MINISTRY OF SCIENCE AND TECHNOLOGY
AGRICULTURAL RESEARCH CORPORATION
LAND AND WATER RESEARCH CENTRE
WAD MESKIEN PROJECT AREA

ENTRO Eastern Nile Irrigation and Drainage Studies

FIELD INVESTIGATION AT WAD MESKIN

SOIL SURVEY REPORT

PREPARED BY

LAND AND WATER RESEARCH CENTRE

FOR

SHOURACONSULT CO.LTD

FINAL REPORT

WAD MEDANI **LWRC: SSR No. 182**

APRIL 2010

SUMMARY

This study has been requested by SHORACONSULT CO. for EASTERN NILE TECHNICAL REGIONAL OFFICE (ENTRO**)** to map and evaluate an area of 9,000 hectare between Hawata and Wad Miskeen on the right bank of the Rahad River, Sudan , as part of the African development Bank funded Eastern Nile Irrigation and Drainage Study (ENIDS).

The Terms of Reference (Article 1) required the consultants to find a net area of 9,000 ha of land suitable for irrigated agriculture.

The main objective was to identify and evaluate the soils of the project area for irrigated agriculture.

The field survey was based on grid survey system at interval of one observation every 100ha (1 km X 1km grid). Observations were made to 100 cm soil depth, and two samples at 0-45 and 45-90cm were collected from each site and analyzed for EC, pH and ESP. Six soil profiles were dug, described, sampled and analyzed.

The soil analytical data was used to evaluate the soils for irrigated and the results revealed the following:-

- All soils are non-saline and non-sodic.
- 72% of the total area is 6912 ha has been classed as S2, moderately suitable for irrigated agriculture.
- 27.1% of the total survey area, 2593 ha has been classed as S3, marginally suitable for irrigated agriculture at their current condition and if certain measure were taken, they could be upgraded to S2.
- 0.9% of the total area is classed as N2 permanently unsuitable land.

This report contains information about the area, the environment, the soils and their chemical and physical properties, field and laboratory data, soil and suitability maps, and a review of previous studies.

The field work took two weeks. The field team from the Land and Water Research Centre (LWRC) consisted of:

- Dr. Abdelmagid Ali El Mobarak – team leader
- Dr. El Fatih El Agib - team member
- Syd. Abdelrahiem El Tayeb - team member
- Syd. Omer Belail - camp manager

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1. ENIVIRONMENT

1.1 Location and Extent

The study area lies south of the railway line, and east of Hawata town. It covers an area of about 9,600 ha it is located between latitudes 1,472,500- 1,478,000 m. and longitudes 678,000- 695,000 m in zone 36P- WGS-84. It extends southeast from the railway to Ingammena village. Fig.1.1 shows the location of the area.

1.2 Climate

The climate of the area is tropical sub-humid with annual rainfall between 500-800mm and 2-3.9 humid months (Walsh, 1991). This climatic zone is suited for dry land farming system and lies within the major zone for mechanized agriculture. According to van der Kevie (1976) the area lies within the semi-arid climatic zone (Figs.1.2 and 1.3) shows the rainfall and the potential Evapotranspiration in two stations one to the east (Gadarif) and one to the west (Abu Naama) of the survey area both stations are about 100 km From the area, while Table 1.1 shows long term rainfall for Hawata town.

The moisture calendar for the Gadarif and Abu Naama stations is calculated using Newhall Simulation Model programme for the moisture and temperature regimes and the tentative subdivision for the moisture regime is given (Van Wambeke *et al*, 1986). This calendar is used to calculate the beginning and end of the rainy season (Tables 1.2 and 1.3).

1.3 Geology

The area represents the eastern part of the Central Clay plain of Sudan. (FAO, 1970) It is covered by thick clayey deposits of colluvial-alluvial origin. The colluviated material is originating from the Gadarif-Gallabat ridge while the alluvial material is brought from the Ethiopian highlands by the Blue Nile and its tributaries. Far to the east of the area there are isolated inselbergs on the Basement complex rocks.

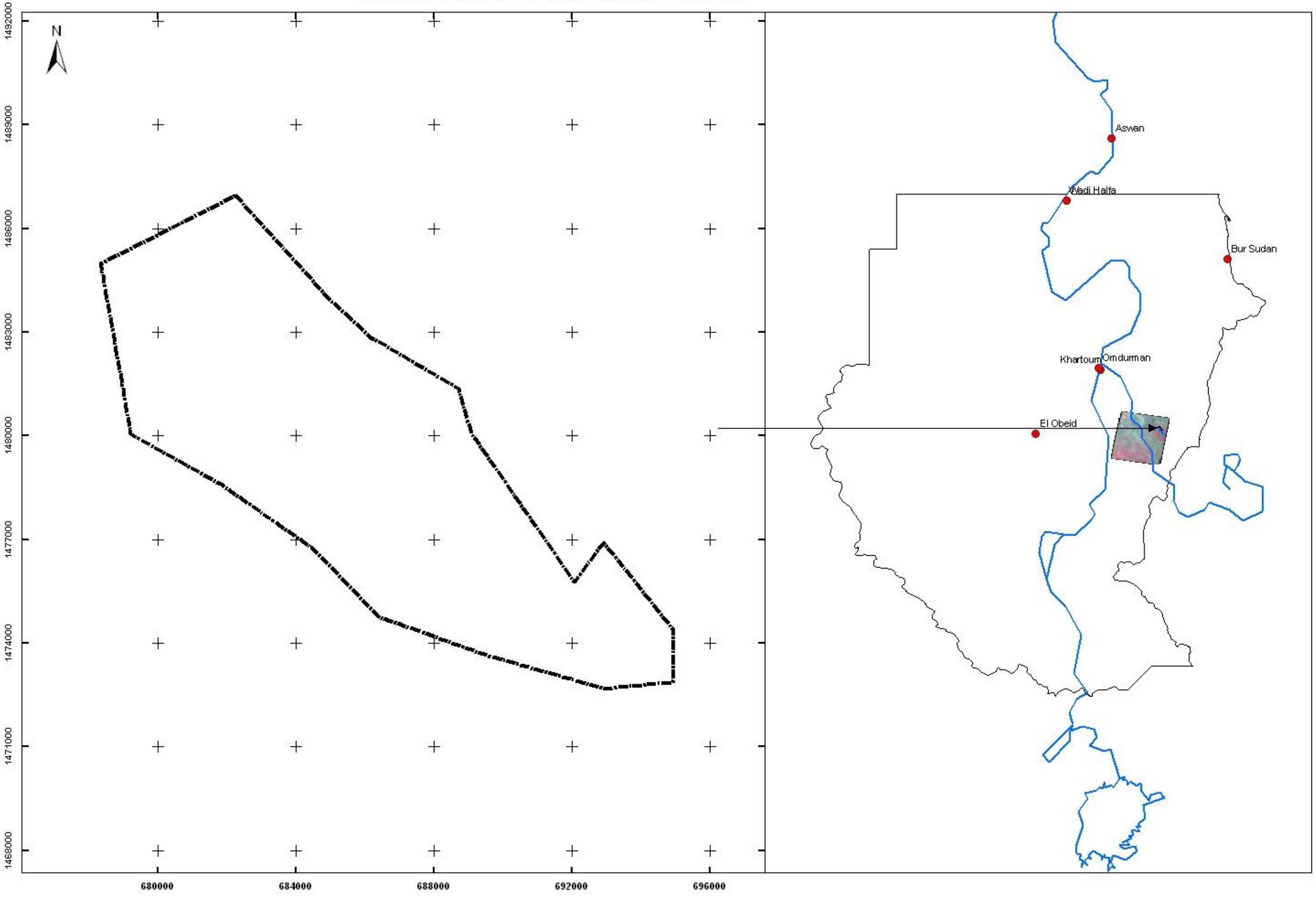
The dominant topographic feature is the cracking clay which covers the whole area. The landscape is gently sloping from southeast to northwest draining towards the Rahad River. The main features of the western part include a low lying area (depressions) with water pools (Mayas), cut off meanders, and ox-bow lakes. These constitute the recent and old flood plain of the Rahad.

