NILE BASIN INITIATIVE
Initiative du Bassin du Nil

Efficient Water Use for Agricultural Production (EWUAP) Project

BEST PRACTICES FOR WATER HARVESTING AND IRRIGATION

Sudan

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SUDAN

March 2008

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ARC	**Agricultural Research Corporation**
EWUAP	**Efficient Water Use for Agricultural production**
GDP	**Gross Domestic Product**
GS	**Gezira Scheme**
HRS	**Hydraulic Research Station**
NBI	**Nile Base Initiative**
SGB	**Sudan Gezira Board**
TTEA	**Technology Transfer and Extension Administration**
UCWR-SD	**UNESCO CHAIR IN WATER RESOURCES, SUDAN**
WH	**Water Harvesting**
WUS	**Water User Association**

MAP OF THE SUDAN

Map No. 3707 Rev. 10 UNITED NATIONS Department of Peacekeeping Operations April 2007 Cartographic Section

CHAPTER ONE: INTRODUCTION

Agro-Climatic Zones of the Sudan

The Sudan is characterized by its high climatic and ecological diversity, ranging from no rain desert in the north to high rainfall humid areas in the south. The country is a gently sloping plain with the exception of Jebel Marra in the West, the Red Sea Hills in the East, Nuba Mountains in the center and Imatong Hills in the South. Its main features are the alluvial clay deposits in the central and eastern, the stabilized sand dunes in the western and northern part and the red ironstone soils in the south. Annual rainfall ranges from less than 50 mm in the north, 350–800 mm in the central clay plains and savannah belt to more than 1500 mm in West Equatorial region in the south (figure 1.1). The main rainy or monsoon season is from June to September but the duration will vary with latitude. In the south, there are two rainy seasons.

1.1.1 Agro-climatic Zones

The six agro-ecological zones of the Sudan according to Harrison and Jackson (1958) are shown in figure 1.2. These include: desert, semi-desert, low rain savanna, high rain savanna, flood, and mountain zones. Details of these zones are depicted in table 1.1.

1.1.2 Major Agricultural Enterprises in Each Zone

(i) Desert zone: Irrigated agriculture is practiced along the banks of the River Nile and Atbara River and on the neighboring lands where irrigation water is conveyed by canals; mainly small privately owned farms, cooperative agricultural schemes, semi-governmental as well as privately owned schemes growing field crops, vegetables, spices and fruit trees. The practiced systems of irrigation include:

- basin irrigation depending on diversion of Nile water during flood periods; crops are then grown utilizing residual moisture stored in the soil; crops include faba beans, field beans, maize, lablab, and vegetables. These areas are now mostly replaced by pump schemes.
- water pumped from the Nile and conveyed by canals to irrigate fields where crops such as sorghum, wheat, beans, spices, alfalfa, sorghum, fruit trees and vegetables, are grown;

- water pumped from ground aquifers and conveyed by canals or modern irrigation systems (drip or central pivot) to grow wheat, alfalfa, fruit trees, vegetables and field crops.

(ii) Semi-desert Zone: This zone has rainfall <300 mm/annum hence rain-fed cultivation is limited to traditional farming on the 'Qoz' sand (mainly millet) and areas with higher clay content where water harvesting is practiced to grow sorghum and millet. Irrigated agriculture utilizing water from the Blue Nile, the White Nile and Atbara River is practiced on large scale schemes, e.g. Gezira, New Halfa, Rahad, Suki, Guneid, Blue, and White Nile Agricultural Schemes. Water flows by gravity from dams or is pumped directly to irrigate fields where crops such as cotton, sorghum, wheat, groundnuts, sugar cane, fodder crops and vegetables are grown. Spate irrigation, utilizing seasonal rivers such as the Gash, Baraka, and Abu habil is practiced in Kassala, the Red Sea, and North Kordofan states. Gates, bunds and canals are used to direct water flow to farmland which is subsequently cultivated with crops such as millet, sorghum, groundnuts and vegetables.

Figure 1.1Mean annual rainfall in the Sudan (mm)

