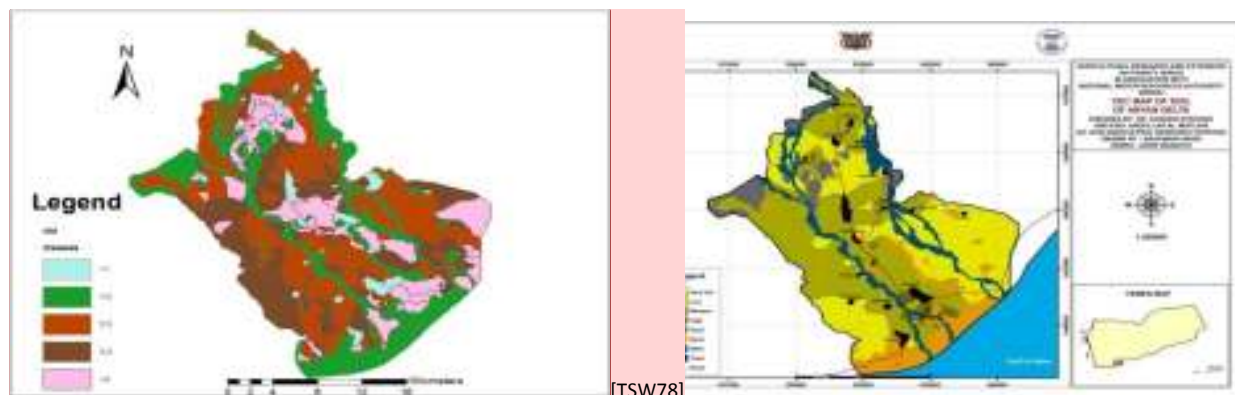


Figure 9: Organic matter content (%) values map of the study area

Figure 10: Cation Exchange Capacity (cmol/kg) map of the study area

Determination of the percentage content of Calcium Carbonate (CaCO_3) shows that the level in most soils in the study area is lie in the range between 10 and 15% (moderate) (Figure 11). The total nitrogen is very low as it is less than 0.005% and indicates high deficiencies (Figure 12).

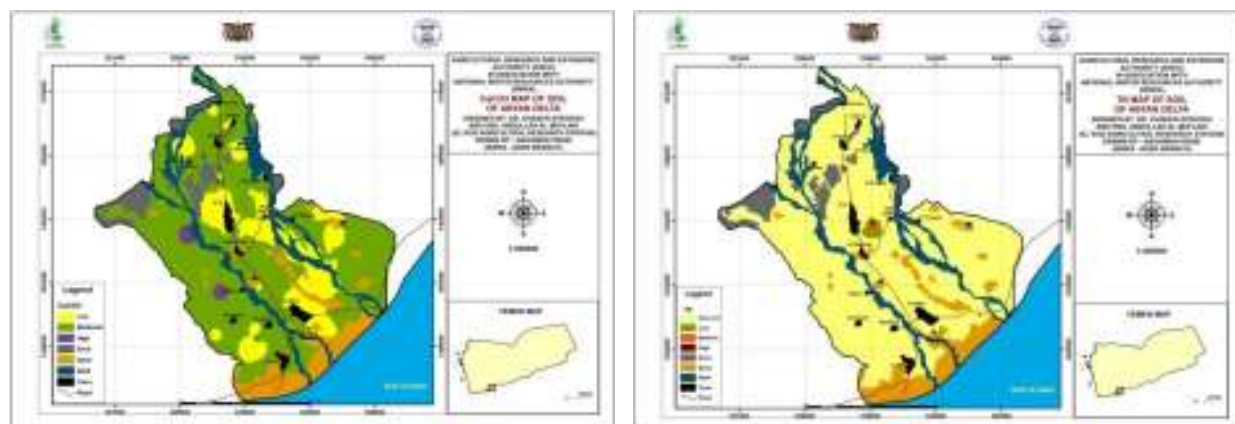


Figure 11: Calcium carbonate (%) in soil values map of the study area

Figure 12: Total nitrogen (%) map of the study area

The main soil textural classes are sand loam, loam, clay loam, silt loam and clay loam/clay (Figure 13). Available phosphorus levels are very low in most soils at the northwestern and some of the southeastern parts of the study area, less than 10 ppm and usually nil below the surface.