Hunting Technical Services (1966) reported that the clay deposits are believed to be a weathering product of the basement complex of the high surrounding areas. All previous studies stated that the alluvial deposits of the Blue Nile and Rahad can hardly be found in areas above 400 masl contour line. The area is above the 400 m contour line therefore considered as colluvial –alluvial except some parts near Rahad River as alluvial.

The area is underlain by Basement Complex. Outcrops of this Basement are clearly seen on the east of the project area. The main rock types are gneises and granites (GRAS, 1988)

	MINISTRY OF SCIENCE AND TECHNOLOGY AGRICULTURAL RESEARCH CORPORATION LAND AND WATER RESEARCH CENTRE WAD MESKIEN PROJECT AREA	

Fig.1.1 Location Map of Wad Miskeen Survey Area

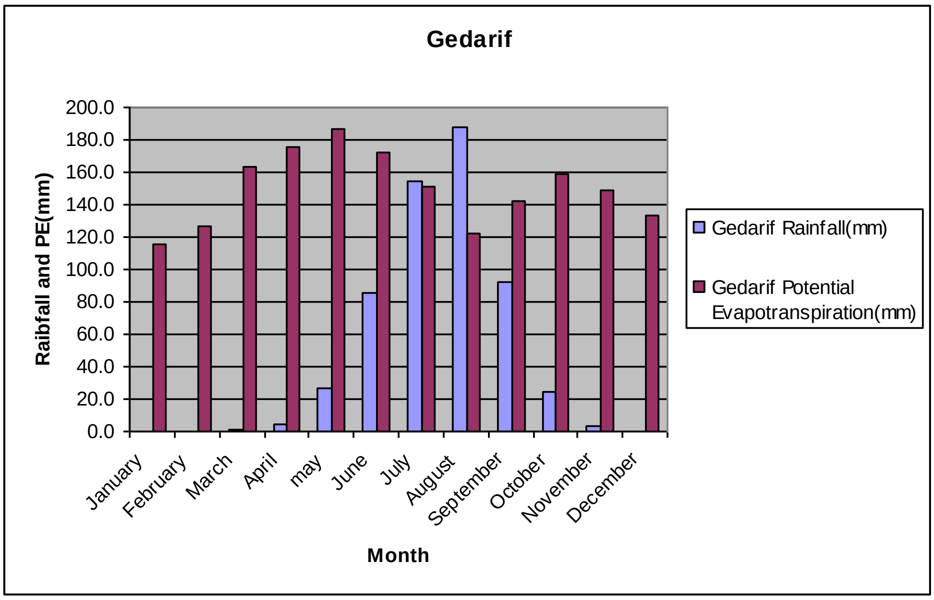


Source : LWRC, Wad Miskin Soil Survey, 2009

Table 1.1 Long term Mean Annual Rainfall for Hawata

Station Name	Period	Long (º)	Lat (º)	Alt masl	Jan mm	Feb mm	Mar mm	Apr mm	May mm	Jun mm	Jul mm	Aug mm	Sep mm	Oct mm	Nov mm	Dec mm	Annual mm
HAWATA	1950-1988	13.40	34.60	440	0	0	0	1.2	15.1	99.5	154.1	201.7	79.5	15.8	0.6	0	568

Fig.1.2 Rainfall and Potential Evapotranspiration of Gadarif Station



Source: Sudan Meteorology Department

Table 1.2 Moisture Calendar for Gadarif Station

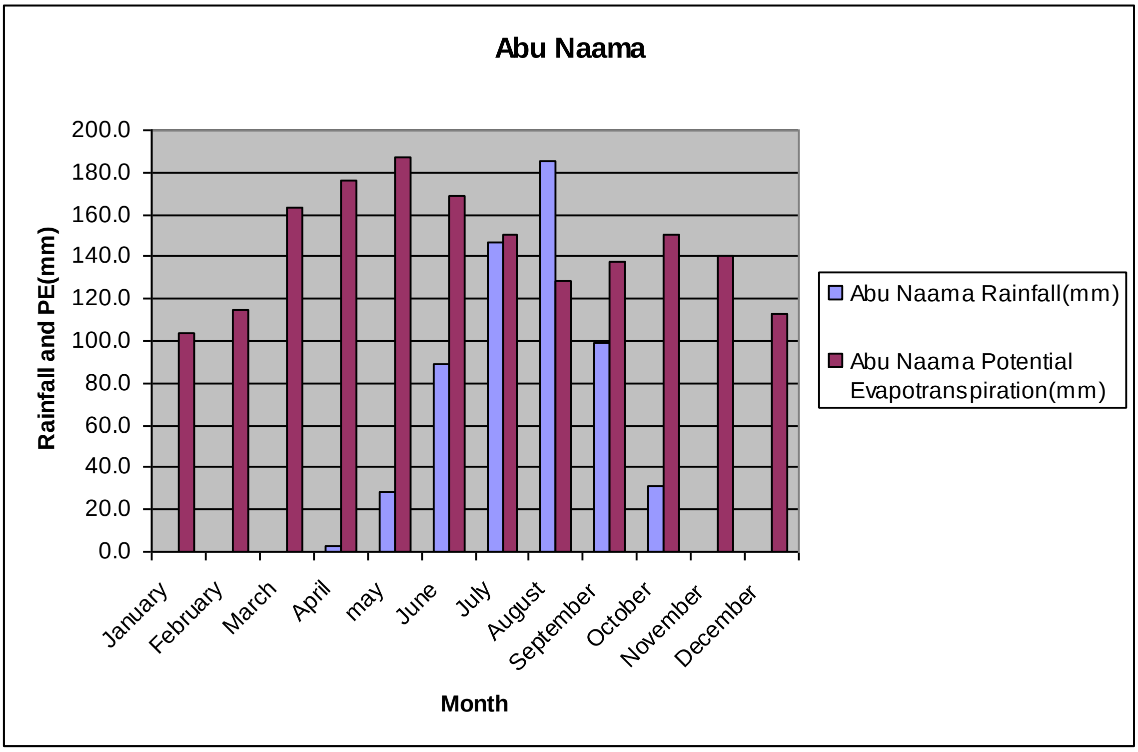
	1************15**************30
January	111111111111111111111111111111
February	111111111111111111111111111111
March	111111111111111111111111111111
April	111111111111111111111111111111
May	111111111111111111111111111111
June	111111111111111222222222222211
July	111111111111111333333333333333
Aug	333333333333333333333333333333
September	333333333333333333333333333333
October	333333333333322222222222222221
November	111111111111111111111111111111
December	111111111111111111111111111111

1=dry; 2= dry/moist; 3= moist
Temperature Regime: Isohyperthermic

Moisture Regime: Ustic

Tentative subdivision: Aridic Tropustic
Calculated by: Basic Program NSM, Nov.1986
Source: Van Wambeke *et al*, 1986.

Fig.1.3 Rainfall and Potential Evapotranspiration of Abu Naama Station



Source: Sudan Meteorology Department

Table 1.3 Moisture Calendar for Abu Naama

	1************15**************30
January	111111111111111111111111111111
February	111111111111111111111111111111
March	111111111111111111111111111111
April	111111111111111111111111111111
May	111111111111111111111111111111
June	111111111111111222222222222211
July	111111111111111222222222222222
Aug	222222222222222333333333333333
September	333333333333333333333333333333
October	333333333333332222222222222222
November	211111111111111111111111111111
December	111111111111111111111111111111

1=dry; 2= dry/moist; 3= moist

Temperature Regime: Isohyperthermic

Moisture Regime: Ustic

Tentative subdivision: Aridic Tropustic

Calculated by: Basic Program NSM, Nov.1986

Source: Van Wambeke *et al*, 1986.

1.4 Vegetation and Land Use

The northern part of the area is cleared for rainfed cultivation with patchy shrubs of Acacia spp. Table 1.4 shows the local and botanical (Latin) names of the trees and shrubs found in the survey area. The southern is covered with a dense trees and shrubs cover, where a private forest owned by a farmer who used to sell the trees for coal and wood as fuel wood. The forest regenerates naturally. Figs.1.4 and 1.5 shows the distribution of the trees and shrubs cover of the area. The tree and shrubs cover is found to be:

Trees			shrubs		
Code	description	Area (ha)	Code	description	Area (ha)
0	No trees	8700	1	<5% shrubs cover/ha	5800
1	1-10 tree/ha	700	2	6-10% shrubs cover/ha	1000
2	11-25 tree/ha	200	3	11-25% shrubs cover/ha	2800

According to the Ministry of Agriculture Office in Hawata(personal communication), the ownership in the survey area lands consists mainly of privately owned schemes of 500-1000 feddans; 16,000 feddans is allocated to a refugees project, another 1600 feddans for small farms also for refugees; and small holdings of 7-10 feddans that are owned by villagers.