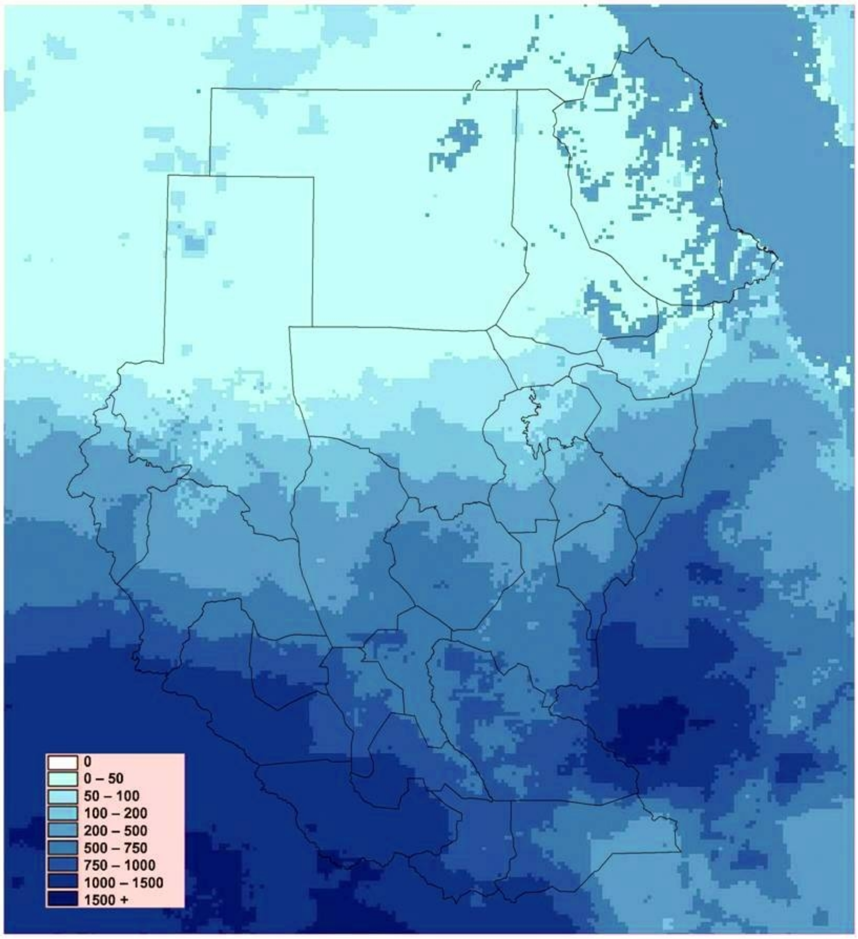

0
0 – 50
50 – 100
100 – 200
200 – 500
500 – 750
750 – 1000
1000 – 1500
1500 +

Figure 1.2 The agro-climatic zones of the Sudan

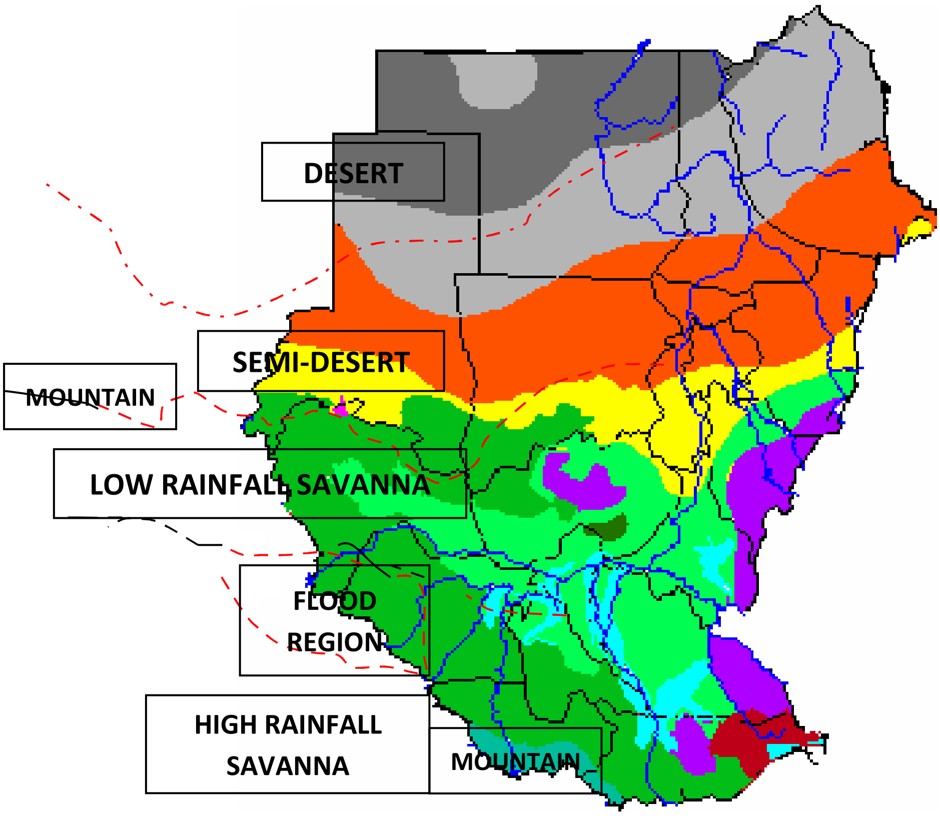


Table 1.1 Ecological Zones of the Sudan*

Zone	% of Sudan area	Mean annual rainfall (mm)	Wet season	Dry season	Main land use types
Desert	28.9	<75	July to September	October to June	□ Irrigated agriculture □ Grazing along seasonal water courses
Semi-desert	19.6	75-300	July-September-November-January	November-June March-September	□ Irrigated agriculture □ Dry land farming in conjunction with water harvesting-Pastoral
Low rainfall savanna	27.6	300-800	May-September	November-April	□ Irrigated agriculture □ Rain-fed traditional cultivation □ Mechanized farming □ Pastoral □ Forestry
High rainfall savanna	13.8	800-1500	April-October	December-February	□ Rain-fed traditional cultivation □ Mechanized farming □ Pastoral □ Forestry
Flood region	9.8	600-1000	May-October	December-April	□ Traditional cultivation □ Pastoral □ Wild life
Mountain vegetation	0.3	300-1000	Variable	Variable	□ Traditional cultivation □ Pastoral □ Forestry –

					Horticulture

* Source: Harrison, M.N. and J.K. Jackson (1958). Ecological Classification of the Sudan, Forest Department, Forest Bulletin No. 2, Ministry of Agriculture, the Republic of the Sudan

(iii) Low Rainfall Savanna Zone: This zone hosts irrigated agriculture as the large scale schemes such as Gezira extend south into this Zone. Other large irrigated projects include Suki, Rahad, Blue Nile Agricultural Schemes, White Nile Agricultural Schemes and the large scale sugar cane plantations of Kenana, Guneid, New Halfa, Asalaya and West Sennar. Traditional farming on clay soils produces sorghum and sesame while on sandy soil millet, sesame, groundnuts, Roselle and water melon grow. This Zone is also the major producer of gum Arabic from *Acacia Senegal* trees. Mechanized farming is practiced, particularly towards the southern part of the zone; this is mostly large scale commercial rain-fed cultivation where agricultural operations are partially or totally mechanized; production units are 400 ha in size and main crops grown include sorghum, cotton, sesame and lately guar and sunflower. Recently zero tillage (ZT) technologies were introduced to the mechanized rainfall sector. These ZT technologies involve using direct seeding, herbicides, improved varieties, fertilizers, and modern machinery.

(iv) High Rainfall Savanna: Traditional cultivation as well as mechanized farming are practiced, as in the Low Rainfall Savanna Zone; however, in the higher rainfall areas in the south west two crops may be produced per year due to the bimodal nature of the rainfall. Forestry is an important activity producing fuel wood and wood for local industries.

(v) The flood plain: This zone is also known as the Sudd, where the land is flooded to different degrees and for variable periods; is one of the largest fresh water swamps in the world. The conditions of the Sudd environment made transhumant pastoralism inevitable and has given rise to a mixed economy of herding, traditional cultivation, fishing and hunting. Main crops grown are maize, sorghum, cowpeas, tobacco and pumpkins.

(vi) Mountains: Jabel Marra is the area utilized for agricultural production on a reasonable scale; important for horticultural production e.g. citrus, mangoes, potatoes, other vegetables and field crops such as wheat and sorghum, and timber.

1.2 Agricultural Production in the Sudan

Although production and export of oil are growing significantly in importance, agriculture still remains the major source of income for most of the country's population, 70% of who live in rural areas. In the period 2002-2006, agriculture contributed between 38.8% and 46% to GDP, employed 57% of the total economically active population and contributed about

90% of the non-oil export earnings (Ministry of Finance and national Economy). Sorghum is the principal crop; livestock, cotton, sesame and groundnuts comprise the major agricultural exports. Millet, wheat, gum Arabic, sugar cane and cassava are also grown. Within the agricultural sector, crop production accounts for 53% of agricultural output, livestock 38% and forestry and fisheries 9%.

Agriculture is generally divided, based on source of water, to irrigated and rain-fed. The most salient features of agricultural production in Sudan are low productivity, low value of crops, high fluctuation in areas and low water use efficiency (WUE).

Irrigated Agriculture 1.2.1

The total area of the irrigated sub-sector is about 1.9 Million hectare. It includes the Verisols of Eastern and Central Sudan, the banks of the Nile (Blue, White, and main Nile) in additions to Toker, Gash deltas, and Abu Habil. The irrigated sub-sector contributes 10.5-12.7 % of the GDP. This sub-sector produces long and medium staple cotton, sorghum, groundnuts, wheat, vegetables, legumes, fodders, sunflower, and maize. This sub-sector contributes to 100% of sugar, 99% of cotton produced in the country in addition to 20-30% of sorghum, 30-40% of groundnut produced in the Sudan. The irrigated sub-sector is characterized by its stable production that forms a unique combination with the rain fed sub-sector. The irrigated sub-sector played a key role during drought years and saved the country from major famines.

Irrigated agriculture could be divided, based on level of technology used, into modern and traditional. Traditional agriculture is practiced along banks of the River Nile mainly in Khartoum, Nile, and Northern States. In traditional irrigated agriculture surface irrigation and flood irrigation are practiced. Tillage operations are performed by animals as well as tractors. Seeding, weeding, and harvesting are manually performed. Recently small stationary threshers were introduced to thresh wheat, sorghum, and legumes. Fertilizers and pesticides are used in a limited manner. In modern irrigated agriculture higher levels of mechanization are practiced. These include seed bed preparation, harvesting, and pest management using tractor mounted field sprayers as well as knap sack sprayers. Mechanical seeding is recently adopted with appreciable levels. Inputs are largely used in modern irrigated agriculture. These include improved seeds, fertilizers, herbicides, pesticides, and growth hormones in sugar projects. In modern irrigated agriculture a wide range of irrigation systems is used. These include: surface irrigation, furrow irrigation, long furrow irrigation, gated pipes, drip irrigation, as well as center pivot and linear sprinkler systems.

