Efficient Water Use for Agricultural Production (EWUAP) Project

RAPID BASELINE ASSESSMENT OF AGRICULTURAL WATER IN

Sudan

By

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CHAPTER 1

Introduction

Sudan Water Resources:

Sudan is the largest country in Africa with an area of 250 million hectares and a population of around 35 millions living on 15% of the land mainly around the Nile and its tributaries. Sudan embraces 60% of the Nile basin within its boarders.

The river Nile receives its water from two major sources: the equatorial lakes plateau with its year round rains and the Ethiopian plateau with its summer rains. It is worth mentioning that the flow contribution of the main tributaries of the Nile River from the Ethiopian highlands is 86% (EL Daw, 2003). And from equatorial lakes is 14%.during flooding (July to October) over 90% of the Nile River flow is from Ethiopia and less than 10% from Equatorial lakes. The low contribution of the Equatorial lakes basin to the River Nile is attributed to the loss of water by evaporation in the swamps while the Ethiopian plateau with its steep slopes drains effectively into the River Nile. Table 1 below shows that most of the rivers flows occur during July to October.

Table 1**. Seasonal and total flows of the Nile River and Tributaries (1913-1989) (MM3)**

River	July-Oct	Total Discharge
Main Nile at Aswan	57,396	83,953
Blue Nile	40,506	48,312
Atbara	12,023	12,466
Malakal	12,087	29,796
Sobat (White Nile)	6,454	13,298
Rahad & Dinder	3,761	3.761

US$ 1: SD 257.5 (Sudanese Dinars)

[1]: Including costs of ploughing, bund construction and maintenance, mulching material, mulch management and other farm practices.

[2]: Including returns from sorghum (grain and straw). And groundnut (pods and vine).

Groundwater:

Groundwater development in Sudan and indeed in the whole Nile Basin riparian countries is on the increase for both rural and urban domestic water supply, particularly in regions where groundwater is the only resource. The demand for groundwater is expected to increase drastically in the short and medium term as the countries strive to achieve millennium goal of water supply for all by year 2025.

Groundwater is also very important for maintaining the environment through sustenance of stream flows. Wetlands and support to vegetation among other thins, (Tinddimugaya, 2002).

Quantification of groundwater is difficult under the economic hardship facing developing countries like Sudan and without assistance from the international agencies. They extend at depths ranging from 40 to 400 meters and have total dissolved solids ranging from 100 to 2000 PPM. The Nubian sandstone covers about 28% of surface of the country and subdivided into number of sub-basins. Estimation of the rate of groundwater recharge is a basic prerequisite for efficient groundwater resources management especially in areas where this resource is key top economic development. Groundwater recharge normally exhibits time and space variability.

The annual recharge of groundwater is difficult to assess accurately, however the potential has been estimated to be about 4.0 Billion Cubic Meters (BCM). 75% of the potential groundwater may by utilized for agriculture during the coming 5 – 10 years, however, current uses for both agriculture and others domestic uses is about one BCM.

Generally the quality of round water in Sudan is good, except in few locations, but more investigation is needed, however, successful projects were attempted in the Northern and Western states. The main constraints in utilizing the groundwater are the cost of exploration, quality, and extraction technology. In some locations due to the limitations of resources, remoteness, and absence of other alternatives there is no other resource than the groundwater.

Table 2. **Estimate potential of groundwater (storage, recharge). And abstraction in Sudan (After Salih, 2003).**

Major basins	**Storage Million m^3**	**Recharge Million m^3**	**Abstraction Million m^3**
Nubian Sand Stone	503000	1000	700
Umm – Ruwaba – Gezira Basin	60000	600	150
Sedimentary Basin	1000	375	160
Total	**564000**	**1975**	**1010**

Rainfall:

Rainfall varies from practically no rain in the desert zones in the north to some 1000 mm in the extreme south. The major issue to be highlighted is that the rainfall in the country is characterized by its spatial and temporal variability. In the most southern quarter, the area is dominated by swamps and inhabited by insects, many of which are harmful to human and livestock.

Water Availability:

The current annual amount of water available to Sudan from all internal and external sources is about 30 BCM, Table 3. this is the summation of the Sudan's share in the Nile waters according to the 1959 Agreement with Egypt as measured in central Sudan, 20.5 BCM, the average flow of non – Nile streams, 5.5 BCM, and the renewable groundwater estimated as, 4.0 BCM.

Table 3. **Water resources availability and their limitations and constraints**

Water Availability (Billion Cubic meters)		
Water Resources	**Quantity**	**Limitations and constraints**
Sudan share from the Nile	20.5	High seasonality, requires storage facilities
Streams (other than the Nile river)	5.5	High seasonality, requires storage facilities
Groundwater	4.0	High cost for exploration and extraction, plus, requires technology
Present total	30.0	
Potential share from swamp reclamation	6.0	Environmental
Total	**36.0**	

As the rate of growth in population is 2.9% annually, and as the need for water increases with development at a higher growth rate, that any potential increase from water development will be consumed. Thus the water stress situation is expected to continue. Expectations of other Nile countries and those sharing non-Nile streams with Sudan might influence the amount of water available and its distribution in the region.

Water Use:

Sudan population in 2002 is estimated to be 32 millions. The sum of the internal and external water resources available to Sudan is about 30 BCM. This shows that Sudan is already below the water stress margin of 1000 m^3 per capita. The actual per capita consumption is much less than 1000 m^3 as the water used fluctuates between 14 and 18 b cm out of the 30 BCM. This is mainly because of the varying nature of rain and flow of the Nile and the non-Nile streams coupled with limited available storage capacities, which are continuously decreasing by silt accumulation. The actual per capita consumption of water is just over 500 m^3 per year, way down in the water stress zone. The remaining shares in the Nile waters and the available non-Nile and renewable groundwater are all committed to pre-studied, highly fertile land awaiting the availability of enough storage capacities and pumping facilities. Many irrigation schemes have the entire infrastructure but their cropping intensity is very low because of scarcity of water during the long dry season. Heightening of Roseires Dam, which is currently slowly executed from the country's financial resources, is supposed to avail such water.