The yields for different crops are very low with sorghum yields between 130 to 200 kg / feddan; sesame yield is about 190 kg/ feddan; millet 230 kg/ feddans; and groundnut are about 7 sacks/ feddan. The extension officers of the State Ministry of Agriculture attributed these low yields to the removal of vegetation cover, and continuous use of the wide disk level for ploughing a shallow layer that rarely is deeper than 15 cm.

Table 1.4 Local and Latin names of the trees and shrubs

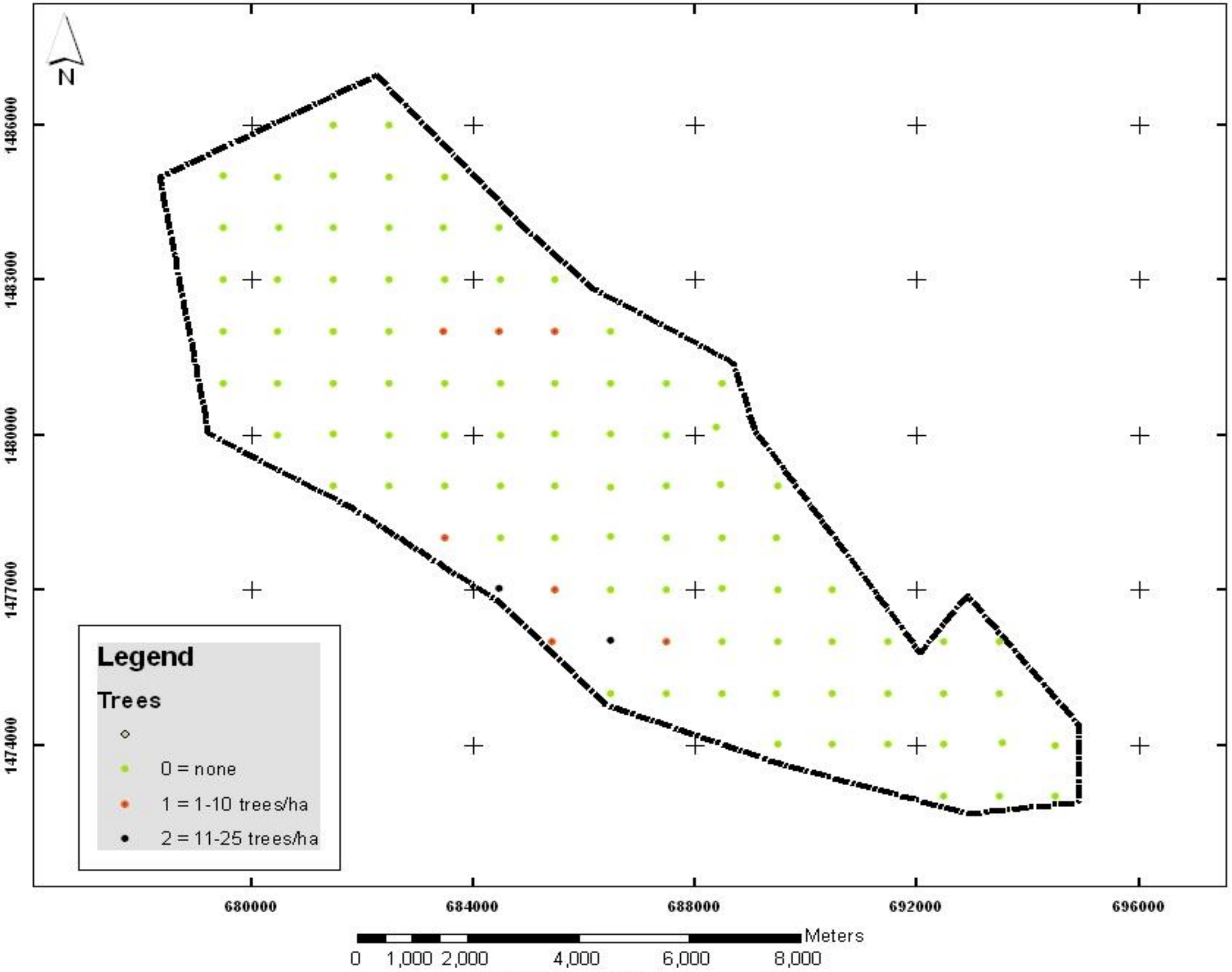
Trees:

1. Local name	Latin name
2. Heglig	*Balanites aegyptiaca*
3. Talih	*Acacia seyal*
4. Hashab	*Acacia senegal*
5. Sunt	*Acacia nilotica*
6.Sidir	*Ziziphus spinachristi*

Shrubs:

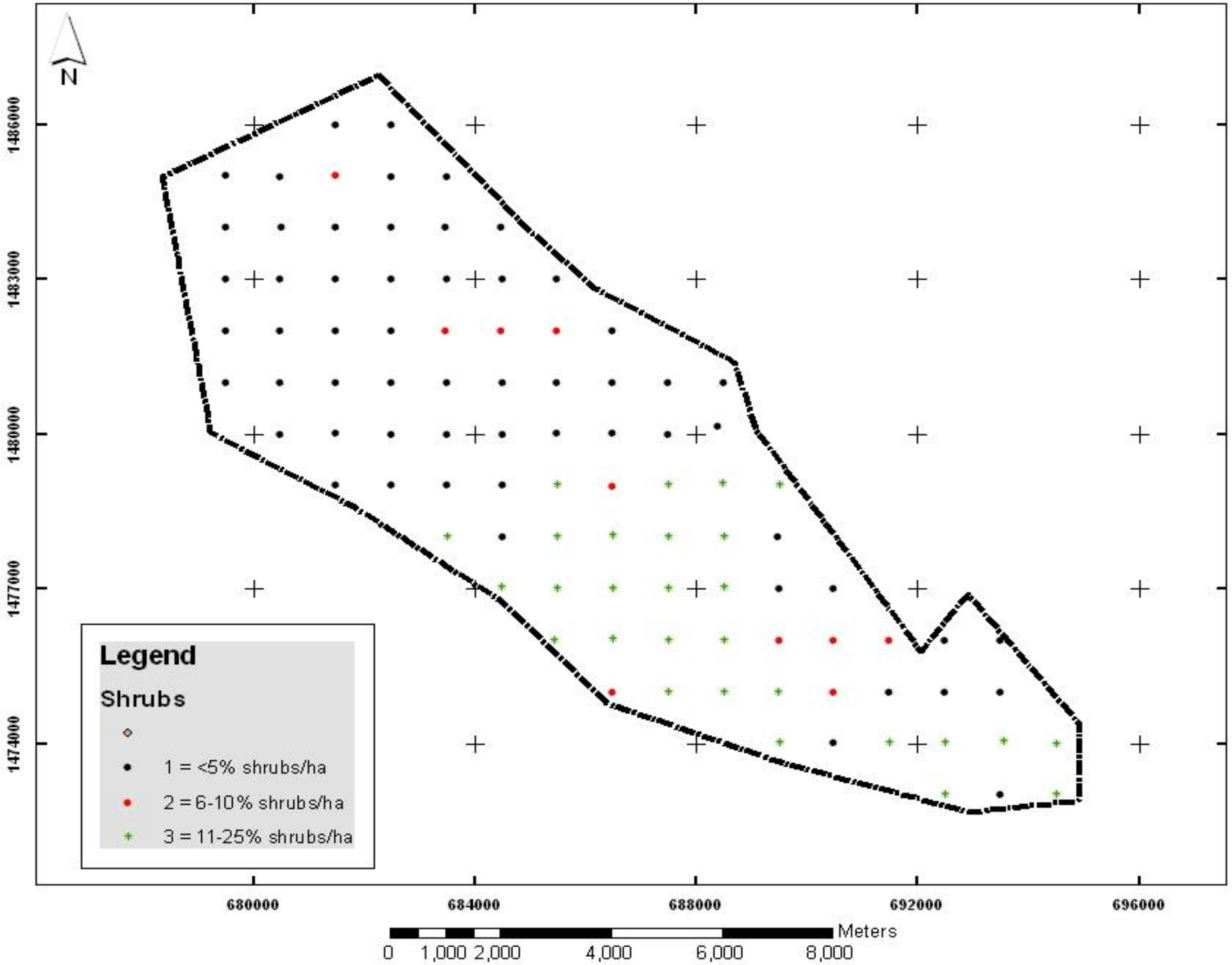
Local name	Latin name
Hashab	*Acacia senegal*
Talih	*Acacia seyal*
Laot	*Acacia nubica*
Kitir	*Acacia mellifera*
Ushar	*Calotropis procera*