Rain fed Agriculture 1.2.2

The total area of the rain fed sub-sector amounts to about 15 Million ha depending on the rainfall. All the rain fed areas lie south of 300 mm rain line and extend to the Southern borders of the Sudan where the mean annual rainfall amount to 1500 mm. The rain fed sub-sector contributes to about 6.8-9.9% of the GDP. The cultivated rain fed areas of the Sudan amount to about 80% of the total cultivated area. This sub-sector contributes to about 70-80% of sorghum produced in the Sudan, almost all the millet and all the sesame, and 60-70% of produced groundnut.

The rain fed sub-sector is characterized by its huge potential for horizontal expansion. A three-fold increase in the area is possible. There is also great potential for a vertical increase in productivity. It is estimated that a three to four fold increase in yield is possible if by new and improved technologies were adopted. Further more the rain fed sub-sector is characterized by its low investment costs compared to the irrigated sub-sector. The rain fed sub-sector could be divided into two: mechanized and traditional. The mechanized sub-sub-sector uses tractors, disc harrows, mechanical seeders, combine harvesters and herbicides. The mechanized sub-sub-sector is located on the Central Clay Plain of Eastern, central, and Western Sudan, south of 500 mm rainfall line. The traditional sub-sub-sector a labor-intensive system using hand tools and is located in the sands of Western Sudan in addition to Southern Sudan.

1.3 Irrigation systems in the Sudan

Due to the diversity of climatic zones, soils, and farming systems a wide range of irrigation systems are found in the Sudan. These irrigation systems could be classified according to type of delivery of water from source to final field to three main categories: pump, gravity, and flood. These categories are further divided according to size, source of water, or final field type. Figure 1.- shows these systems.

A. **Pump System:** This system includes large, medium, and small pump schemes:

1. **Large pump systems** (area more than 20000 ha). This could be further divided into public and private

    a. Large public irrigation pumps systems: These include New Halfa, Rahad, and Suki agricultural schemes that depend on electric pumps. These schemes are owned and managed by the government. The federal government is responsible for management of the irrigation system that includes the pumps as well as the canals. The government delivers and avails irrigation water to farmers at cost. Farmers manage water at the field levels.

b. Large private irrigation pump systems: These are owned by private companies such as White Nile Sugar Company and Kenana Sugar Company in White Nile state. The company owns and operates the irrigation system that includes the pumps and the canalization system. The company also manages water at the field level. Sugar Estates are owned by a government company, Sudanese Sugar Company and managed as a para-statal. The company owns Guneid, New Halfa, Sennar, and Assalaya sugar factories. The company owns and operates the irrigation system that includes the pumps as well as the canalization system. The company also manages water at the field levels using direct labor; no farmers are involved in this system (except Guneid).

2. **Medium irrigation pump systems (Area between 20000 ha and 420 ha)**

   a. **Medium pump systems:** Along the White, Blue and main Nile scatter a number of small and medium size irrigation schemes. These are mainly located in Northern, Nile, White Nile, Blue Nile, Sennar, and Khartoum states. Some of these agricultural schemes are managed by cooperatives. The scheme management is responsible for management of the irrigation and also responsible for providing inputs such as seeds and fertilizers and also for availing mechanized agricultural services such seed bed preparation and harvesting. The cooperative sometimes avail credit for these inputs and services.

3. **Small pump schemes (area less than 420 ha):** In small pump schemes farmers sometimes share the same pump or the pump is owned by an individual but farmers are sharing and managing the water distribution by themselves. This system is common in Nile and Northern states. Farmers have the freedom to cultivate what they decide. The cost of water delivery is collected as cash or sometimes in kind as a share of the harvested crop.

   a. **Small irrigation pumps from rivers:** Large numbers of small size irrigation projects privately owned are found along the Blue Nile, White Nile, and the main Nile. Diesel and electric pumps are used to pump water to cultivate a variety of crops. Theses include field crops, vegetables, and fruit trees.

   b. **Small irrigation pumps from ground aquifers:** This privately owned system is the most widely spread all around the Sudan in the desert, light and heavy

Savanna zones. Small size diesel or electric water pumps are used to cultivate different types of crops.

B. Gravity irrigation:

The Gezira scheme is considered the largest irrigation system in the world under one management. The irrigation system that includes Sennar Dam and the canals is jointly managed by the Ministry of Irrigation and Sudan Gezira Board. Farmers are responsible to manage water at the field level. Recently, after the implementation of the Gezira Act for 2005, the Management of the lower irrigation system (minor canals and field canals) was agreed to be transferred to farmers groups in the form of water user associations (WUA). These associations will maintain the canals, control weeds, clean sedimentation, and distribute water to farmers. The cost of management will be paid by farmers and fees will be collected by these associations. Today the Gezira Scheme is passing through a transitional stage in which preparatory activities are going on, such as building the capacities of farmers and preparing the irrigation system to be handed to the WUAs.

C. **Flood system:** This system is divided to flood and spate systems.

a. **Flood system** could be divided furthermore according to type of final field into:

i. **Flood irrigation on river banks:** Traditional flood irrigation takes place on banks of rivers, mainly the Nile, in Khartoum, Nile, and Northern states. During the flood season, water covers the cultivated agricultural land for some time and then resides. The period of inundation varies with seasons depending on the flood. After the end of the flood, the soil is covered with a water saturated silt layer. Farmers using hand tools, perform seeding operations. The majority of these lands are privately owned.

ii. **Flood irrigation on seasonal rivers banks:** After flooding of seasonal streams such Atbara River**,** a flood plain is formed. This plain is cultivated by individual private farmers to grow sorghum and vegetables. The same technologies used in flood irrigation on rivers are adopted here.

iii. **Flooded islands:** A number of islands on the main Nile north of Khartoum practice flood cultivation. These islands are inundated by water totally or partially during the flood season. After the flood, farmers use residual water to cultivate legumes, field crops, cereals, in addition to aromatic and medicinal crops. Sometimes supplementary irrigation is applied using pumps.