Table 4. **Annual projection of the water consumption (Billion Cubic meters)**

Annual Projection of the Water Consumption by Year 2003				
Year	**Irrigation**	**Water supply**	**Animals & others**	**Total**
2000	17.5	0.4	1.3	**19.2**
2010	27.1	1.1	3.9	**32.1**
2020	32.6	1.9	5.1	**39.6**
2030	40.3	2.5	5.3	**48.0**

The current situation is that irrigated agriculture consumes about 94% of the water, 5% goes to human and animal consumption and 1% to industrial and other uses. A study by the Ministry of Irrigation and Water Resources Staff (MOIWR, 1998) projected the irrigation needs to be 32.6 BCM, Table 4. If the incremental rise in evaporation from water stored form the proposed hydropower dams is added (6.6 MCM), the total demand would be 46.2 BCM. This would by more that all the water available to Sudan including its share from the conservation of the southern swamp. It is assumed here that all the water flowing in the seasonal streams is harvested, the groundwater is pumped to the limit of its recharge and the storage facilities are available for the entire share forms the Nile waters. In addition, Sudan population at that time is expected to be 56 millions. Even if the gap in water availability were bridged some how, the per capita water consumption would be 867 m^3 per year, still under the water stress margin. It should be noted here that the above mentioned study assumed that the irrigated area would be 2.44 million ha which still is less than 4% of the arable land of the country. Sudan has got the potential to be the breadbasket for its neighbors and possibly the World at large as it has the vast fertile arable land and human power to develop it. The limiting factor is the availability of water and the adequate storage facilities.

Limitations, Constraints, and Problems:

Watershed Degradation and Sedimentation:

Existing information on watershed degradation in Sudan are mostly qualitative, descriptive and/or very theoretical in nature and often conflicting. Watershed degradation mainly resulted form the clearance of vast areas of forested lands for cultivation, fuel wood, brick making, and over grazing. Silt deposition in the Blue Nile and Atbara Rivers has interfered with their flow regimes. Bank erosion along the rivers has contributed to increased sedimentation elsewhere.

Silt and debris carried down the Blue Nile and Atbara River have affected the water supply system especially the limited reservoir storage facilities. Operational measures are taken to minimize the rate of sedimentation during the flood season. Nevertheless, Roseires, Sennar and Girba reservoirs have lost 30%, 40%, and 60% of their original capacities respectively. Inlet channels for the pumps on those rivers are frequently blocked by the deposition of silt carried during the flood season. It become more acute when the rainy season is good as the water needed for supplementary irrigation is minimum and the pumps would be idle most of the time. Inlet channels are usually dredged each year after the recession of the flood.

Floods and Droughts:

Sudan has experienced many devastating floods and droughts spells during the last two decades. Loss of property, damage to irrigation facilities and water services and the spread of water related diseases result from floods. On the other hand, drought disrupts social and economic life, different elements impacting heavily on the economy and aggravating environmental degradation, threatening the sustainability of he ecosystem and the fragile environment. Climate change and population pressures intensify the impact of droughts. Nation efforts and regional cooperation are required to establish national and regional early warning systems, public preparedness and other disaster management measures.

Drought is also a major problem in western and northern part of Sudan within the semiarid portions of the Basin. A succession of dry years from 1978 to 1987 resulted in severe drought impacts, including many human and livestock fatalities and resettlement of close to three million people close to the Nile and in urban areas. Drought problems in Sudan appear to be increasing due a trend to wards reduced rainfall and desert creep form the Sahara. On other land, droughts benefits (if any) are raising the awareness of the stakeholder and removing harmful weeds and insects.

Capacity Building: human and institutional strengthening:

Capacity building in particular is now widely regarded as a key element in ensuring sustainable water development. It is also an essential requirement for the optimal and efficient management and planning of water resources. Capacity building is along-term, holistic, integrated and continuous process, in which all stakeholders of water affairs participate. Ti is an important global concept and strategic element for sustainable management of the water.

In developing countries, institutional weakness and malfunction are major causes of ineffective and unsustainable water services. This requires urgent attention to build institutional capacity at all levels. The need to manage overall water resources more coherently and to facilitate the allocation of water among all users requires an expansion of national integrated planning. The critical new institutional challenge is to develop policy, rules, organizations and management skills that can address both needs simultaneously without constraining the major aims of each.

Land Uses

Sudan extends over an area of more than 250 million hectars. Land is by far the most important resources for over 80% of the population who live in rural areas for farming and herding. Both activities are completely land dependent. Often times, land ownership and accessibility are the critical issues that determine the two activities. The arable land constitutes one third of the country area. Pasture and forest accounts 40% of the total land. The table below summaries the different land uses.