Fig. 1.4 Distribution of Trees Cover in Wad Miskin Area



Source : LWRC, Wad Miskin Soil Survey, 2009

Fig. 1.5 Distribution of Shrubs Cover in Wad Miskin Area



Source : LWRC, Wad Miskin Soil Survey, 2009

2. SOIL SURVEY METHODOLOGY

2.1 Use of previous soil surveys

All of the survey area has been previously mapped at a semi-detailed level by Hunting Technical Services (1966) and by the General Soil Survey Administration now (LWRC) (1993).

The density of auger and pit observations is overall one site per 100 ha. The location of the sites is manually located, not accurately geo-referenced. There are 96 auger sites from HTS and 4 profiles pits from SSA with chemical analyses attached to this report.

We have studied the previous data and have incorporated their findings into the present survey as follows:

All previous auger and profile sites that can be located have been included in our maps.

All analytical data have been consulted and used in our assessment of soil types and land suitability.

We have reviewed the previous survey data and concluded that:

- Soils are very similar and do not need to be separated or/and features visible / mapped from imagery show no soil difference on the ground.
- Our survey enhances on the earlier work by making a more intensive survey.
- All previous surveys show the presence of shallow 'receiving' sites on the clay plain close to Rahad River: these were based on the use of aerial photography that is no longer suitable due to land use change. They are very difficult to precisely define in the field and do not always show up on recent dry-season imagery. We have taken particular care to delineate these features by a combination of field observation and detailed contours.

2.2 Field survey

The intensity of field survey was one soil auger observation per 100 hectares. If combined with HTS at the same intensity, then the overall intensity is one auger site every 50 hectare.

Field survey was located by GPS and adhered to a basic 1.0 km x 1.0 km grid. The survey comprised soil auger observations to 1.0 m and soil profile pit descriptions to at least 2.0 m at selected sites representative of all the major soil types.

A total of 96 augers and 6 profile pits were made. The location of all pit and auger sites is shown on the accompanying Soil and Land Suitability Maps. The GPS co-ordinates (WGS-1984, UTM) of all sites are given in Appendices accompanying this report

Field recording of soil auger sites and soil profiles was on standardised proforma and soils were described according to the "Guidelines for Soil Description" (FAO, 2006).

The following site, land and soil information was recorded at each auger site:

- Auger number; Surveyor; Date; GPS co-ordinates(WGS-1984, UTM); Landform; Topography; Slope; Site; Surface Features; Termitaria; Trees; Shrubs; Land Use; Water-table; Soil drainage class; Samples; Soil type; Depth of cracking; Soil code; Soil horizons (for each: boundary, colour, colour code, mottles, texture class, cracks, clayskins, slickensides, coarse fragments, reaction to dilute hydrochloric acid, calcium carbonates, iron-manganese, gypsum, other features).

In the field, all auger data were stored onto an MS Excel spreadsheet (see appendices). At all auger sites soil samples were collected from the 0-45 and 45-90 cm depths for salinity (EC) and sodicity (ESP) screening. All the results are included in the soil auger database.

The results of bulk density and hydraulic conductivity analyses from selected sites are also included.

2.3 Soil analyses

A total of 36 soil samples were collected from the soil profile pits and these samples were analysed in the LWRC laboratories in Wad Medani. Table 2.1 shows the analyses that were undertaken and the methods used.

Table2.1 Soil Analyses and Analytical Methods

• Particle Size Analysis All results refer to oven dry soil. The soil was treated with HCL acid to destroy calcium carbonate, washed to remove soluble salts, dispersed with calgon and boiled. Pipette method used to determine the clay fraction and wet sieving for the separation of the fine and coarse sand fractions. The silt fraction was obtained by subtraction from 100 %. Coarse and medium sand 2.0 – 0.25 mm; fine sand 0-25 – 0.05 mm; silt 0.05 – 0.002mm; clay < 0.002mm.
• Soil Textural Class The FAO textural triangle was used to determine the different textural classes of soils.
• Dry Bulk Density (BD), g/cc Determined using natural soil clods (Brosher, 1966).
• Coefficient of Linear Extensibility (COLE) Calculated as the difference between bulk density values measured at 1/3 bar and oven dry condition.
• Available Water Capacity (AWC), mm/m The AWC was calculated as the difference between moisture contents at 1/3 (field capacity) and 15 (wilting point) bars as measured by pressure plate.
• Hydraulic Conductivity (HC), cm/hr Determined by the constant method on disturbed soil samples (Black, 1965).
• Organic Carbon (OC), %

Modified Walkely & Black method. Oxidation of soil samples was carried out using potassium dichromate and sulphuric acid. The excess K-dichromate was titrated with ferrous ammonium sulphate. Recovery factor is 0.77.

- Total Nitrogen (N), %

  Modified micro-Kjeldahl method. Pre-moistened soil treated with concentrated sulphuric acid for digestion. Distillation using NaOH for ammonia liberation which was received in 2% boric acid and titrated using 0.01m sulphuric acid.

- Available Phosphorus (P), ppm

  Determined by Olsen sodium bicarbonate extract method.

- Soil pH

  Determined on the saturated soil paste. The pH was read by a glass/calomel electrode (concentrated KCL) system.

- Calcium Carbonate ($CaCO_3$), %

  Titration. The soil was boiled with 1N HCL. Excess acid was titrated versus 1N NaOH using phenophthelin indicator.

- Electrical Conductivity (EC) dS/m at $25^{O}C$

  Saturated soil paste prepared by adding soil to a known quantity of water to paste consistency. Saturation extract was sucked off using a vacuum pump. EC of the saturation extract read from a battery-operated conductivity meter.

- Cation Exchange Capacity (CEC), cmol(+)/kg soil

  The soil was treated with IN sodium acetate (pH = 8.2) and washed with ethanol (95%). The adsorbed sodium was extracted from the sample using ammonium acetate solution (pH=7.0). Sodium concentration in the extract was determined by flame-photometer.

- Exchangeable sodium (Na), calcium (Ca), Magnesium (Mg) and potassium (K), cmol(+)/kg soil

  Exchangeable Na and K extracted with IN ammonium acetate (pH=7.0) and determined by flame-photometer. Ca and Mg extracted by triethanolamine plus barium chloride and titrated versus potassium permanganate.

- Soluble Cations and Anions, me/l

  Soluble Na was determined in the saturation extract by flame-photometer. Ca and Mg were determined by titration with EDTA. Soluble K, which is usually cited as traces or in negligible values, was determined using the flame-photometer. Carbonates and bicarbonates and chlorides were determined by extraction using the H_2SO_4 and $AgNO_3$ respectively. Sulphate (precipitated as barium sulphate) was gravimetrically determined.

- Exchangeable Sodium Percentage (ESP)

  ESP = (Exchangeable Na ÷ CEC) × 100

- Sodium Adsorption Ratio (SAR)

  SAR = Na / (√ Ca+ Mg/2); Soluble Na, Ca and Mg substituted in the equation, are in meq. /litre.

  Trace element analyses (manganese, zinc, copper, iron)

  Results in mg/Kg (ppm) were determined by atomic absorption in the extraction solution: (DTPA+$CaCl_2$ at pH 7.3).

2.4 Data management and mapping

MS Excel spreadsheets compatible with ArcGIS version 9.x are used for data management and mapping. All field and laboratory data were recorded initially in MS Excel spreadsheets so that all data can be displayed in GIS.