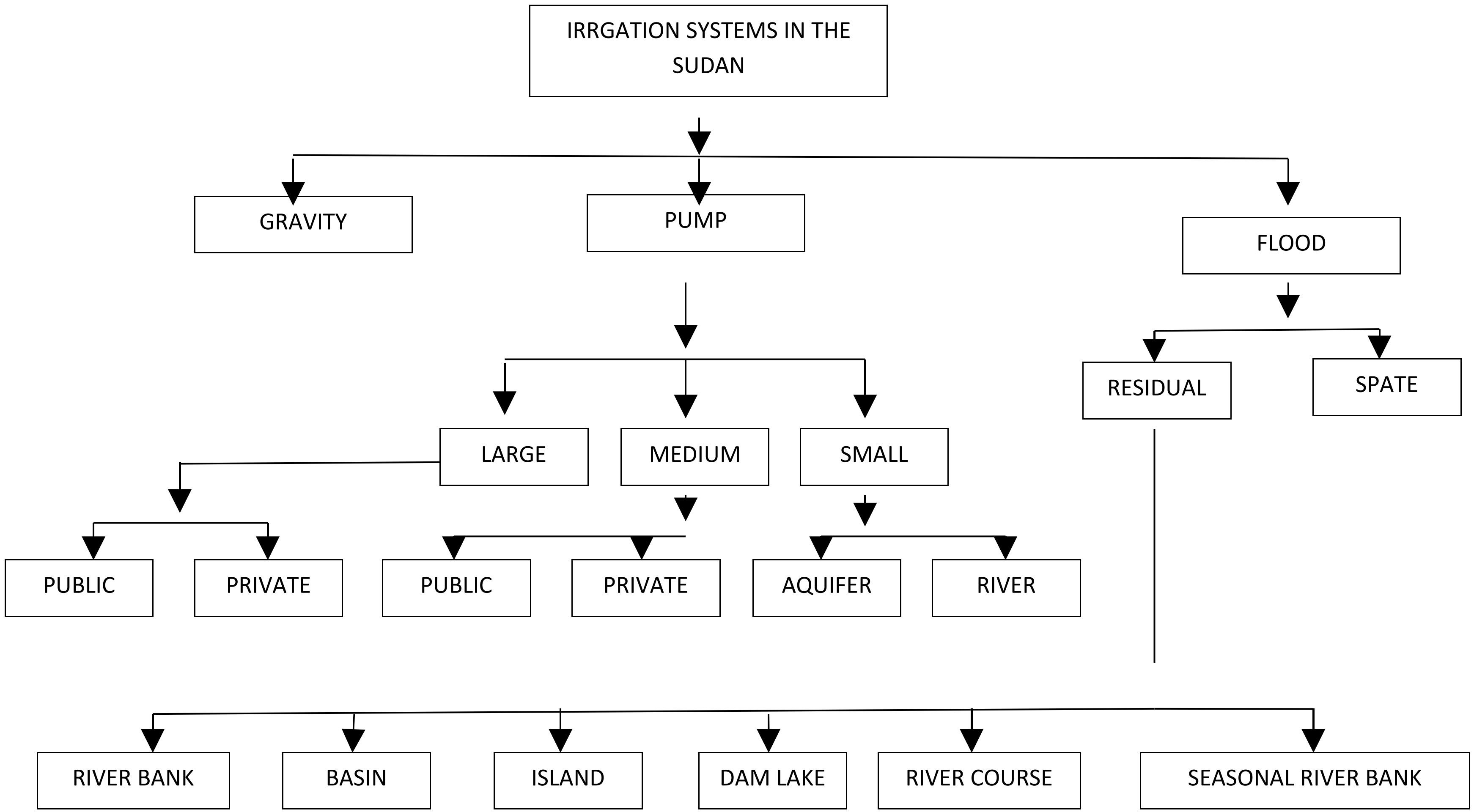
iv. **Seasonal streams water courses:** This takes place after the end of the season in some seasonal streams and tributaries of the Nile, such as Dinder and Rahad in Eastern Sudan, and in some Wadis of Eastern and Western Sudan. Farmers use residual soil moisture to cultivate vegetables and fruits mainly tomatoes, cucurbits, and legumes.

v. **Banks of Reservoirs:** After the emptying periods of_Roseiris, Sennar, and Jebel Aulia reservoirs, fertile and water saturated areas on the banks are formed. Theses areas are utilized by small farmers to grow different types of vegetables and fruits. The same simple technologies used in flood systems are also used here.

vi. **Basin irrigation:** basin irrigation is practiced in locations where there is a low land is inundated by the Nile during the flood season. This found in Seleim basin in Northern State, in Salawa and Wad Hamid basins in Nile state. Farmers in these basins collectively organize themselves, work together to facilitate flood water movement in their lands. After water resides, crops such as wheat, legumes, fodders, and vegetables are sown. No additional irrigation is needed. Recently, small pumps were introduced to supplement basin irrigation. In some place like Seleim (Northern State) large pumps replaced the traditional basin irrigation.

b. **Spate system:** Three locations practice spate irrigation in the Sudan. These are Gash in Kassala State irrigated by Gash River, Toker in Red Sea State irrigated by Khor Baraka, and Abu habil in North Kordofan state. The roaring water from the seasonal rivers is directed by diverting structures and canals to flood demarcated areas. The irrigable area is decided every year by the volume of water carried by the river. This area is divided by the community in a well defined system by the tribes to farmers. Farmers perform the seeding operation and control weeds using manual tools. The crop grows on residual moisture in the soil and no irrigation is needed. Sometimes two crops are grown in one season. Cultivated crops include sorghum, millet, vegetables, watermelons, and recently sunflowers were introduced to these areas.

Figure 1.3 Classification of irrigation systems in the Sudan



1.

CHAPTER TWO: BEST PRACTICES

In this chapter currently used water harvesting and irrigation practices and technologies adopted at different agricultural systems of production in the Sudan will be identified and listed. Some of these are traditional, some are developed locally or in the region, while some are modern, transferred and adopted through importation or from research findings.

Best Practices in Water Harvesting

Water harvesting (WH) is practiced at wide areas across the Sudan in low rainfall and high rainfall Savanna regions in traditional agriculture, human and animal use, as well as forest production in places having rainfall starting from 75 mm per annum. Water harvesting practices are actually found in all the states of the Sudan. The effectiveness and efficiency of WH practices depend on factors such as soil type, rainfall, and crop.

a. **Bunds or terraces:** This is one of the traditional technologies that had been used for hundreds of years in low rainfall areas. Bunds are built to collect water in sloping areas according to the contour. Seeding of crops starts when there is enough moisture in the soil. The rain water is collected and efficiently used by the crops. The main crops cultivated are sorghum and millet. Contour bunds are mainly found in eastern, central, and northern regions of the Sudan. These include states of Red Sea, Kassala, Gedarif, Khartoum, Gezira, White Nile, Sennar, and Nile.

b. **Ridges:** Four body ridging machines fully mounted on tractors were introduced in large irrigated areas in the Central clay plane of the Sudan to build ridges in surface furrow irrigation systems. The use of these machines extended to neighboring rain-fed areas. After the on set of rains, the hard soils become workable for tillage tools. Ridgers are used to break the soil, control weeds, and build ridges. This is followed by manual seeding in the furrow. Farmers put the seeds in the open furrows and cover these seeds by foot pressing.

c. **Tied ridge:** Tied ridge is an improved ridge system. In the ridge system furrows are open built without any consideration to slope and are left open-ended. In the tied ridge system ridges are built at right angles to slopes and closed (tied) by cross ridges to prevent water run-off.

d. **Sayreen:** This is a new innovation by farmers in Sennar state. It is a modification to the ridge system. Two persons holding seeds will ride on the back of the tractor carrying the ridging machine. During the ridging operation the two persons start manually drilling the seeds in the furrows. This combined operation of ridge formation and seeding saves much time and effort. It helped farmers catch early rain showers and resulted in a good harvest.

e. **Micro-catchments:** These practices are newly tested and developed by research in the Sudan. A number of techniques were evaluated including triangular, rectangular, and semi-circular shapes. Results showed that rectangular and triangular shapes are suited for trees and field crops while semi-circular shapes are best for range production. These improved technologies are being transferred in many development projects and are now spreading across the country especially in the low rain savanna zone.

f. **Small dams:** Small dams are now found in greater Kordofan, greater Darfur, Gedarif, White and Blue Nile, Sennar, kassala, Nile, and in Red Sea states. These are used for drinking water and for crops cultivated by communities and individual farmers depending on size of the dam. Small dams are also constructed in some places to help recharging ground aquifers. Federal, United Nations Agencies, NGOs, as well as state governments had allocated large funds for establishment of small dams.

g. **Boabab trees:** In North Kordofan state, the stems of the baobab tree (Adansonia digitata) is engraved and used as a tank to store rain water. This proved to avail clean water for drinking during the dry season. The stored volume of water ranges between 3 m^3 and 5 m^3 depending on tree size.

h. **Haffirs:** A haffir is an artificial excavation into which surface water run-off is converged during the rainy season to be stored and used during the dry season. The size of haffirs varies much depending on location, hydrology, soils, rainfall and ranges between 5000 and 30000 m^3. Haffirs are divided into traditional and standard. Traditional Haffirs go back to more than hundred years. Standard Haffirs were developed using modern engineering design. Components of standard Haffirs include: stilling pool, inlet and outlet wells, inlet and outlet valves, energy dissipater, stainer, Haffir pond, embankments, pump units, animal troughs, filters, drainage canal, and fencing. Haffir water is used for drinking by humans and animals.