Table 5. **Land use in Sudan in (000) hectares (1977 to 1995 estimates)**

Item	MEPD	Item	FAO 1980	Dep. Statistics 1977	World Bank 1977
Land area	237,443	Land area	237,600	-	-
Area under water	12,986	Agric. land	-	84,030	35,920
Arable land	84,034	Arable permanent	12,390	-	-

		crops			
cultivated land	17,471	Permanent pasture	56,010	23,990	101,400
Uncultivated land	66,563	Forests and woodland	48,910	91,510	23,340
Forests and woodland	64,360	Other land	120,210	38,110	86,290
Other	49,569				
Total area	**250,429**				

Source: Abdulla,1984

Salt affected soils and Soil Recalamation

Little information is available about salt affected soils in Sudan. However, there exists large areas of suitable arable land where soil salinity is the main limiting factor, especially in the northern part of Sudan, in the Khartoum State and in Gezira State. In order to maintain food security for the increasing population marginal land becomes more and more important. The availability of high quality irrigation water from the river Nile would make it possible to reclaim the salt-affected soils. Nevertheless, reclamation and conservation possibilities are very different due to the variable soil properties in these areas.

Total area of potentially irrigable land affected by soil salinity and/or sodicity (LAND AND WATER RESEARCH CENTRE, 2001).

Northern States (Nile and North States): 188 200 ha

Khartoum State: 76 000

Gezira State: 84 545

Total 348 745

As the land is not limiting agriculture, little efforts are made to reclaim lands, Only near big cities or near the Main Nile where land is scares some reclamation is practiced using organic manures, gypsum application, tolerant crops and deep ploughing.

The Agriculture Sector:

Agriculture is the mainstay of the national economy with about 80% of the people engaged in crop and animal production. This makes millions of people in the country directly dependent on natural resources for their livelihood and employment.

Nearly 84 million hectares are cultivable. Only about 10% of this figure is currently utilized for agriculture. Because a large portion of these cultivated lands depend on rainfall, the amount actually cultivated in any particular year cans greatly vary due to fluctuations in rainfall.

Only 21% of the total arable land is under cultivation. Both annual and perennial crops are grown over a wide range of climatic conditions. Agricultural production in Sudan is practiced under five distinct systems:

1. Irrigated agriculture
2. Mechanized rain fed agriculture
3. Traditional rain fed agriculture
4. Flush irrigation agriculture and
5. Livestock raising
6. The irrigated farming system from underground or surface water. All state owned schemes are under the irrigated sub-system like the Gezira, Rahad, New halfa and Suki. This system covers about 4.89 million hectares, and the size of holding ranges between 4.2 and 16.8 hectares.
7. the mechanized or semi-mechanized rain-fed farming, mainly in the central clay plain. Composed of large to medium farm units (about 400 hectares). This system is in fact semi-mechanizes as only land preparation and threshing are done by machines.
8. The traditional rainfed farming comprised of small holdings and grows different crops for subsistence and export as well and is a typical example of low input agriculture. No use of fertilizers chemicals for pest and weed control is practiced.
9. Flush irrigation is practiced in privately owned land along the Nile and its tributaries. Large scale spate irrigation is practiced in large areas in the deltas of Tokar and Gash seasonal rivers. The land which is irrigated once, sore enough water to support two consecutive crops.

The Agricultural Bank of Sudan give the estimates presented in the table below

Table 6. Total arable area by farming sector

Agricultural sector	Area (million ha)
Irrigated	2.254
Mechanized	7.140
Traditional rainfed	3.360

Major Crops:

1. Sorghum is grown under the first 4 system for stable food

2. Cotton is a historically important cash crop. Grown under irrigation and mechanized farming. Irrigated cotton is grow in the government irrigated schemes, the Gezira, Rahad, New Halfa and Suki and under flush irrigation in Tokar and Gash deltas.
3. Wheat is grown traditionally along the Nile north of Khartoum. Due to increased consumption, wheat is now also grown in the major irrigated schemes like the Gezira and Rahad.
4. Sugarcane is grown in 4 plantation schemes.
5. Gum Arabic

Rainfed Sector.

Rainfall is seasonal in nature with coefficient of variation varying from 20 to 60%. Rainfall agriculture is practiced throughout Sudan and constituted one of the major means of food production in the country. The rainfall stored as soil moisture is the only source for crop evapo-transpiration in rain-fed agriculture, rangelands and forestry.

Table (7) shows the agro-climatic zones for the different states and regions of the Sudan. In the northern states 62% of their total area falls in the desert and arid zones and about 19% in the dry boundary of the semi arid zone suffering from high rainfall variability. Rainfall diminishes as one moves north.

Based on Sudan Meteorological data, Potential evapo-transpiration is far greater than rainfall Fig (1). Annual evapo-transpiration varies from 3000 mm in the north to 1700 mm in the south, while on the other hand rainfall varies from 100mm in the north to greater than 800 in the south. This means that over most of the year there are water deficits. The patterns displayed in Table 1.2 show the considerable unreliability of rainfall. This unreliability has its great impact on rainfall production. Fig (2) shows a typical relationship between sorghum yield and rainfall. There is a strong correlation between rainfall amount and productivity in which the correlation coefficient is 81%. That is, 65% (square of the correlation coefficient) of the variability in production can be attributed to rainfall. Another factor is the distribution of rainfall and its suitability for the crop demands. Temporary interruption of rainfall at flowering can effectively reduce yield even if the total rainfall is sufficient. This bad rainfall distribution is a major cause of low water use efficiency, particularly in the mechanizd sector and always leads to fluctuation in production. Taking sorghum as an example, for the period 1970-96, productivity per feddan is about 250 kg compared to 750-1000 kg/feddan in the irrigated sector.