All soil auger sites and soil profile pits were classified into their appropriate 'soil unit' as outlined in chapter 3 and 'land suitability class' as described in chapter 6 by interrogating the databases against defined criteria for the soil units and land suitability classes.

For the Soil Map, the 'soil unit' classification of every auger and pit site was plotted onto:

- 1:10,000 scale contour maps (for final map compilation).

The map datum is WGS 84 and the auger and profiles sites have the same datum.

The Land Suitability Map was derived from plotting the 'land suitability' classification of every auger and pit site onto the final Soil Map (at 1:10,000 scales). Final land class boundaries were interpreted, drawn and then digitised.

3. SOIL CLASSIFICATION AND MAPPING

3.1 Soil units

Vertisols cover the whole survey area. They are deep[1] cracking clays with a smectitic mineralogy formed under a semi-arid climate.

Conventionally, Vertisols are classified as ‘chromic’ if they are brownish or greyish coloured and ‘typic’ if they are very dark coloured. The soils of the area are mainly Typic with very few sites identified as Chromic. All soils have very fine clay family class (> 70% clay).

3.2 Soil phases

Where the soil units have features that will affect the use or management of the land we have identified soil phases, for example VTg gently undulating, VTd seasonally flooded. These phases are shown in Table 3.1.

Table 3.1 Soil Phases

g	Gently undulating (2-3% slope)	10%
d	Seasonally flooded (receiving sites; shallow depressions)	25%

3.3 Classification of soil units and phases

Each soil unit has been classified according to the Soil Taxonomy (USDA, 1999) and the Keys to Soil Taxonomy (USDA, 2006). This classification is based on the soils’ control section (25 cm – 100 cm depth) and is shown in Table 3.2. The typical classification is given.

Table 3.2 Classification of the Soil Units

	USDA soil classification	Typical profiles
Vertisols		
VC	Chromic Haplusterts	5
VT	Typic Haplusterts	1;3;6

The soil properties that have been considered during the soil survey to classify the soil units and their phases are:

- soil climate;
- degree of soil profile development;
- presence and absence of cracks, cracking pattern and pressure faces;
- presence, quantity and distribution of clayskins, slickensides and pressure faces;
- Clay percent;
- levels and distribution of ESP;
- levels and distribution of EC;

[1] ‘Deep soil’ in an irrigation context is taken to be 2.0 m. Less than 2.0 m depth, the soil is described as ‘shallow’.

- presence, nature and distribution of gypsum content;
- soil depth to hard rock;
- thickness of any sand or loamy sand;
- Evidence of any recent alluvial deposition.

3.4 Description and characteristics of soil units and phases

A full description, with supporting chemical analyses and photographs is given in the appendices attached to this report for each soil profile, representing the major soil units and their phases. The profiles most typical of each soil unit are listed in Table 3.2. Following is a brief description of the soil units.

Soil Unit	Description
VT	Deep flat cracking, very fine clay, very dark grey or very dark grayish brown
VTg	Similar to VT, but gently undulating
VTd	Similar to VT, occupying low-lying sites
D	Mostly VT, occupying very low receiving sites(Mayas)
VC	Deep , flat, cracking very fine clay, Brown, dark grey or dark grayish brown

3.5 Soil mapping units

Every soil auger and profile site with their phases has been plotted on a project contour map, lines drawn include as much as possible the same soil unit or phase. The contour base map highly influenced the positioning of every soil boundary.

The recorded slope measurement and topography classification of every auger site is used for mapping the undulating, gently undulating or depression phases of the soil units along with the contour map (Table 3.3).

Table 3.3 Soil Mapping Units

Mapping Unit	Dominant soil unit	Other soil units	Area	
			Ha	%
VT	VT		6624	69
VTd	VTd		2315	24.1
VTg	VTg		288	3
VC	VC		288	3
D	VTd		85	0.9

Maps of the different soil units are attached to this report at scale 1:10,000 as well as land suitability maps. For salinity and sodicity mapping it was found on this survey that there are no saline or sodic soils (all soils are non-saline and non-sodic), so these maps are not added.
The mapping unit D is a low lying sites (maya\) used a water reservoir during the dry season for human and animal use. It is evaluated as N2 permanently unsuitable land for agricultural use.

4. PHYSICAL AND CHEMICAL PROPERTIES OF SOIL MAPPING UNITS

The field, chemical and physical data are attached to this report and give full view of the soils of the area. The data is briefly summarized and discussed in the following sections.

No tests were carried out for infiltration rate on the Vertisols because conventional methods don't properly apply to shrink-swell smectitic clays.

Evaluation of the trace elements levels follows Fink and Vankateservanto (1982) where:

Element	Mn	Zn	Cu	Fe
Critical level	5.00	0.75	1.50	2.50
Method	DTPA	DTPA	DTPA	DTPA

The results of the trace elements analyses are shown in Tables 4.1, 4, 2 and 4, 3. The data showed that:

- Cu and Zn are below the critical levels.
- Fe is above the critical level.
- Mn is very high, in some cases it reaches the toxic levels (the range for Mn toxicity is 100 to 600 ppm) as outlined by Tandon, 1995.

4.1 Very dark greyish brown cracking mapping unit (Typic Vertisols, VT, VTd, VTg).

These soils (VT) have dark colour (values moist is 3 or less) and chromas of moist colour less than 3 throughout the soil profile.
Two units are recognized: the low receiving sites of the clay plain (VT1d), and gently undulating sites (VT1g).
This unit have clay contents between 72-78, thus they are very fine textured, and this implies that care should be taken for the management of these soils especially if heavy machinery is used under moist conditions. The bulk density ranges from 1.72-1.82 g cm^{-3} for the top 30cm soil depth and from 1.58 to 1.83 g cm^{-3} for the lower depths whereas the hydraulic conductivity is between 1.19 and 1.90 cm hr^{-1} for the top soil (0-30cm) and 0.14 to 1.73ch hr^{-1} for the lower depths. Table 4.1 shows the summary of the main chemical and physical properties and according to the average values:

- The clay content is high
- The CEC is high
- The nitrogen levels are low.
- The available phosphorous is low.
- The potassium content is adequate
- The ECe is low
- The ESP is low

Table 4.1 Summary of Soil Chemistry, Typic Vertisols

		VT		**VTd**	
	Cm	0 – 30	30 – 90	0 – 30	30 – 90
Clay	*Average*	75	74	74	73
%	*Range*	70-78	70-78	73-75	73-74
pH	*Average*	7.7	7.8	7.5	7.9
paste	*Range*	7.6-7.7	7.8-7.9	7.3-7.8	7.7-8.1
CEC	*Average*	73	78	81	81
cmol(+) kg-1	*Range*	64-86	73-87	75-87	81-82
Ex. Ca	*Average*	45	46.5	48	49.5
cmol(+) kg-1	*Range*	37-55	38.0-56.0	42-53	49.2-49.8
Ex. Mg	*Average*	22.7	25.1	26.7	26.3
cmol(+) kg-1	*Range*	19.2-26	23.1-26.9	25.6-27.9	25.2-27.4
Ex. Na	*Average*	1.74	2.15	2.21	3.72
cmol(+) kg-1	*Range*	1.43-2.30	1.75-2.58	1.99-2.43	2.87-4.58
Ex. K	*Average*	0.31	0.30	0.18	0.12
cmol(+) kg-1	*Range*	0.17-0.40	0.12-0.45	0.17-0.19	0.12
Ca : Mg	*Average*	2	2	2	2
	Range	2	1-2	2	2
Total N	*Average*	0.051	0.055	0.058	0.055
%	*Range*	0.042-0.065	0.042-0.071	0.047-0.070	0.043-0.067
Org. C	*Average*	0.575	0.515	0.681	0.687
%	*Range*	0.560-0.58	0.499-0.567	0.552-0.810	0.516-0.858
C:N	*Average*	12	10	12	12
	Range	9-14	8-14	11-13	12-13
$CaCO_3$	*Average*	5.1	5.8	6	5
%	*Range*	4.6-5.7	4.8-7.3	6-7	5-6
Avail. P	*Average*	10.9	10.2	22.9	12.8
ppm	*Range*	9.5-13.1	9.0-11.8	9.5-36.3	12.0-13.7
ECe	*Average*	0.2	0.2	0.3	0.5
dS/m	*Range*	0.2-0.2	0.2-0.3	0.3-0.4	0.3-0.7
ESP	*Average*	2	3	3	5
	Range	2-3	2-4	3	3-6
Cu	*Average*	1.06	0.92		
ppm	*Range*	0.99-1.26	0.83-0.98		
Zn	*Average*	0.3	0.33		
ppm	*Range*	0.23-0.38	0.9-0.32		
Fe	*Average*	9.23	7.85		
ppm	*Range*	7.10-10.69	6.60-10.18		
Mn	*Average*	36.55	32.03		
ppm	*Range*	29.90-44.03	26.99-35.10		