Best Practices in Small scale irrigation

b. **Surface irrigation:** Is practiced in almost all irrigation systems except flood systems. Depending on the type of cultivated crop, the tilled land is either left flat, or shaped in ridges or beds. Ridges vary in width between 60 cm to 90 cm, while beds vary from 1.0 m to 1.5 m.

c. **Basin irrigation:** basin irrigation is practiced in locations where there is a low lands inundated by the Nile during the flood season. This found in Seleim basin in Northern State, in Salawa and Wad Hamid basins in Nile state. Farmers in these basins collectively organize themselves, work together to facilitate flood water movement in their lands. After water resides, crops such as wheat, legumes, fodders, and vegetables are sown. No additional irrigation is needed. Recently, small pumps were introduced to supplement basin irrigation. In some place like Seleim (Northern State) large pumps replaced the traditional basin irrigation.

d. **Spate irrigation:** Three locations practice large flood or flush or spate small scale irrigation in the Sudan. These are Gash in Kassala State irrigated by Gash River, Toker in Red Sea State irrigated by Khor Baraka, and Abu habil in North Kordofan state. The roaring water from the seasonal rivers is directed by diverting structures and canals to flood demarcated areas. The irrigable area is decided every year by the volume of water carried by the river. This area is divided by the community in a well defined system by the tribes to farmers. Farmers perform the seeding operation and control weeds using manual tools. The crop grows on residual moisture in the soil and no irrigation is needed. Sometimes two crops are grown in one season. Cultivated crops include sorghum, millet, vegetables, watermelons, and recently sunflowers were introduced to these areas.

e. **Flood irrigation on river banks:** Traditional flood irrigation takes place on banks of rivers, mainly the Nile, in Khartoum, Nile, and Northern states. During the flood season, water covers the cultivated agricultural land for some time and then resides. The period of inundation varies with seasons depending on the flood. After the end of the flood, the soil is covered with a water saturated silt layer. Farmers using hand tools, perform seeding operations. The majority of these lands are privately owned.

f. **Flood irrigation on seasonal rivers banks:** After flooding of seasonal streams such Atbara River**,** a flood plain is formed. This plain is cultivated by individual private farmers to grow sorghum and vegetables. The same technologies used in flood irrigation on rivers are adopted here.

g. **Flooded islands:** A number of islands on the main Nile north of Khartoum practice flood cultivation. These islands are inundated by water totally or partially during the flood season. After the flood, farmers use residual water to cultivate legumes, field crops, cereals, in addition to aromatic and medicinal crops. Sometimes supplementary irrigation is applied using pumps.

h. **Seasonal streams water courses:** This takes place after the end of the season in some seasonal streams and tributaries of the Nile, such as Dinder and Rahad in Eastern Sudan, and in some Wadis of Eastern and Western Sudan. Farmers use residual soil moisture to cultivate vegetables and fruits mainly tomatoes, cucurbits, and legumes.

i. **Banks of Reservoirs**: After the emptying periods of Roseiris, Sennar, and Jebel Aulia reservoirs, fertile and water saturated areas on the banks are formed. Theses areas are utilized by small farmers to grow different types of vegetables and fruits. The same simple technologies used in flood systems are also used here.

j. **Bubbler systems:** These are used in a very limited scale in orchards to irrigate vegetables and fruits**.** Examples could be seen in Khartoum and kassala States.

Best Practices in Large scale irrigation

c. **Long furrow:** long furrow irrigation was first largely introduced to the Sudan in Rahad Agricultural Project in eastern Sudan in mid 1970's but was abolished for many reasons. Today long furrows are only largely used in Kenana Sugar fields in the White Nile state. Long furrows that reach 2.75 km are established after the land is prepared and laser leveled. Siphons are used to deliver water from the canals to the furrows.

d. **Gated pipes:** The gated pipes system was introduced lately and adopted largely in Kenana sugar fields in the White Nile state. This system helped in reducing irrigation water delivery losses and also reduced time and cost of irrigation of sugar fields.

e. **Stationary sprinkler systems:** These systems are used in limited areas of vegetable production and commonly used in landscaping to irrigate turfs and ornamental plots in Khartoum state.

f. **Center pivot sprinkler irrigation:** This type is practiced in Khartoum, Nile, and Northern states. It is mainly used by modern investment companies to cultivate alfalfa for export and other field crops such as wheat. Source of water for these systems is either from the Nile or from ground aquifers.

g. **Linear sprinkler irrigation:** Is used in Khartoum and Nile states by modern investment companies. These systems, same as center pivot systems, are used to cultivate wheat, alfalfa, and vegetables.

h. **Drip irrigation systems:** Are largely used in landscaping and to irrigate house gardens. Drip irrigation is used in orchards to irrigate trees and also used in green houses to produce vegetables in Khartoum and Gezira states.

CHAPTER THREE: SELECTED SITES

3.1 Preliminary sites

In order to select the sites of best practices for efficient water use in agricultural production, a long list of sites was first established based on the information presented in chapter two. Tables 3.1, 3.2, and 3.3 show these long lists of sites for water harvesting, small scale irrigation, and large scale irrigation respectively. It was found to be very difficult in a country like the Sudan, to evaluate the different sites and select one site due to the wide and diversified irrigation practices. Hence it was decided to rely on judgment in selecting sites of best practices.

Table 3.1 Best practices in Water Harvesting

No.	Best practice	Site Location	Technology level
1	Bunds	a. Butana, Gezira State b. Managil, Gezira State	• Traditional • Traditional
2	Ridges	a. Sennar b. White Nile	• Modern • Modern
3	Tied ridges	a. Sennar b. White Nile	• Modern • Modern
4	Sayreen	a. Sennar State b. White Nile state	• Modern • Modern
5	Micro-catchments	a. Butana, Gezira State b. North Kordofan	• Modern • Modern
6	Small dams	a. North Darfur b. Nile state c. Khartoum state d. Red sea State	• Modern • Modern • Modern • Modern
7	Boabab trees	a. North Kordofan State	• Traditional
8	Haffirs	a. Kordofan States b. Darfur States c. Kassala State d. Red sea State e. Sennar state	• Traditional • Modern • Modern • Modern • Modern