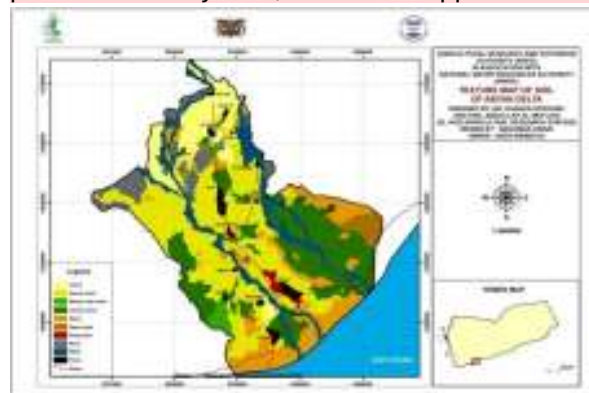


Figure 13: Soil textural classes values map of the study

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[TSW80]

3.3 Land Suitability Model Outputs RESULTS AND DISCUSSION

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^[TSW81] 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. The land suitability classes for each industrial these crops are presented in Table (4) and Figures (14 - 16), which summarizes the results of the land suitability evaluation, where five classes of land suitability maps have been given such as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently unsuitable (N1) and permanently unsuitable (N2) with the area covered by each class shown as hectare and percentage. They were all adapted from the FAO system. In this study all thematic maps already mentioned have been combined through an index overlay with multi-class maps and summing of each pixel 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. 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 condition in a condition that the requirement of water is met.^[TSW82]

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
Total mean	12075	19877	6787	879	13983	53600

Land suitability results show the From the GIS data as shown in Table 4, currently the total area of Abyan delta is 53600 ha of which only 14862 ha (27.6 percent) is unsuitable land (N1 & N2) for growing industrial crops. Highly suitable land units (S1) for the selected industrial crops are 12075 ha (22.5 percent), Moderately Suitable (S2) is 19877 ha (37.1 percent) and Marginally Suitable (S3) is 6787 ha (12.7 percent). If land condition is improved and updated from current physical suitability with appropriate management actioninput, increased potential land suitability couldwill be achieved^[TSW83]. Each land mapping unit is bases for the suitability analysis which collectively makes the overlaying thematic maps in GIS tool. ^[TSW84]The total output is portrayed in the thematic maps of the study area. In this case physical land evaluation includes parameter that satisfy requirement of the main crops cultivated in the study area. Final result of the land suitability evaluation of the study area show that 72.3 percent (38739 ha) land area (represent S2, S2 & S3) can supporthold the three good crops cultivation. Hence,Our results can be of this study has to communicated to farmers to assist them in making make full use of land potential for the development of the industrials crops cultivation. The major crop limitations includerefer to poor soil physical properties such as texture, soil depth, erosion and slope as observed in the majority of the areas. In addition. soil chemical properties such as low organic carbon content, calcium carbonate also inhibit successful cultivation etc.

3.4 Land Suitability for Cotton

The land suitability for cotton an important fabric crop grown in large areas of Abyan Delta has been shows carried out. A map showing the distribution of the suitability of soils for cotton was prepared and depicted in

(Figure 14). The highly suitable class (S1) accounts for 22.2%, moderately suitable (S2) constitutes 36.7%,

marginally suitable (S3) is 13.1% and the remaining 1.9% and 26.1% are currently not suitable (N1) and permanently not suitable (N2) respectively of the total area (Figure 14).