Source: LWRC, Miskin Soil Survey 2009

4.2 Dark brown / dark grey cracking mapping unit (Chromic Vertisols, VC)

These soils are characterised by brown to dark brown colours which mean a colour value of the top soil is equal or more than 4 and the chroma of 3 or more (VC1 unit). This unit is deep soil and moderately well drained. The clay content is ranging between 76 % to 81% and has bulk densities of 1.72 to 1.88 g cm^{-3} for the top 30cm soil depth and 1.73-1.82 g cm^{-3} and hydraulic conductivity 0.97 to 3.83 cm hr^{-1} and 0.22to 0.97 cm hr^{-1} for the lower depths.
.

The main chemical and physical properties are summarised in Table 4.2, The Chromic Vertisols are similar to the Typic Vertisols above in their chemical properties having:

- High clay content (76-81%)
- High CEC
- Low nitrogen content
- Low available phosphorous.
- Low potassium content
- Low ECe
- Low ESP

4.3 Low-lying mapping unit (maya, D)

This unit is used as water reservoir during the dry season for human and animal use. So is evaluated as N2 permanently unsuitable land for agricultural.

Detailed description on the management of these soils is given in chapter 7.

Table 4.2 Summary of Soil Chemistry, Chromic Vertisols

		VCd	
		0 – 30 Cm	30 – 90 Cm
Clay	*Average*	80	77
%	*Range*	80	77
pH	*Average*	7.8	7.9
paste	*Range*	7.8	7.9
CEC	*Average*	88	87
cmol(+) kg-1	*Range*	88	87
Ex. Ca	*Average*	55	53.6
cmol(+) kg-1	*Range*	55	53.6
Ex. Mg	*Average*	25.5	27.9
cmol(+) kg-1	*Range*	25.5	27.9
Ex. Na	*Average*	1.8	3.1
cmol(+) kg-1	*Range*	1.8	3.1
Ex. K	*Average*	0.25	0.14
cmol(+) kg-1	*Range*	0.25	0.14
Ca : Mg	*Average*	2.5	2
	Range	2.5	2
Total N	*Average*	0.05	0.04
%	*Range*	0.05	0.04
Org. C	*Average*	0.6	0.5
%	*Range*	0.6	0.5
C:N	*Average*	13	13
	Range	13	13
$CaCO_3$	*Average*	7.8	5.7
%	*Range*	7.8	5.7
Avail. P	*Average*	23	17.3
ppm	*Range*	23	17.3
ECe	*Average*	0.23	0.4
dS/m	*Range*	0.23	0.4
ESP	*Average*	2	4
	Range	2	4
Cu	*Average*	1.40	1.30
ppm	*Range*	1.36-1.43	1.25-1.58
Zn	*Average*	0.63	0.63
ppm	*Range*	0.45-0.98	0.51-0.98
Fe	*Average*	7.71	6.71
ppm	*Range*	7.32-7.91	6.36-7.70
Mn	*Average*	24.07	28.43
ppm	*Range*	18.2-27.00	18.20-53.00

Source: LWRC, Miskin Soil Survey 2009

Table 4.3 Trace elements analyses

Pit No.	Lab. No.	Depth cm	Cu ppm	Zn Ppm	Fe ppm	Mn ppm
wmp 1 - 01	1	0 - 15	0.99	0.21	6.94	29.80
wmp 1 - 02	2	15 - 55	0.99	0.26	7.18	30.08
wmp 1 - 03	3	55 - 90	0.94	0.32	6.03	23.90
wmp 1 - 04	4	90 -135	0.84	0.37	5.40	87.10
wmp 1 - 05	5	135 - 180	1.01	0.33	4.01	61.70
wmp 1 - 06	6	180 - 200	0.80	0.38	9.24	60.00
wmp 2 - 01	7	0 - 25	1.00	0.49	10.02	32.00
wmp 2 - 02	8	25 - 50	0.76	0.26	5.67	13.00
wmp 2 - 03	9	50 - 75	0.78	0.34	8.40	10.00
wmp 2 - 04	10	75 - 120	0.80	0.24	5.74	25.50
wmp 2 - 05	11	120 - 155	0.90	0.42	7.73	128.10
wmp 2 - 06	12	155 - 200	0.76	0.35	5.74	95.00
wmp 3 - 01	13	0 - 10	1.74	0.33	11.19	50.10
wmp 3 - 02	14	10 - 30	1.02	0.28	8.44	41.00
wmp 3 - 03	15	30 - 85	0.98	0.30	6.60	34.00
wmp 3 - 04	16	85 - 125	0.83	0.42	5.25	23.90
wmp 3 - 05	17	125 - 170	0.85	0.42	4.18	29.10
wmp 3 - 06	18	170 - 210	0.65	0.38	4.14	83.80
wmp 4 - 01	19	0 - 10	1.11	0.35	8.61	90.10
wmp 4 - 02	20	10 - 60	0.83	0.28	5.45	31.50
wmp 4 - 03	21	60 - 100	0.81	0.43	9.81	24.10
wmp 4 - 04	22	100 - 145	0.75	0.28	5.21	24.40
wmp 4 - 05	23	145 - 175	0.98	0.52	5.63	67.60
wmp 4 - 06	24	175 - 215	0.62	0.60	4.31	13.20
wmp 5 - 01	25	0 - 20	1.43	0.45	7.91	27.00
wmp 5 - 02	26	20 - 45	1.36	0.98	7.32	18.20
wmp 5 - 03	27	45 - 85	1.25	0.51	6.36	29.20
wmp 5 - 04	28	85 - 130	1.58	0.51	7.70	53.00
wmp 5 - 05	29	130 - 170	1.49	1.00	6.60	44.50
wmp 5 - 06	30	170 - 210	1.29	0.67	11.80	90.90
wmp 6 - 01	31	0 - 10	0.95	0.49	5.73	41.40
wmp 6 - 02	32	10 - 60	0.90	0.33	13.18	32.90
wmp 6 - 03	33	60 - 95	0.83	0.32	7.17	35.10
wmp 6 - 04	34	95 - 135	0.83	0.36	7.11	34.90
wmp 6 - 05	35	135 - 180	0.85	0.41	5.70	36.40
wmp 6 - 06	36	180 - 200	0.75	0.39	5.83	34.70

Source: LWRC, Meskin Soil Survey 2009

5. SOIL SALINITY AND SODICITY

5.1 Introduction

The presence of salts including sodium, in the arid and semi-arid zones, is a widespread phenomenon in many areas of the world, and Sudan is no exception. The salinity or sodicity may result as a consequence of physical weathering, under low rainfall conditions coupled with low humidity and high temperatures by evaporation or by capillarity. Aeolian dust is another factor that carries appreciable amounts of salts. All these conditions exist or have existed in Sudan.

A combination of cations and anions are the main factors for soluble salts in the soils. The solubility varies of the salts ranges from very slightly soluble to extremely soluble. The most common salts found in the soils of Sudan are sodium chloride and sodium sulphate (Gabir, 1986; Buraymah, 1998; Lahmeyer, 2005). In the north Gezira area the dominant salts are sodium sulphate whereas in the north both sodium sulphate and chloride are dominant (Buraymah, 1998)

5.2 Assessment of salt-affected soils:

Salt affected soils are assessed using the following criterion, where soils are grouped into four categories as follows:
Non-saline, non-alkali soils (ECe<4 $dS.m^{-1}$ and ESP <15)
Saline, non-alkali (ECE>4 $dS.m^{-1}$ and ESP<15)
Non-saline –alkali (ECe<4dS/m and ESP >15).
Saline and alkali (ECe>4dS/m and ESP >15).