Table 3.2 Best practices in Small scale irrigation

No.	Best practice	Site Location	Technology level
1	Surface irrigation	a. Gezira Scheme b. New halfa Scheme c. Rahad project d. Suki project	• Traditional
2	Basin irrigation	a. Wad Hamid, Nile State	• Traditional
3	Spate irrigation	a. Gash b. Toker c. Abu Habil	• Traditional
4	Flood on river banks	a. Nile state b. Khartoum State	• Traditional
5	Flood on seasonal river banks	a. Atbara River	• Traditional
6	Flooded islands	a. Northern State	• Traditional
7	Seasonal streams water courses	a. Rahad b. Dindir	• Traditional • Traditional
8	Banks of Reservoirs	a. Roseirs b. Sennar c. Jabel Aulia	• Traditional • Traditional • Traditional
9	Bubbler system	a. Khartoum State b. Kassala State	• Modern • Modern

Table 3.3 Best practices in Large scale irrigation

No.	Best practice	Site Location	Technology level
1	Long furrow	Kenana	• Modern
2	Gated pipes	Kenana	• Modern
3	Stationary sprinkler systems	Khartoum State	• Modern
4	Center pivot sprinkler irrigation	a. Nile state b. Northern State	• Modern • Modern
5	Lateral sprinkler irrigation	a. Khartoum State b. Nile state	• Modern • Modern
6	Drip irrigation systems	a. West Omdurman b. African/Malaysian	• Modern • Modern

Selected site for water harvesting

Looking at the different sites of best practices in WH, and recognizing the diversity of practices and the distribution of these sites, it appears that selecting one specific site would not help in achieving the objectives of dissemination the exchange of experiences, and sharing of knowledge and information in the region. It is therefore decided that it is logical to select a state rather than a location. At the state level different sites representing the best practices in WH could be visited, thus objectives could be achieved.

Criteria for selecting the state as shown in table 3.4 include:

- Accessibility of the state,
- Types of best practices,
- Diversification of these practices, and
- Involvement of the state in dissemination of technologies.

Table 3.4 evaluation for selecting best practices in WH

State	Accessibility 10= accessible 0= un-accessible	Types of practices 10= many 0=few	Diversification 10=high 0=low	Involvement in dissemination of technologies	Total Scores	Rating
1. Gezira	10	4	6	6	26	6
2. Sennar	10	10	10	10	40	1
3. White Nile	8	8	10	8	34	2
4. Khartoum	10	6	8	6	30	4
5. Nile	10	4	8	6	28	5
6. Kassala	6	6	10	8	30	4
7. North Korfodan	6	8	10	8	32	3
8. North Darfur	4	8	10	8	30	4
9. Red Sea	4	8	8	6	26	6

As shown in table 3.4 out of nine states, Sennar state had the highest scores; hence it was selected to be the best site for water harvesting best practices in the Sudan.

Selected Site for small scale irrigation

The Gezira Scheme is considered as the largest irrigation project under one management in the world. This uniqueness of the Gezira qualified it to be the site for best practices in small scale irrigation systems.

The Gezira Scheme (GS), located between the Blue and White Nile was established in 1925 when the Sennar Dam across the Blue Nile was completed. In 1959-63 the original Gezira Scheme was extended to include the Managil area. The combined Gezira/Managil Scheme now covers a command area about 2.1 million feddan (about 882,000 hectares) under gravity irrigation. Estimates of the total potential cultivable area under irrigation in Sudan within the Nile Basin vary, but it is approximately between four and five million feddan . Hence the GS represents about a quarter of all irrigation area in Sudan and half the area of irrigation schemes drawing water from the Nile system. It uses about 35 percent of Sudan's current allocation of Nile water, About 55% of the GS is the property of the central Government. The remainder of about 45% of the land is still owned by previous landholders and with whom the central government has a long term rental agreement. Designed for a cropping intensity of 0.75 the achieved cropping intensity is usually no more than 0.50 which is very low by any international standard.

Irrigation water is supplied from the Blue Nile reservoirs at Roseires and Sennar. The Blue Nile has an average annual flow of 50-billion cubic meters at Roseires, with large seasonal and annual variations. The flow of the Blue Nile rises steeply from the end of June to an end-of-August peak, followed by a sharp decline, to a minimum flow of about two percent of the peak, at the end of April. The Blue Nile carries large quantities of silt as a result of its steep gradient and heavy seasonal rainfall in its upper catchment area. The silt load in the Nile is heaviest during July and August and as a result of an increase in irrigation during these months.

Water is diverted from the Sennar reservoir by means of twin main canals with a combined maximum daily discharge capacity of 31.5 million cubic meters (354 cubic meters per second), running north to the first group of canal regulators 57 kilometers from the dam. From there four branch canals convey water to the Managil extension, while the Gezira main canal runs north for another 137 kilometers. Major canals take off from main and branch canals and supply water to minor canals. These canals flow continuously throughout the growing season. The network consists of 2,300 kilometers of branch and major canals, and over 8,000 kilometers of minor canals. Minor canals supply water via gated outlet pipes to field channels (Abu Ishrin) each irrigating 90 feddans, (38 hectare), called "Numbers". Each number is divided into 18 tenant fields of 5 feddans (called hawasha). Water flows in the primary canal network (main, branch and majors) continuously during the irrigation season - July through April. Minor canals were designed to store water at night as irrigation was to be carried out only during the hours of daylight but this is no longer practiced. The water is released based on an indenting procedure whereby at the beginning of each cropping season the demand at each minor canal and the delivery losses are calculated for various reaches of the canals up to the Sennar Dam. The volume of water released is regulated by various control structures throughout the system. The major canals have peak design capacity of 20 cubic meters/feddan/day (equivalent to 0.55 liter/second/feddan) in Managil and between 13.5 and 15 cubic meters/feddan/day in Gezira (equivalent to between 0.37 and 0.41 liter/second/feddan). These capacities were based on the peak water requirement of the cropping pattern and intensity envisioned at the design stage. They determine the optimum capability of the irrigation system for water delivery and distribution and crop diversification and intensification, which indicates that there is greater flexibility at Managil extension. The minor canals are grossly over designed for the flows (0.5 to 1.5 cubic meters/second) that they are intended to carry. Minor canals are set at very slight slopes, 0 to *5* cm per kilometer, and flow with very low water velocities, and thus have a very limited sediment transporting capacity. They act as sediment traps particularly at the head reaches of the canals. Weed growth reduces velocities further, enhancing rates of sediment deposition. The result is a massive de-silting requirement as part of annual maintenance.

In the Gezira scheme seepage losses are virtually nil due to the extremely impermeable nature of the soil and subsoil. Irrigation water does not contribute to the deep groundwater table underlying the scheme. Evaporation and breakage from the canals to the roads and fallow areas are the major sources of water losses from the system. Therefore, the water use efficiency of the irrigation network is potentially very high.

The present drainage system consists of 1,500 km of major drains and about 6, 000 km of minor drains. There are no on-farm drainage facilities due to the nature of the soil and absence of high groundwater table. The main purpose of the drainage is to remove the surface runoff due to rain or excess irrigation.

The Gezira scheme was built with the primary objective of producing cotton. The land is divided into about 138,000 tenancies with an average size of 20 feddan (about 8 ha). Each tenant has plots in five numbers (tertiary units) and has to plant according to the approved rotation so that all the cotton fields are together, all the fallow together in another "Number" and so on. In the very early days a six-course rotation was practiced, but following some failures, this was changed in the early 1930's to an eight-course rotation (cotton, fallow, fallow, cotton, fallow, sorghum, lubia, and fallow) with nominal cropping intensity of 50%. This kept the demand for water within the capacity of the irrigation system to deliver. Since that time there has been further diversification and intensification. Until recently, the main Gezira scheme had a nominal intensity of 75% in a five-course rotation of cotton, sorghum, groundnuts, wheat with one fallow, while the Managil extension had 100% with no fallow. At the present, however, fallow has also been introduced in Managil where the target cropping intensity is 75% throughout, although various problems have kept the actual intensity well below that figure in recent years.