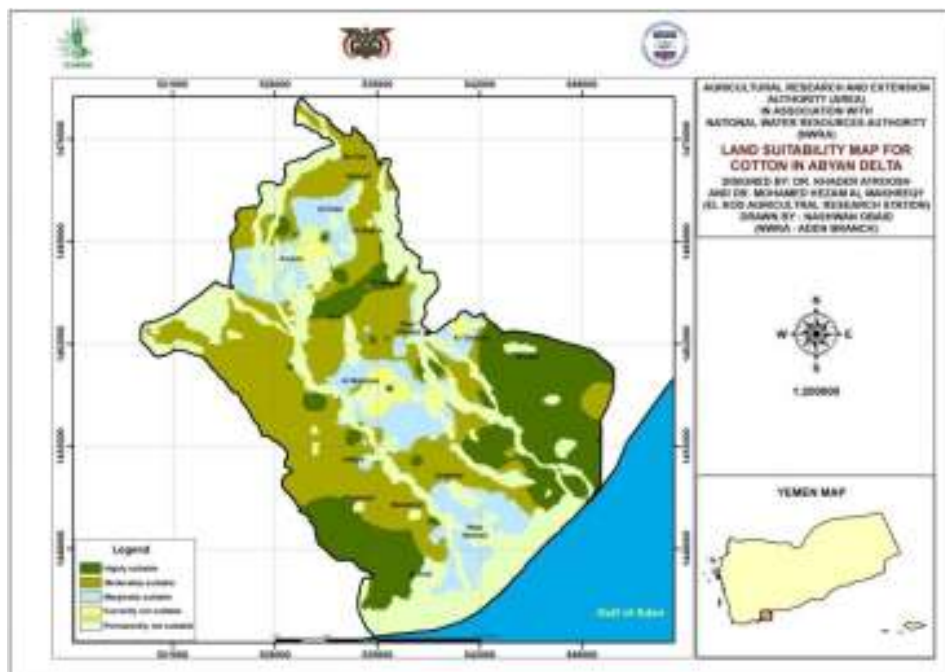


Figure 14: Overall suitability map for cotton crop in Abyan Delta

3.5 Land Suitability for

Sesame [TSW85]

The land suitability for sesame an important oil crop grown in ~~command areas of the~~ Abyan Delta ~~has been conducted. A map showing the distribution of the suitability of soils for sesame was prepared and depicted in (Figure 15).~~ The highly suitable class (S1) accounts for 22.6%, moderately suitable (S2) constitutes 37.2%, marginally suitable (S3) is 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 (Figure 15).