The land suitability classification system adopted in Sudan by Land and Water Research Centre (van der Kevie and El Tom, 2004) based on research findings incorporated ESP values of up to 35 in the topsoil and 50 in the subsoil as acceptable values for the potential rating of the soil as marginally suitable land in Gezira soil and other soils in Sudan. The system adopted used the following values for salinity and/or sodicity assessment (Tables 5.1 and 5.2)

Table 5.1 Salinity Rating for Current Land Suitability

Land Char.	ECe (0-30 cm)		ECe (30-120 cm)	
Rating	(NaCl)	(Na_2SO_4)	(NaCl)	(Na_2SO_4)
1	<4	<5	<6	<8
2	4-8	5-10	6-12	8-15
3	8-16	10-16	12-24	15-24
4	>16	>16	>24	>24

Source: van der Kevie and El Tom 2004.

Table 5.2 Sodicity Rating for Current Land Suitability

Land Char. Rating	ESP (0-30)	ESP 30-90)	SAR (0-30)	SAR (30-90)	Texture
1	<10	<20	<8	<18	All textures
2	10-20	20-35	8-18	8-38	Clayey soils
3	20-35	35-50	18-38	38-68	"
4	>35	>50	>38	>68	"

Source: van der Kevie and El Tom 200

All soils of the survey area lie within the land class 1.

5.3 Salinity and sodicity in the Survey Area

The two Vertisols –Typic and Chromic Vertisols- in this study are non-saline and non-sodic (their ECe and ESP values being less than 4dS/m and 15% respectively). The highest ESP value reported for the top soil is about 11 (HTS, 1966), where as for this study the highest value is 9. Therefore, as all soils are non-saline and non-sodic it is of no use to produce salinity and sodicity maps.

6. LAND SUITABILITY

6.1 Introduction

Land suitability assessment is a procedure that evaluates the soils for a specific land use. The assessment is based on matching a number of site and soil characteristics against the requirements of the intended land use. Land may have characteristics that render it unsuitable for the intended use; for each characteristic there is a minimum requirement or value to separate <u>Suitable</u> from <u>Not Suitable</u> land (FAO, 1976).

Land suitability is defined by FAO as the fitness of a specific area of land for a specified kind of land use – a so-called land utilisation type (LUT) – under a stated system of management.

The FAO Framework for Land Suitability for Land Evaluation (1976) has been adapted for Sudan by Van der Kevie & El Tom (2004) *Manual for Land Suitability Classification for Agriculture with Particular Reference to Sudan*.

6.2 Assumptions

Sustainability – or sustained use of the land in the way envisaged – is also embodied in the FAO definition of land suitability. Land where the proposed use cannot or will not be sustained without risk of damage to environmental quality is regarded as Not Suitable for the LUT. Examples of damage that can result from improper irrigation, drainage or poor husbandry in semi-arid areas include soil degradation (i.e. deterioration of soil structure and decline of soil fertility), erosion and salinization.

In assessing the suitability of land a realistic assessment should be inherent as to project ability to satisfactorily develop land for irrigated agriculture and the farmer's ability to maintain their land and their production. If such development and maintenance cannot be properly achieved the livelihood of participating farmers will be seriously jeopardised. Our major concerns are:

- Enough water should be delivered upon demand at a reasonable cost.
- Appropriate irrigation method should be selected.
- A proper drainage system should be installed at the start.
- Provision of fertilizers should be made at a reasonable cost.

We must assume a 'yes' to the above questions. However, should these concerns be unattainable, reduced or overlooked then the land should not be developed as intended; the following suitability classification is predicated on this.

6.3 Land suitability orders and classes

The system used is composed of two orders designated as S for suitable order and N for unsuitable order, five classes and a number of subclasses and units as shown in Table 6.1

Table 6.1 FAO Recommended Land Class Definitions

Class	Designation	Definition
S1	Highly suitable	Land having no significant or only minor limitations to sustained application of a given use that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
S2	Moderately suitable	Land having limitations that, in aggregate, are moderately severe for sustained application of a given use. The limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
S3	Marginally suitable	Land having limitations which, in aggregate, are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.
N1	Currently not suitable	Land otherwise suitable (S1 to S3) for sustained application of a given use but having a limitation(s) which, although possibly surmountable in time, cannot be corrected at currently acceptable cost. The limitation(s) is so severe as to preclude successful sustained use of the land in the given manner at present.
N2	Permanently not suitable	Land having limitations that appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner.

Source: FAO 1976.

Suitable land is divided into three land classes that reflect predicted differences of profitability, where it is usually inferred that the further the departure from optimum soil conditions (for the LUT being considered) either lower yields would be expected from similar inputs or more inputs are required to maintain the same yield.

We have adopted the view that where a major land improvement is needed and is technically feasible, for example a drainage scheme, soil reclamation or soil fertilisation programme, then such land is never “permanently not suitable”, class N2. Until such statement that there is no budget or intention to undertake the required improvement then the land remains class N1, i.e. “currently not suitable” but becoming suitable if the required improvement, outside of normal project costs, is implemented.

6.4 Land suitability for irrigated agriculture

6.4.1 Requirements for Irrigation

For all irrigated agriculture in semi-arid areas where there exists, or is a risk of, salinization a minimum soil depth of 2.0m is required to allow leaching of salts and drainage of the soil.

Sustainable surface irrigation demands the minimisation of water, uniform in-field water distribution and adequate drainage. For this, the critical land requirements are gentle and smooth slopes (<3%), water-retentive top soils and deep, water-retentive but permeable sub soils. Soils that are coarse-textured and/or stony in the upper 0.5 m – generally equating with high infiltration rates above about 60 mm/hr are not suitable for surface irrigation because an even distribution of water is difficult to maintain without very short furrows or very small basins, which are undesirable.

Land that is suitable for surface irrigation is usually equally suitable for sprinkler irrigation. However, land that is unsuitable for surface irrigation may be suitable for sprinklers. Sprinklers can be used for sandy soils and slopes up to about 20%. Water can be applied more evenly and more frequently and there is far less or no need for land-levelling or for furrows. Deep, permeable sub soils are still required.

Both surface and sprinkler irrigation are suited to saline or alkaline soils that require reclamation by leaching and drainage, so long as there is sufficient drainable soil depth. For drainage, hydraulic conductivity values of 8 mm/hr (0.2 m/day) are normally considered the lowest acceptable.

6.5 MINIMUM REQUIREMENTS TO ESTABLISH LAND SUITABILITY

Van der Kevie & El Tom (2004) have listed the relevant land qualities that should be considered in analysis for irrigated agriculture generally. Their approach and the limits for suitability for each land quality have been followed this study. Table 6.2 shows the limits of suitability for different irrigation regimes. This table sets out the requirements for the soils to suitable(S) or not-suitable (N). Some of these criteria do not apply to the Vertisols, such as drainage class, permeability rate, infiltration rate and available water capacity (AWC). The availability of water to plants is governed by factors that affect root growth and development like aeration, depth of cracking, readily available water and soil structure.