Table 7. **Rainfall data for the different states of Sudan and probability of occurrence**

No.	Region	Station	Annual rainfall (mm)			
			Min	Max	Average	80% Prob of Occurrence
1	Northern	Atbara	0	240	60	20
2	Khartoum	Shambat	3	446	128	40
3	Eastern	Kassala	76	394	215	178
4	Kordofan	El Obied	16	544	318	223
5	Central	Medani	115	504	306	225
6	Darfur	Nyala	197	621	398	297
7	Upper Nile	Malakal	518	1025	732	628
8	Equatoria	Juba	678	1294	973	835
9	B. El Gazal	Wau	733	1429	1075	911

Mechanized rain-fed farming is practiced mainly in the central and southern clay plains. These montmorillonitic clay soils are characterized by deep cracks when dry, very sticky when wet and very hard dry. These soils can only be worked under very narrow range of soil moisture. These soils are low in nitrogen and organic carbon. These soils are highly prone to water logging due to their very slow permeability. They generally pose a difficult physical environment, but are suitable for production of sorghum, cotton, sesame and sunflower. Available water in these soils is estimated from our data to be 90 – 95 mm per meter depth. The Permanent wilting point is around 22% by weight.

There are 42 weather Stations distributed in this sector the total area in the rain-fed sector is estimated at 30 million feddans, so it is clear that the weather stations are far below the required for data good collection (one weather station for every feddans). It must be noted that the quality of data collected is not always high for reasons related to old equipment and poor training of technical staff and the general unawareness about the importance of the information.
The Table below summarizes the areas, yields and water use efficiency under rain-fed conditions for the period 96/97-2001/2001

Irrigated Agriculture

The Gezira Scheme occupies about half the irrigated area of Sudan. The irrigated sector of Sudan produces 95% of the cotton produced in the country, 100% of the sugar production, 36% of the sorghum and 32% of the ground nuts production. In spite of the fact that irrigated agriculture started more than 100 years ago, yet the water productivity is very low, not exceeding 0.2 kg/m3 for the major rotational crops (cotton, sorghum, ground nuts and wheat). This may be due to two main reasons:

1. Water is not delivered in the right time with the right quantity due to poor canal condition (silting, aquatic weeds) and

2. Poor management of irrigation water at the field level.

The Irrigation system of the Gezira Scheme was initially designed to give 952 m3 of irrigation water to a Hectare of land every two weeks. The minor canal was designed to deliver 5000 m3 every 12 hours.The problem with this design is that it does not take into consideration the differential water requirement of the crop with the growth stages and the climatic conditions. Evaporation ranges between 5mm/day in January to 10 mm/day in June.the research done during the 1960s was the base for calculating the crop requirement according to growth stages and evapo-transpiration;

$$\text{Water requirement} = \text{crop coefficient} \times \text{evapo-transpiration}$$

Field water management practices and level of cultural practices:

A salient feature of the Gezira scheme is a leveled and gently sloping topography from south to north and east west. This feature made gravity irrigation easy and commandable. Another feature is the narrow variation in farm size and the cropping pattern of cotton, groundnuts and sorghum in the summer and wheat in the winter. The water management in the irrigated schemes is based on a water demand driven system. The water requirements were estimated from the fields, added up to estimate the water needed in each minor canal. The water needed in the major canal is the sum of all minors taking off from the major canal. According to the demand thus estimated, water is released from the Dam to satisfy the demand and sent to the majors and minor canals. Important management practices that affect yields include planting dates, plant population, weeding, pest and disease control and irrigation management at the field level. Here, emphasis will be on irrigation practices

Irrigation Management

The field is usually divided into small commandable irrigation plots, where each plot is irrigated separately. If the field is not well leveled, additional plots may be required. Significant differences are observed in yields due to poor water management at the field level. These could be mainly due to unattended watering resulting in over irrigation of some parts of the field and depriving other parts. Over irrigation is a serious problem in the irrigated agriculture.

A study conducted by Farah et al 1993 in the Gezira scheme on wheat crop indicated that the highest grain yield was obtained when water was applied in the range of 9500 to 10800 m3/ha. The amount of water applied by farmers was, on average, greater than the crop water requirement as estimated by the method of Farbrother and Adam (1975) by 46% in 1992/93 and 36% in1993/94. Water use efficiency decreased from 0.27 to 0.11 kg/feddan/m^3, respectively.

Table 8. **Over irrigation in wheat crop**

m³/ha /day	Irrigation number						
	3	4	5	6	7	8	Total
Amount of water added	78	87	118	130	122	116	**651**
Actual water requirement	59	65	63	64	46	42	**339**
Excess water added	18	22	55	66	76	74	**312**
% excess water added							**47%**

Irrigation Interval

The irrigation system in the irrigated sub-sector is designed to deliver one irrigation every 14 days at the rate of 950 cubic meters/hectare regardless of the season or the crop. The optimum water intervals is as follows (after Faki, 1989).

Table 9. **The optimum water intervals (cubic meters/ha)**

Time Period	Soil-Moisture Measurement (cubic meters/ha)			Optimum watering interval (days)		
				Cotton	Groundnuts	Sorghum
Early Oct	860	882	882	12	13	24
Mid-Oct	960	825	825	12	17	30
Early Nov	930	852	852	10	32	60

Major crops:

Cotton:

Cotton is the most important cash crop of Sudan. It is grown in almost all production systems, irrigated, rain-fed and flood. The average areas grown to the different cotton varieties are as follows:

Egyptian (Long stable) : 111000 feddans

Acala (Medium stable : 340000 feddans

American (short stable : 500000 feddans

Sudan total : 951000 feddans

Rangelands

An assessment done by RPA in 1997 estimates rangeland area to be 117 million hectares. About 80% of rangelands are located in the semi-desert and low rainfall savannah that are characterized by low and unreliable rainfall. Rangelands are the backbone of the livelihood of pastoralists and agro-pastoralists through provision of needed feed resources, where it supplies about 80% of the total feed requirement for national herd; also provides habitat for wildlife, soil and water conservation, biodiversity and ecological balance. This sector is negatively affected by a set of socio-economic factors as follows:

- Absence of clear cut policies coupled with sectoral approach in development planning which resulted in irrational allocation of land resources as well as conservation and development of the resource itself. All expansion in the agricultural sector was done at the expense of range and forest land.
- Absence of legislation and law enforcement to protect rangelands.
- Over grazing has led to disappearance of many palatable grasses and the dominance of unpalatable and poisonous ones. The carrying capacity of the land is often exceeded especially in dry years
- Uncontrolled burning also contributed to the reduction of rangeland

Animal Production

Sudan is endowed with a large number livestock (Table) and also large livestock genetic resource (cattle-sheep-camels). Unfortunately very little has been done to identify and characterize the genotypes existing in country. Locally available breeds of livestock are important economic resources since they are adapted to the existing production constraints such as feed shortages, prevalent diseases, etc. the productivity of indigenous breeds is low compared to temperate breeds, but their ability to survive and produce in the harsh and mostly unpredicted tropical environment is remarkable.

Livestock are raised mostly under pastoral, agro-pastoral and village-based systems of production. The former two systems are distinguished by seasonal movement between wet and dry season grazing lands but in the agro-pastoral system (transhumance) of production both livestock and crop cultivation are practiced. Some pastoral groups specialize in raising one animal species e.g. sheep, camel or cattle. In both agro-pastoral and village-based systems of production multiple animal species may be raised. The proportion of cattle in herds increases in regions where transhumance becomes more important. The utilization of the rangeland for grazing by different tribal groups is based on traditional rights. The major goals in pastoral systems are to assure subsistence for the community and to reduce the negative impact of diseases and drought on livestock population by maximizing livestock numbers. Rangeland is a cheap source of livestock feed but is vulnerable to draught and exhibit marked seasonal fluctuations in quantity and quality. Moreover, the utilization of the rangeland for grazing will be greatly impaired if enough supplies of stock water are not available.

The pastoral and agro-pastoral systems of livestock production supply most of the meat consumed locally and all export live animals and meat. Sudan is generally self-sufficient in red meat and partially sufficient in fresh milk. However, there are important inter-annual, geographical, regional and household variations. Annual meat production from cattle, sheep, goats and camels in the country is about 2 million tones. However, only about 0.94% of the total meat is converted into value added products. The domestic marked has not been tapped for ready-to-eat and semi-processed meat products. There are attractive opportunities for investment in supporting services including construction and operation of modern slaughter facilities and development of cold chains in meat and poultry processing sector.

Table 10. **Animal Resources of Sudan.**

livestock	Number
Sheep	48910000
Cattle	39760000
Goats	42179000
Camels	3519000
Total	**134368000**

Source: Dep of Info and Stat., Ministry of Animal Resources, 2004

CHAPTER 2

Productivity and Water Use efficiency of Major Crops in the Irrigated and Rain-fed Sector

Cotton: Productivity : (kg/feddan) and water use efficiency for season 2006/07 compared with the period 1996/97 - 01/02) for major production areas.

Production areas	96/97 - 01/02		2006/2007	
	Productivity	WUE	Productivity	WUE
Egyptian :				
Sennar	200	0.045	-	-
El Gezira	396	0.083	200	0.118
Tokar	375	0.137	396	0.136
Akala :				
El Gash	200	0.073	0	
El Suki	455	0.108	710	0.169
El Gezira	695	0.158	705	0.16
Sennar	385	0.093	564	0.134
White Nile	318	0.084	390	0.103
New Halfa	522	0.109	740	0.156

Upper Nile	500	0.159	500	0.149
ElRahad	605	0.141	710	0.161
Northern Kordufan	200	0.154	200	0.132
American :				
Blue Nile	83	0.02	113	0.027
Sennar	-	-	113	0.028
El Gadarif	111	0.059	185	0.094
Southern Kordufan	59	0.029	120	0.055
Western Kordufan	200	0.125	0	0

Sorghum productivity is largely dependent on rainfall amount and distribution as seen from Fig.1 for the rainfed sector and Fig 2 for Gedaref area which is the most important sorghum producing area in .Sudan