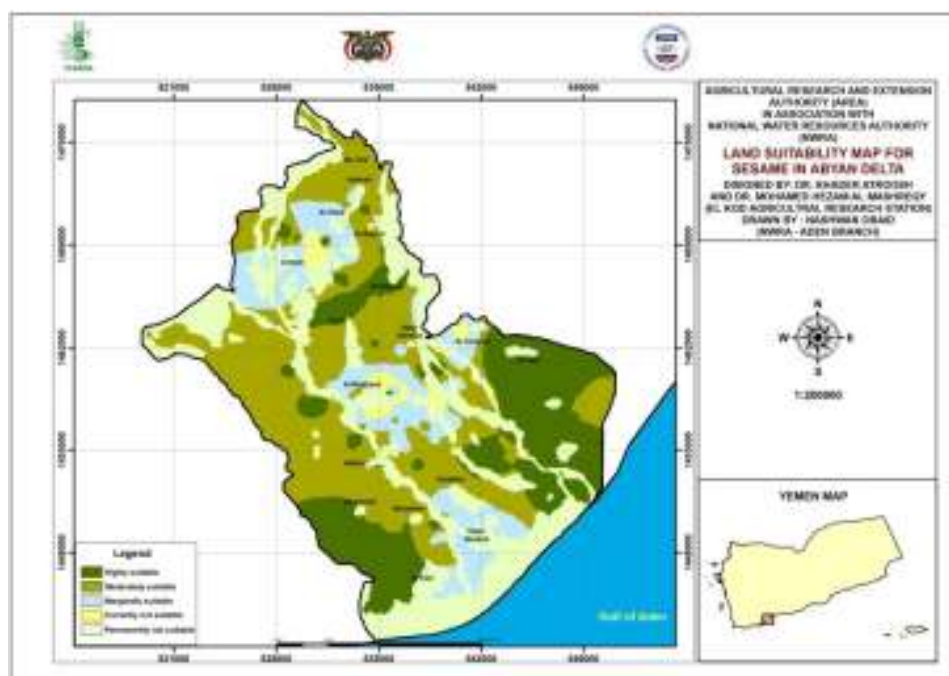


Figure 15: Overall suitability map for sesame crop in Abyan Delta

3.6 Land Suitability for Groundnut

Land suitability for groundnut, major nuts crop grown in dry land tracts ~~has been worked out~~ (Figure 16). Shows the highly suitable class (S1) accounts for 22.8%, moderately suitable (S2) constitutes 37.4%, marginally suitable (S3) is 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 (Figure 16).

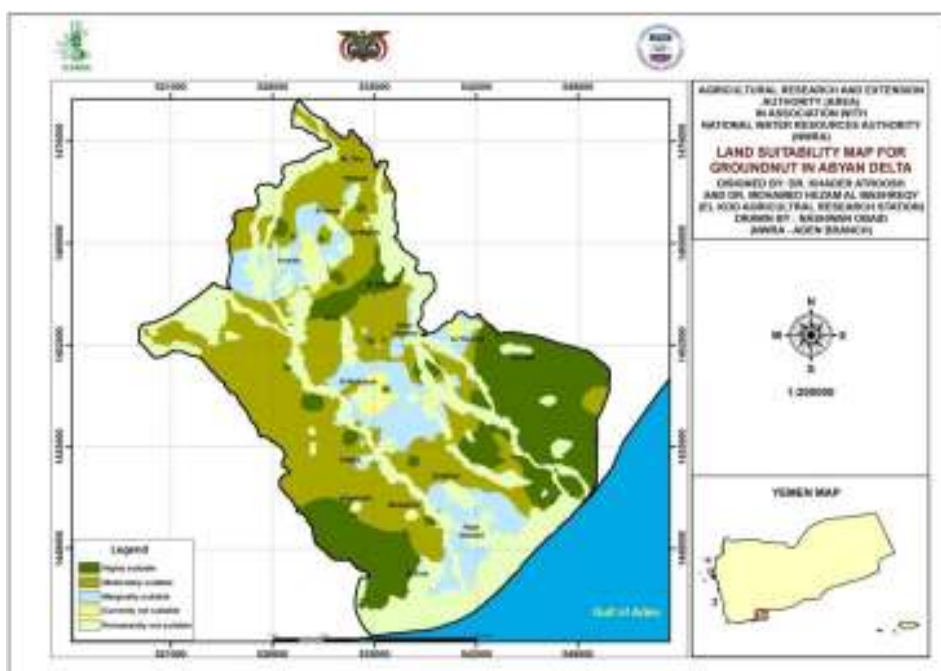


Figure 16: Overall suitability map for groundnut crop in Abyan Delta

3274. CONCLUSIONS

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329 ~~All the objectives of the study have been met and achieved. It has been found that A GIS weighted sum~~
330 ~~overlay technique has~~ve the potential and capability to integrate spatial and attribute data for producing
331 ~~thematic maps and generating~~ land suitability classification maps for the main industrial crops of the
332 ~~Abyan Deltastudy area. Physical land suitability method based on FAO Framework was developed~~
333 ~~using GIS technology through weighted overlay technique (GIS model).~~ The results are reflected by the
334 existing conditions in the study area logically and in an acceptable way. |
335 [TSW87]