Current water management in the Gezira Scheme is substantially different from the original design, which was used satisfactorily prior to the 1960's. The two-fold expansion of the irrigation area and successive crop intensification in mid-1960's following completion of Managil extension required additional quantities of water to be diverted and distributed. Accordingly, the volume of water released to the system at Sennar increased by more than three-fold from 2,000 million cubic meters in 1957-58 to 7,100 million cubic meters in 1997-98.

The management of the GS in respect to irrigation water has always been divided between the Ministry of Irrigation and Water Resources (MOIWR) and Sudan Gezira Board (SGB). MOIWR is responsible for supply and delivery of water to the minor canals. In 1995, MOIWR established the Irrigation Water Corporation (IWC), a financially independent parastatal, to operate and maintain the irrigation system in the GS and other large central Government-owned.

In practice the tenants are involved in operation and maintenance of the smallest field canals (Abu Sittas) control of the operation of the larger tertiary canals (Abu xx). On the other hand maintenance of Abu xx canals is carried out by SGB at the tenant's expense. The Gezira Scheme is now passing through a transformation process in which farmers are starting to manage the lower level system (minors and field canals) through the Water User Associations established by the new Gezira Act for 2005.

The visitor to Gezira Scheme will be able to see the extensive irrigation system, know how it was designed, and how it is managed and maintained.

3.3 Selected site for large scale irrigation

Kenana Sugar Estate is one of the best examples of adoption of new technologies especially in irriation. It is also recognized as one of the best managed agricultural projects. This is why Kenana Sugar Estate was selected to represent best practices site for private irrigation in the Sudan. Kenana Sugar Estate (latitude 13ºN 3, longitude 30º East) is located in the Central Clay Plain of the Sudan about 300 km south of the capital Khartoum near the town of Rabak (White Nile State) on the eastern bank of the White Nile. The total area of the project is 70 000 hectares, the cultivated area amounts to 45 000 hectares.

Six pumps are connected in series along the main canal to lift irrigation water to 46 meters above the White Nile level. The first two Pump stations were designed to pump $42m^3/s$. the main canal is branched into primary canal to divert irrigation water to the field canal via off take pipes. Each field canal is designed to irrigate one field (40-90 hectare), which is split into two sectors and each sector consists of 60 furrows with 1.55 m spacing. Furrows run perpendicular to contour lines with lengths ranging from 300 to 2750 meters.

Irrigation practice in Kenana was subjected to many changes. In 1981 the water indenting was based on fixed days per cycle, and different sizes of siphons were used in the same field to maintain the cycle regardless of the field gradient of furrow length. An irrigation system bases on evapo-transpiration 910 mm/day) was introduced in 1983. In 1987 an indenting system of irrigation based on the number of operating pumps was adopted. Recently, the Estate field was divided into three categories (A, B, and C) based on steepness and furrow length. These categories received water every 12, 10, and 7 days respectively. In 2002 the open channel furrow irrigation system was gradually changed to the close system of gated pipes. Today about 75% of the planted area is using the closed irrigation system.

The visitor to Kenana will observe the high efficiency of management and the modern technology adoption in seed bed preparation, laser leveling and will also observe the modern irrigation systems such as gated pipes and long furrow systems.

CHAPTER FOUR

NATIONAL INSTITUTIONS

4.1 Identification of institutions

The objectives of this chapter is to identify, list and describe potential institutions in the Sudan to be used in organizing capacity building activities and other field related activities such as demonstrations and dissemination of technologies in the fields of water harvesting, irrigation, efficient use of water for Agriculture, watershed management, and integrated water resources management. The target institutions are categorized into:

A. Research institutions
B. Universities and institutions of higher learning
C. Non-government organizations
D. Public institutions

A. Research in water management, water harvesting and irrigation is performed by research institutions and universities. However, the majority of this research is performed by two institutions: Agricultural Research Corporation (ARC) and Hydraulic Research Station (HRS). ARC is part of the Ministry of Science and Technology while HRS belongs to the Ministry of Irrigation and water Resources (table 4.1).

Table 4.1 Research institutions

No.	Institution	Activity in relation to EWUAP/ experience with NBI	Contact details
1	Land and Water Research Institute, agricultural Research Corporation	Research in water management, crop water requirements, water harvesting, capacity building, and modeling.	P. O. Box 126 Wad Medani, Sudan Tel +249511843055 Fax +249511843213
2	Water Harvesting Institute, Agricultural Research Corporation	Research in water harvesting	P.O.Box 11391 Khartoum Fax+249155116858
3	Hydraulic Research Station,	Research in	Hrs-sudan@hotmail.com

	Ministry of irrigation	hydrology, hydraulics and irrigation.	P.O.Box 318 wad Medani, Sudan +249511842222

B. Universities and institutions of higher learning: In the Sudan there are about 25 universities. A survey was conducted to identify institutions that teach irrigation and water management subjects. These included water harvesting, irrigation, advanced irrigation, and irrigation management. Results of the survey shown in table 4.2 revealed that eight institutions are involved in these activities.

Table 4.2 Universities and institutions of higher learning

No.	Institution	Activity in relation to EWUAP/experience with NBI	Contact details
1	Department of Agricultural Engineering, faculty of Agriculture, University of Khartoum	Under graduate and post graduate studies in irrigation	P.O. Box 32 Postal Code 13314 Khartoum North - Sudan Tel: +24918513310101 Fax: email: agri@uofk.edu
2	Department of Agricultural Engineering, faculty of Engineering, University of Khartoum	Under graduate studies in irrigation	P.O. Box 321 Postal Code 11115 Khartoum- Sudan Tel: +249183776973 Fax: +249183771516 Email: engineering@uofk.edu
3	Department of Agricultural Engineering, College of Agricultural Studies, Sudan University of Science and Technology	Under graduate and post graduate studies in irrigation	cas@sustech.edu +249185311007 +249185311082
4	Department of Agricultural Engineering, faculty of Agriculture, Omdurman Islamic University	Under graduate and post graduate studies in irrigation	P. O. Box 382 Omdurman, Sudan Tel +249 87511536
5	Agricultural engineering department, faculty of agriculture, university of	Under graduate studies in irrigation	P. O. Box 47 Dongola, Northern State

	Dongola	and pumps	Tel +249 248121519 Fax _249 248121514
6	Water harvesting Institute, faculty of Engineering, University of Nyala	Training in water harvesting	P.O.Box 7722 Khartoum - 155 Nyala Tel. : +24971133122 ; +24971133124 Fax: +24971133123
7	Water Management and Irrigation Institute, University of Gezira	Training and applied research in water management	E-mail: watharv@yahoo.com Tel/ Fax: +249511842 810
8	UNESCO-Chair in Water Resources, Omdurman Islamic University	Research systems, capacity building, information transfer, consultancy, awareness raising and documentation in water resources and related fields.	Chairwr@Sudanmail.net Phone +249 18311779599 Fax +24918311779604 Street - P.O. Box 1244 City – Khartoum
9	Department of Civil Engineering Faculty of engineering, University of Khartoum	post graduate studies in Water resources engineering	P.O. Box 321 Postal Code 11115 Khartoum- Sudan Tel: +249183776973 Fax: +249183771516 Email: engineering@uofk.edu

C. Non-government institutions: A number of non-government institutions were involved in water harvesting activities since 1980's. Today limited number of organizations is involved in such activities, like Practical Action (PA), which mobilized local communities in Darfur state to build small dams. Unfortunately, accessibility to these locations is difficult due to the security conditions.