Fig. 1. Varaiation in Sorghum Productivity for Rain-Fed Sub-Sector

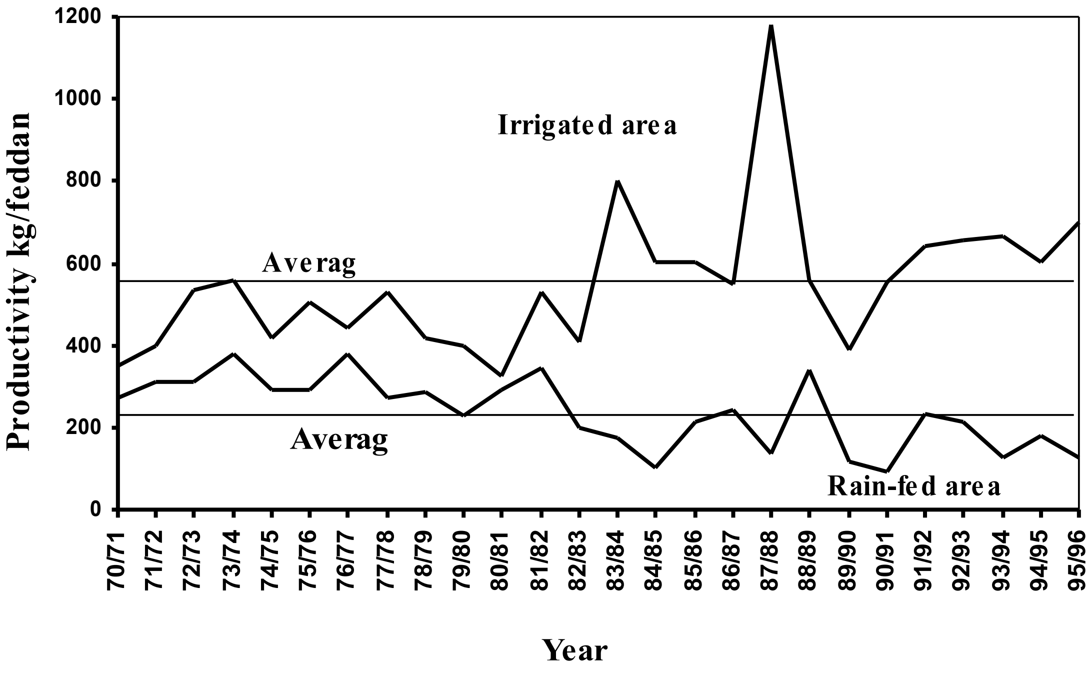
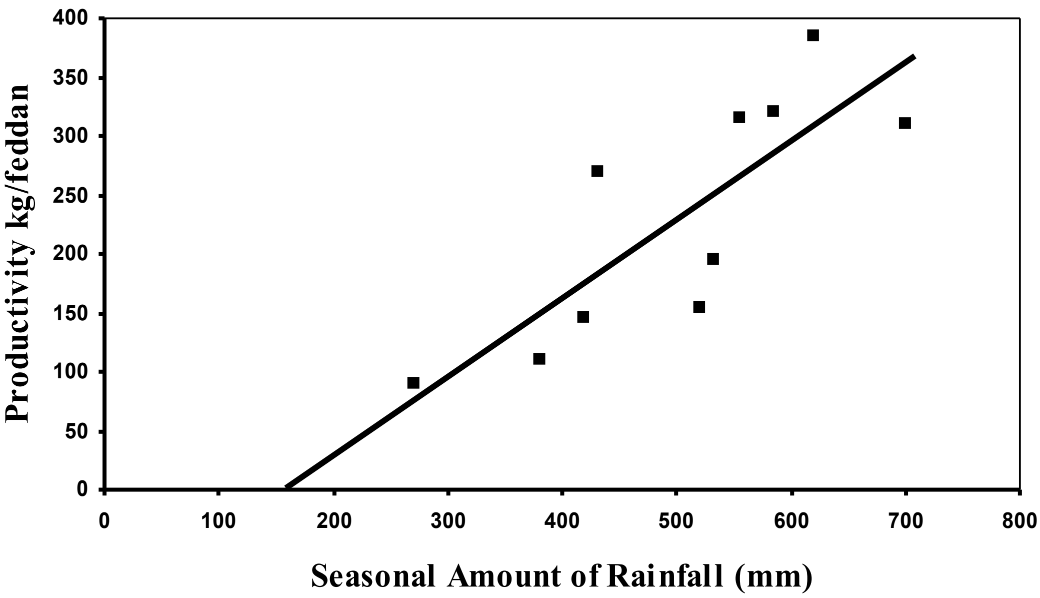


Fig. 2. Relationship Between Sorghum Productivity and Amounts of Rainfall at Gedaref Area (Hussein 1994)



Food Crops

Cereals, especially sorghum are the stable food of the Sudanese people. The table below summarizes the production of food crops in the Sudan for seasons 2006/2007

Table 11. **The production of food crops in the Sudan for seasons 2006/2007.**

Crop	Production (1000 metric tons)
Sorghum	4327
Millet	675
Wheat	416
Groundnuts	555
Sesame	400

Cereals Balance:

Total production of cereals on average is around 7.5 million metric tons annually and annual consumption is around 6.6 million metric tons. Sudan exports sorghum and imports wheat and rice. The table (12) below depicts the cereal balance of the Sudan for 2007.(1000 metric tons)

Table 12. **Cereal balance of the Sudan for 2007.(1000 metric tons)**

	Storage	Sorghum	Wheat	Millet	Maize	Rice	Total
Production	1000	5011	680	797	70	23	7581
Imports			1400			38	
Total	1000	5011	2080	797	70	61	9019
Losses		351	48	56	4	1	459
Human use		3050	1982	670	74	54	5830
Animal use		200		8			208
Seeds		60	50	12	2	1	125
Total consumed		3661	2080	746	80	56	6623
Self suff (%)		3661	2080	746	80	56	

Sorghum: Productivity : (kg/feddan) and water use efficiency for season 2006/07 compared with the period 1996/97 - 01/02) for major production areas

Production areas	**96/97 - 01/02**		**2006/2007**	
	Productivity	**WUE**	**Productivity**	**WUE**
Irrigated :				
Northern State	684	0.428	1000	0.652
River Nile	860	0.538	1000	0.625
Sennar	887	0.554	754	0.471
White Nile	573	0.358	660	0.413
El Gezira	921	0.576	1000	0.625
El Rahad	920	0.575	1093	0.683
El Suky	1045	0.653	1033	0.646
New Halfa	737	0.46	1146	0.716
Mechanical:				
El Gadarif	198	0.131	187	0.114
Kassala	247	0.19	180	0.117
Blue Nile	289	0.164	415	0.206
Sennar	208	0.124	184	0.1
White Nile	227	0.154	280	0.175
South Kordufan	199	0.121	340	0.193
Upper Nile	-	-	306	0.121
Northern Kordufan	-	-	222	0.182
Traditional:				
El Gezira	213	0.169	170	0.107
Blue Nile	243	0.138	360	0.179
Sennar	224	0.133	200	0.108
White Nile	252	0.171	360	0.226