Table 6.2 Measured Land and Soil Characteristics. Minimum Values to Establish Land Suitability for Irrigated Agriculture

	SURFACE	SPRINKLER	DRIP
Landform	Any except jebel, kerrib, khor, floodplain		
Topography	Flat – gently undulating, long smooth slopes	Flat to rolling but excluding badlands	Flat to undulating but excluding badlands
Slope	< 3%	< 20% [1]	< 8%
Erosion	Exclude severe; i.e. > 50% of area with one or more of dunes; hummocks > 0.4m; gullies > 0.5 m deep		
Flooding	Exclude floodplain land inundated annually by main rivers (Dinder, Rahad, Khor El Atshan)		
Soil depth	> 2.0 m	> 2.0 m [2]	> 1.0 m
Sandy / gravel cover	< 0.15 m	n/a	n/a
Topsoil (0-0.25 m) stone, gravel	< 40% volume		
Topsoil (0-0.25 m) texture	Loamy or clayey (i.e. not sandy, not gravelly (>15%) loamy)	Any	Loamy or clayey (i.e. not sandy, not gravelly (>15%) loamy)
Infiltration rate [3]	1 – 60 mm/hr	> 1 mm/hr	> 1 mm/hr
AWC, top m	> 90 mm	> 50 mm	> 90 mm
Permeability rate	> 8 mm/hr (0.2 m/day)		
Soil drainage class	Any except very poor (and poor if drainage is not feasible)		
Water-table depth	> 3.0 m (or >1.0 m if drainage is feasible)		
Cation exchange capacity	> 8.0 $cmol^{(+)}\ kg^{-1}$ (or < 8 if extra fertilisation is feasible)		
pH, top m	< 9.0 (or > 9.0 if associated with sodicity where reclamation is feasible)		
EC, top m [4]	< 16 (or > 16 if reclamation is feasible) dS/m		< 4 dS/m
ESP / SAR, top m [4]	< 35; < 50 for Vertisols (or higher if reclamation is feasible)		< 15

Notes:

1. Based on criteria for centre-pivot irrigation. Other sprinkler systems are restricted to slopes < 15%.
2. I.5 m with proven well-managed centre-pivot irrigation and no evidence or risk of rising water-table or salinisation.
3. Italicised parameters are measured from soil profile analyses or site tests. Non-italicised parameters derive from soil auger survey. Soil depth is measured from auger and profile pit.
4. See Table 6.2

Since 1976 the Soil Survey Administration (SSA, now the LWRC) has gradually relaxed its criteria for salinity and sodicity. Prior to 1976 the limits of suitability for salinity were set at an ECe of 5.3 dS/m for the topsoil (0-30cm) and 8.0 for the subsoil (to 90cm). In 1976 these criteria were relaxed to 8.0 for the topsoil and 12.0 for the subsoil. Now (Van der Kevie & El Tom, 2004) the values have been further relaxed to 16.0 for the topsoil and 24.0 for the subsoil for marginally suitable lands. Even higher values – up to 32.0 for the topsoil and 48.0 for the subsoil – are acceptable if the soils are loamy and can, presumably, be easily leached, but the soils are classified as currently unsuitable Table6.3.

As with salinity there has been a gradual relaxation of sodicity criteria. In 1976 an ESP of 15 in the topsoil and 25 in the subsoil defined the limit of suitability, and this later became 35, or 50 below 60cm. Now, the limits are 35 for the topsoil and 50 below 30cm, but placing the soils into currently unsuitable land (Table 6.3)

Table 6.3.Salinity and sodicity limits for land suitability classes

		Non-Vertisols				Vertisols			
Salinity	Cm	**S1**	**S2**	**S3**	**N1**	**S1**	**S2**	**S3**	**N1**
ECe, dS/m	0 – 30	< 4	4 – 8	9 – 12	> 12	< 4	4 – 8	9 – 12	> 12
	30 – 90	< 6	6 – 12	13 – 16	> 16	< 6	6 – 12	13 – 16	> 16
Non-saline < 4, Slightly saline 4-8, Moderately saline 9-12, Strongly saline 13-16,Very strongly saline>16									
		Non-Vertisols				**Vertisols**			
Sodicity	Cm	**S1**	**S2**	**S3**	**N1**	**S1**	**S2**	**S3**	**N1**
ESP / SAR	0 – 30	< 10	10 – 15	15 – 25	> 25	< 10	10 – 20	21 – 35	> 35
	30 – 90	< 15	15 – 25	26 – 35	> 35	< 20	20 – 35	36 – 50	> 50
N**on-sodic <15, Slightly sodic 15-25, Moderately sodic 26-35, Strongly sodic 36-50, Very strongly sodic > 50.**									

The above mentioned criterion is applied against the soils and site characteristics and we have recognized two categories of suitable land, S2 and S3 class.

The suitability subclasses are defined by the relevant limitation to the use, where v = vertisolic limitation due to high clay content, f = limitation due to low levels of nutrients, w = limitation due to low-lying topography where soils are susceptible to flooding and t = limitation due to the gently undulating topography, i= inundation

The Typic Vertisols and Chromic Vertisols are classified as moderately suitable land with Vertisolic and fertility limitations, whereas, the phases of the Typic Vertisols (VTd and VTg) are marginally suitable for irrigated agriculture. The recommended practice is to add fertilizers NPK. good tillage at optimum moisture content, good drainage system and levelling. Table 6.4 shows the current suitability classes, subclasses and limitations for the development of the soils.

Table 6.4 Current Land Suitability Classification of the Soils of the Survey Area

Soil Unit	Current Suitability Class	Limitations	Current Land Suitability Subclass
VT	**S2**	**v,f,**	**S2vf**
VC	**S2**	**v,f,**	**S2vf**
VTd	**S3**	**w,v,f**	**S3wvf**
VTg	**S3**	**w,v,f**	**S3tvf**
D	**N2**	**i**	**N2**

7 SOIL AND LAND MANAGEMENT

All the soils in the survey area are vertisols, their properties affect their management. The high clay content of these soils affect the trafficability and cultivation especially at high moisture content. Vertisols are known to be of high potential for rainfed agriculture because of their high water holding capacity which allows crop to survive mid-season drought periods or to grow long after the rains have ended. Most of the Vertisols of the study area are occurring in relatively flat landscapes and thus require a minimum effort to be commanded by water supply systems and not to be irrigated by flood or furrow.

Loveday (1984) reported that farm design and land preparation were the key factors to control surface water irrigation. Even tillage operation itself may damage rather than improve soil structure particularly when carried out at inappropriate water contents. Where irrigation is practiced, it will often be difficult to till soils at the optimal moisture content. The surface may be optimum but the sub-soil too wet. This problem has been recognized in sugarcane growing areas in Sennar and Kenana (Ali, 1998).

Farbrother (1987), reviewed field trials testing irrigation intervals and rates on Gezira Vertisols over the period (1925-63). An interval of 14 days between watering, coupled with 100m rate of application, was the optimum irrigation for most of the crops all over the irrigated Sudan Vertisols. The cyclic depth of normal irrigation was known to be 60 cm or 50 cm.

Cracks provide the main route for movement of water and the moisture at any specific depth approximates to the original cross section of the cracks. Water penetration in Vertisols is very important aspect to be considered wherever irrigation water is available. Irrigation water should be applied according to the water infiltration which is normally very slow in the Vertisols of the project area. Water application has to be carefully calculated whatever irrigation method is used. Also, the amount of water should be calculated according to the depth of the roots. In Vertisols and even under severe drought conditions water logging is expected, particularly after heavy rainfall and / or heavy irrigation. In such cases surface drainage has to be carefully maintained. Irregular microtopography leads to irregularity in moisture distribution and in this case the use of suitable technique to obtain a regular slope is important.

One of the important challenges in Vertisols management is how to maintain their organic matter (OM) level upon cropping. Decline of OM upon cropping of Vertisols is the reason of lowering N status of those soils (Dalal and Mayer, 1986). Part of the cause of decline in OM with cropping is that crop residues may be burned or removed for animal feed, fuel or other purposes. In that occasion stubble retention and minimum tillage might be suitable to increase the OM equilibrium level. Structural degradation is known to be of important impact on yield reduction in Vertisols (Ibrahim, 1982). Moreover, severe erosion of cultivated Vertisols is widespread phenomenon in lands with slope ≥ 3% (Hudson, 1984). In such cases conservation measures should be implemented to minimize erosion.

The major constraints to the use of Vertisols are the unfavourable texture and tilth, high bulk density, wide deep cracks, slow saturated hydraulic conductivity, poor permeability and poor trafficability when the soil is wet (Abdullah, 1985; Bunyolo *et al,* 1985).

The soil management may pose serious problems, as the soils become very hard when dry, and very sticky when wet. This means high power consumption when dry and compaction of soils when wet. The levelling of small depressions and gently undulating surfaces is also recommended to avoid accumulation of water in low-lying sites and run-off from higher sites.

Low levels of major nutrients and low organic matter pose another problem. Sustained yields can only be obtained if the major nutrients are supplied in adequate amounts. Crop residues should be incorporated in the soil to increase organic matter content and improve the physical properties by increasing the biological activity.

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