Table 4.3 Non-government organizations

Number	Institution	Activity in relation to EWUAP/experience	Contact details

		with NBI	
1	Practical Action	• Building small dams • Community work in establishing water structures • Promoting water harvesting practices	*PO Box 4172* *Khartoum Central* *Sudan* *Telephone* +249183460419, +249183578821 or +249183578827 *Fax* +249183472002 *Telex* 984 22190 ACROP SD *E-mail:* sudan@practicalaction.org.sd
2	Elsugya Charity Organization	• Water resource development	elsugya@hotmail.com

D. Public institutions: Extension services in the Sudan are carried by the Government. The Technology Transfer and Extension Administration (TTEA) of the Federal Ministry of Agriculture and Forests is in charge of all extension activities including lower system irrigation, water conservation, and water harvesting. TTEA manages a network of state level Technology Transfer and Extension Departments in the 15 north states of the Sudan. Table 4.4 shows these departments, their locations, and the carried activities that are related to EWUAP.

Table 4.4 Public institutions

Number	Institution	Location	Activity in relation to EWUAP/experience with NBI
1	Technology transfer &extension administration	Elobied- north Kordofan –state	Water harvesting
2	Technology transfer &extension administration	Sennar- Sennar state	Irrigation Water harvesting
3	Technology transfer &extension administration	Kassala- Kassala state	Irrigation Water harvesting
4	Technology transfer &extension administration	Eddoym- white Nile state Kosti- white Nile state	Irrigation Water harvesting
5	Technology transfer &extension administration	Khartoum	Irrigation Water harvesting
6	Technology transfer &extension administration	Red Sea State, Port Sudan	Water harvesting
7	Technology transfer &extension administration	Nile State, El Damer	Irrigation Water harvesting
8	Technology transfer &extension administration	Northern State, Dongola	Irrigation
9	Technology transfer &extension administration	North Darfur, El Fashir	Water harvesting

4.2 Selection of Center of Excellence

The criteria for selecting the center of excellence in capacity building and other related activities were adopted based on criteria similar for Tanzania. Table 4.5 shows details of the evaluation. According to the scores, UNESCO CHAIR IN WATER RESOURCES (UCWR-SD) was selected as the center of excellence in capacity building in the Sudan.

UNESCO Chair in water resources (UWCR-SD) is working in the field of water resources development and management nationally, regionally, and internationally. The Chair was founded in

1994 following the Agreement between UNESCO Director General and the Vice Chancellor of Omdurman Islamic University on behalf of the Sudan Government.

The main objectives of UCWR-SD are to promote integrated research, systems, capacity building, technology and information transfer, consultancy, awareness and documentation and dissemination of critical issues in water resources and related fields.

UCWR-SD offers several capacity building programs in collaboration with Omdurman Islamic university, University of Khartoum, Sudan University of Science and Technology, in addition to many national and international institutions. Postgraduate programs include: M. Sc. in Hydrology, M. Sc. And Diploma In Water resources Development and management. The Chair also offers postgraduate studies leading to Ph. D. degree by research and a number of non-degree professional short training courses specially designed to suit institutional needs in the area of water.

UCWR-SD employs about 20 full time staff members in addition to More than 50 Collaborators from National, Regional and international Universities and Institutes.

UCWR-SD has its own Headquarters. It is considered by the Omdurman Islamic University as a separate Institute. It has good logistics and well equipped with computers, plotters, digitizers, printers, lecture rooms, projectors, etc. It has a good library and a decent computer lab with sufficient computers well connected in a network with direct access to Internet and a video Conference hall. Also it has water quality laboratory for water quality management from physical, chemical and biological points of views.

The collaboration and networking programs of UCWR-SD were designed to strengthen the institutional interrelations among the different institutions in the country, region and worldwide to provide grounds for exchanging experience. Accordingly, the Chair started to formulate networks within the region to serve this purpose and participate in other regional and international network programs. A list of such networks include, Friend Nile Networking Project, Nile Basin Capacity Building Network for River Engineering (NBCBN-RE) Network Groundwater Protection Network in the Arab Region (GWPN), Wadi Hydrology Network in the Arab Region (WHN), Arab Network for Water Researchers, Consultative Group for International Agriculture Research (CGIAR), International Network for Capacity Building in IWRM (Cap-net), TIGER Initiative, SWMnet/IMWI, HELP Program, and Nile Basin Initiative, NBI, in applied training and research studies.

The UCWR-SD meets the need for expertise in the real world by providing consultancy services. Several water-related consultancy projects were done annually.

In recognition to its excellent performance in the field of water resources and capacity building UCWR-SD was awarded the UNESCO UNITWIN Distinction Award, UNESCO HQ, Paris, November. 2002. It was also awarded Appreciation award for outstanding performance and distinguished efforts, The National Water Research Centre.

Table 4.5 Evaluation for center of excellence in centers for excellence in capacity building

INSTITUTION	Infra Structure Excel=10, poor=1	Man Power Excel=10, poor=1	Record in R &D Good=10, poor=1	Involvement in best practices High=10, low=1	Experience in training Excel=10, poor=1	Dissimin. Of improved technolo. Excel=10, poor=1	Linkages Excel=10, poor=1	Status at national level Excel=10, poor=1	Total scores
1. Department of Agricultural Engineering, faculty of Agriculture, University of Khartoum	6	8	8	8	8	6	4	6	52
2. Department Of Agricultural Engineering, Faculty Of Engineering, University Of Khartoum	6	4	4		8	6	4	4	42
3. Department of Agricultural Engineering, College of Agricultural Studies, Sudan University of Science and Technology	6	6	6	8	8	6	4	6	42
4. Department of Agricultural Engineering, faculty of Agriculture, Omdurman Islamic University	6	4	4	8	8	6	4	4	40
5. Agricultural engineering department, faculty of agriculture, university of Dongola	4	4	4	8	8	6	2	4	36
6. Water harvesting Institute, faculty of Engineering, University of Nyala	4	4	4	6	6	6	2	2	32
7. Water Management and Irrigation Institute, University of Gezira	6	8	6	8	8	6	4	6	52
8. UNESCO-Chair in Water Resources, Omdurman Islamic University	6	8	6	10	10	6	8	8	60

9. Hydraulic Research station, Ministry of irrigation and water Resources	**4**	**8**	**4**	**4**	**6**	**4**	**4**	**4**	**38**

CONCLUSIONS

1. **Best practices sites:**

    a. Water harvesting: according to the criteria shown in table 3.4, out of nine states, **Sennar State** had the highest scores; hence it was selected to be the best site for water harvesting best practices in the Sudan.

    b. Small scale irrigation: The **Gezira Scheme** was selected as the best site for small irrigation.

    c. Large scale irrigation**: Kenana Sugar** was selected as the best site for large scale irrigation.

2. **Center of excellence in capacity building**: According to the evaluation of Sudanese centers for excellence in capacity building shown in table 4.5, the **UNESCO Chair in Water Resources** (UWCR-SD) got the highest marks. Hence it was selected as the center of excellence for capacity building in water harvesting and irrigation in the Sudan.