Kassala	209	0.161	183	0.119
Red sea	200	0.183	200	0.19
Northeren Kordufan	35	0.029	210	0.156
Southern Kordufan	221	0.135	331	0.188
Western Kordufan	116	0.099	0	0
Northern Darfur	104	0.083	60	0.045
Southern Darfur	255	0.145	290	0.17
Western Darfur	330	0.258	348	0.237
Southern States	254	0.108	349	0.137

Wheat: Productivity : (kg/feddan) and water use efficiency for season 2006/07 compared with the period 1996/97 - 01/02) for major production areas

Area: 1000s Feddan **Productivity: kg/feddan**

Production areas	96/97 - 01/02		2006/2007	
	Productivity	WUE	Productivity	WUE
Northern State	1224	0.5	1450	0.66
River Nile	1094	0.429	1200	0.5
White Nile	571	0.238	800	0.364
El Gezira	695	0.248	900	0.36
El Rahad	400	0.167	0	-
New Halfa	585	0.244	1000	0.476

Water use efficiency varies strongly with climate. Wheat grown in the in central Sudan (Gezira, Rahad Schemes) uses more water and produces less compared to the northern states where the climate is more favorable for the WUE was found to be 0.78 and 0.5 kg/m3, respectively. Differences between wheat varieties in WUE were not significant. The WUE increased significantly when one irrigation was skipped during early plant growth to be 0.81 and 0.49 kg/ha, respectively.

Maize: Productivity : (kg/feddan) and water use efficiency for season 2006/07 compared with the period 1996/97 - 01/02) for major production areas

Area: 1000s Feddan **Productivity: kg/feddan**

Production areas	96/97 - 01/02		2006/2007	
	Productivity	WUE	Productivity	WUE
Northern States	1044	0.597	1100	0.647
Southern Kordufan	261	0.124	240	0.104
Western Stats	100	0.079	200	0.136
Southern States	147	0.058	0	-

Sesame: Productivity (kg/feddan) and water use efficiency for season 2006/07 compared with the period 1996/97 - 01/02) for major production **areas**

Production areas	96/97 - 01/02		2006/2007	
	Productivity	WUE	Productivity	WUE
Mechanical :				
El Gadarif	88	0.058	90	0.055
Kassala	119	0.091	100	0.065
Blue Nile	100	0.057	90	0.045
Sennar	84	0.05	90	0.049
White Nile	89	0.06	100	0.063
Upper Nile	73	0.033	68	0.027
Northern Kordufan	72	0.059	0	-
South Kordufan	-	-	100	0.057
Traditional :				
El Gezira	-	0	70	0.044
Blue Nile	90	0.051	100	0.05
Sennar	83	0.049	100	0.054
White Nile	88	0.06	110	0.069
Northeren Kordufan	21	0.017	70	0.052
Southern Kordufan	94	0.057	105	0.06
Western Kordufan	45	0.038	0	0
Northern Darfur	42	0.04	30	0.026
Southern Darfur	80	0.045	90	0.049
Western Darfur	170	0.104	135	0.08
Southern States	32	0.014	78	0.031

Millet: Productivity : (kg/feddan) and water use efficiency for season 2006/07 compared with the period 1996/97 - 01/02) for major production areas

Area: 1000s Feddan **Productivity: kg/feddan**

Production areas	96/97 - 01/02		2006/2007	
	Productivity	WUE	Productivity	WUE
Mechanical :				
El Gadarif	184	0.146	128	0.102
Sennar	161	0.096	180	0.107
White Nile	175	0.139	197	0.56
South Kordufan	200	0.087	133	0.058
Upper Nile	250	0.108	160	0.069

Rice: Productivity : (kg/feddan) and water use efficiency for season

Season	Flooding sector	
	Productivity	WUE
1996/1997	200	0.036
1997/1998	350	0.062
1998/1999	250	0.045
1999/2000	250	0.045
2000/2001	500	0.089
2001/2002	805	0.144
2002/2003	1500	0.268
2003/2004	2000	0.357
2004/2005	1400	0.25
2005/2006	1500	0.268
2006/2007	1500	0.268

Sugar Cane

Sugar industry started in Sudan started in 1959. Sudan now is a major sugar producing country in Africa and the Arab world. There are now five sugar plantations with an area of 150000 feddans.

The new cane crop can be harvested in 12-14 months, and the ratoon crop in 11-12 months. The crop has 4 distinct growth stages, with different water requirements. For the initial stage which is 4 months long, the water requirement is 3.5 mm/day, increases to 10 mm/day when the crop is 7 months old and decreased to 6.3 mm/day at the end of the season (Table).

The crop is planted on heavy clays which permit the use of long furrow irrigation due to its very slow permeability.

Table 14. **Average water requirement and water use efficiency for sugar cane at (Ginaid).**

Month	ET0/day	Water requirement (mm)	Rain (mm)	Supplementary irrigation (mm)
December	1.0	16	0	16
January	1.3	40	0	40
February	1.6	45	0	45
March	2.7	84	0	84
April	5.1	153	0	153
May	7.5	233	0	211
Jun	7.5	225	22	203
July	7.5	233	33	200
August	7.2	223	61	162
September	6.1	183	92	91
October	5.6	174	22	152
November	5.3	159	0	159
December	5.2	31	0	31
Total (mm)		**1799**	**230**	**1569**

Total (m^3/ha)	17983	2299	15684

Average yield 45 ton/feddan, WUE 2.50 kg cane/m^3

Water Use Efficiency in Gum Arabic Agroforestry Systems

Traditionally, the gum Arabic tree Acacia Senegal is managed in time sequence with agricultural crops as means of restoring soil fertility in the North Kordofan area in the Sudan (Ballal et al 2005). The cycle consists of a relatively short period of cultivation followed by a long period of fallow. The bush fallow cycle starts by clearing an old gum garden for the cultivation of crops. The cleared area is cultivated for a period of 4-6 years, during which time the coppice is cut to inhance the establishment of crops. When the soil fertility declines, the area is left as fallow under A. senegal. Trees are tapped for gum Arabic until the age of 15-20 years when the area is cleared again for crop cultivation. Traditionally, sorghum, roselle (Hibiscus sabdariffa), sesame and ground nuts are grown in this system.