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APPENDIX

Table 5: The soil analytical data

Sr · N o	UTM_E	UTM_N	Exch. Na (meq/10 0g)	ESP	CEC (meq/l)	pH	EC (mS/c m)	CaC O3 (%)	OM (%)	T N (%)	Avai. P (ppm)	Texture
1	537192	1468484	0.027	5.17	6.248	8	6.38	12.7	0.62	0.043	7.5	Loamy sand
2	536222	1468616	0.012	4.98	7.248	8.2	1.87	14.3	0.62	0.048	22	Sand loam
3	535204	1471243	0.023	3.2	5.352	7.7	14.3	10	0.43	0.035	8	Sand
4	531760	1468408	0.366	78.44	11.668	9.5	27.28	13.2	0.33	0.032	14.5	Sandy clay loam
5	532256	1466587	0.003	4.27	4.64	8.3	1.386	6.5	0.32	0.059	4.5	Sand
6	532534	1464985	0.002	8.21	4.682	8	4.312	8.5	0.34	0.028	10	Loamy sand
7	538247	1460243	0.009	2.77	7.54	8.2	1.452	7.5	0.27	0.021	9	Sand loam
8	538754	1460467	0.004	2.15	4.456	8.2	1.188	9.8	0.23	0.022	7.5	Loamy sand
9	539197	1458269	0.27	28.44	4.824	7.2	70.4	10.2	0.41	0.024	11.5	Sand loam
10	539968	1458237	0.004	3.99	4.228	8.4	1.21	7.6	0.11	0.015	6	Loamy sand
11	541714	1454492	0.006	3.44	5.258	8.2	1.276	7.5	0.13	0.018	7	Loamy sand
12	546699	1452130	0.003	3.09	5.968	8.2	1.98	13.5	0.48	0.035	15	Loamy sand
13	550246	1458197	0.004	13.92	9.682	8.1	10.21	13.5	0.34	0.034	15.2	Sand loam
14	547052	1461520	0.039	3.37	4.54	8.3	0.66	12.5	0.27	0.036	11.4	Sand
15	545023	1461602	0.004	3.3	4.258	8.2	6.82	8.8	0.13	0.013	8	Sand
16	544016	1460813	0.002	3.33	5.2	8.2	6.82	9.3	0.1	0.014	14	Loamy sand
17	544597	1460483	0.001	2.35	6.54	8	1.87	9.1	0.27	0.038	12	Sand loam
18	543017	1462222	0.004	3.11	4.228	8.2	2.2	7.3	0.11	0.013	3	Sand
19	543069	1461469	0.001	1.65	5.54	8	0.66	15	0.27	0.043	13	Loamy sand
20	535595	1462354	0.013	1.05	6.192	8.1	7.238	11.4	0.6	0.049	13	Loamy sand
23	535736	1458894	0.002	2.59	4.814	8.4	0.792	9.6	0.16	0.022	10.5	Loamy sand
24	535185	1458594	0.97	90.32	10.966	8.2	194	10.9	0.48	0.021	16	Sand loam

25	537661	1453938	0.013	4.27	9.738	8.3	1.43	15	0.37	0.038	20.5	Sand loam
26	536273	1448548	0.013	13.23	9.512	8.1	6.38	12.1	0.26	0.022	10	Sand loam
27	536434	1447973	0.01	11.48	4.814	8.5	1.254	6.8	0.16	0.02	12.5	Sand
28	535751	1448183	0.013	11.48	5.342	8.5	1.254	7.8	0.17	0.09	12	Sand
29	530961	1458116	0.12	5.87	8.73	8.3	1.848	12.1	0.87	0.048	12	Sand loam
30	533465	1455543	0.013	4.65	5.494	8.3	1.32	10.4	0.5	0.033	19	Sand
31	534903	1454071	0.045	16.39	5.898	8.1	6.82	11.8	0.2	0.027	16.5	Loamy sand
32	532865	1449710	0.013	7.51	11.758	8.3	1.54	11.8	0.13	0.022	10	Sandy clay loam
33	532087	1449351	0.011	2.84	6.908	8.3	0.682	9.3	0.45	0.04	10	Loamy sand
34	531302	1469190	0.011	3.13	6.238	8.3	0.902	9.9	0.37	0.093	14	Loamy sand
35	530513	1468874	0.585	72.72	15.532	8.7	94.6	16.8	0.77	0.072	8	Sand loam
36	528491	1469872	0.026	4.49	4.71	8.2	3.3	7.1	0.36	0.059	8	Sand

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