Intercropping of Roselle with trees at low or high density was found to increase gum yield compared to sole stands. However, yields of roselle and sorghum diminished by more than 40% when grown with trees (Gaafar, 2006).

Table 15. **Effect of *A. senegal* tree density on yields and IWUE of sorghum and karkadeh (*Hibiscus sabdariffa*).**

Treatments	Sorghum yield (kg ha-1)		IWUE (µmol mol-1)	Karkadeh yield (kg/ha)1		IWUE (µmol mol-1)
	Grain	Biomass		Flower	Biomass	
LD + crop	126b (24)	1030a (23)	80.5a	127ab (26)	622a (37)	36.1b
HD + crop	93a (44)	527a (61)	36.7b	77a (55)	422a (57)	87.6a
Mono crop	167 b	1346b	59.4ab	172b	982b	45.7a

Numbers in parentheses indicate % reduction in yield compared to mono crop. LD and HD denote 266 and 433 trees ha^{-1}, respectively. IWUE denotes intrinsic water use efficiency (A/g_S).

Intrinsic Water Use Efficiency in Gum Arabic Agroforestry Systems

WUE of A. Senegal trees calculated as A/gs was highest when sorghum (shallow rooted) was grown with trees at high density and the lowest when karkadeh was grown with trees at low density or when trees were grown solely at high density.

The cropping design significantly affected the IWUE in crops (Table 3). The highest values of IWUE in kardadeh were observed, when karkadeh was grown with trees at high density. In sorghum the highest IWUE was observed when the crop was grown with trees at high density.

Rain use efficiency (RUE) in different cropping patterns

Cropping design	RUE (kg ha^{-} mm^{-1})
LD + K	0.631ab
HD + K	0.468b
LD + S	0.616ab
HD + S	0.705a
LD	0.166c
HD	0.275c
K	0.583ab
S	0.563a

L and H: low and high density of *Acaia Senegal* trees respectively, K: Kakadeh crop, S: sorghum crop

Water and Soil Losses.

Most of irrigated and rainfed agriculture is practiced on the central clay plain where the 4 major irrigated schemes are located (Gezira, Rahad, New Halfa and Suki). These soils are classified as Vertisols. These soils have very slow permeability and the wetted zone does not exeed 60-80 cm. This made the calculation of water requirement easy as deep percolation is assumed nil. However, this character increases the runoff coefficient when precipitation exceeds the infiltration rate, causing serious water erosion

The clearing of trees accelerated the problem. A study by Fadul et al (1999) using multi-date Landsat images in arid and semi-arid eastern Sudan. The interpretation detected the effects of water erosion on geology, lithiology, vegetation and land use. The results showed that traditional rain-fed agriculture around Atbara River has accelerated gully erosion in the semi-arid rather than the arid zone. The progressive rate of gully erosion in the semi-arid zone resulted in loss of arable land at about 13.4 km^2 yr^{-1} and 9.8km^2 yr^{-1} in the periods 1985-1987 and 1987-1990, respectively.
Another study by Hussain et al (2006) revealed that gully erosion can cause serious soil loss especially with high rainfall (Tabl7). The amount of soil loss can be reduced significantly by cut-off drains made against the slope.

Table 17. **Cummulative soil loss over the sampling period (1998-2001) in t/h at Elshowak site.**

Year	Total rainfall ((mm	(Eroded soil (t/ha Cut-off drains	Eroded soil (t/ha) Control	Reduction % of soil loss
98	49	3.023	18.12	83
99	122	4.444	7.283	38.98
2000	109.5	1.472	4.716	66.3
Total	**280.5**	**8.892**	**30.119**	**70.48**

Beside loss of arable land, the eroded material is ssilting up and reducing the storage capacity of dams. The cost of desilting the irrigation system is the highest maintenance cost in the irrigated shemes.

The Way Forward

Rainfall stored as soil moisture is the only source for evapotranspiration for rain-fed agriculture, range lands and forestry. However, there are two major constraints affecting productivity. These are;

- The high variability und unreliability which lead to significant fluctuations in production, and
- Deforestation and denudation of vegetative cover which cause climate change and desert encroachment.

Opportunities:

Water harvesting

In semi-arid regions, the rainfall is known by its scarcity, it strong variability and that the soil water balance being negative almost all the year round. One of the major criteria of water harvesting techniques is the suitability for the plant one wants to grow. A basic difference between trees and annual crops is that trees require the concentration of water at points while annual crops benefit most from an equal distribution of water over the cultivated area.
The potential of water harvesting in Sudan is tremendous. Harvesting

The Future:

Present and Future Usage of water:

Irrigated agriculture is by far the major user of water in Sudan. The main crops grown are cotton, sorghum, groundnuts and wheat. It consumes more than 90% of the water. Human and animal consumption are estimated at 5% and 1% is estimated for the industrial and other uses. The developed agricultural schemes cover a net cultivable area of 4.4 million Feddans (1.85 m ha) expected to rise to

5.5 million fed. (2.31 m ha) in the near future. The total water used by these schemes plus evaporation from the existing reservoirs is estimated at 14.5 bcm (measured at Aswan). The estimate was based on the present performance and cropping pattern, irrigation water requirements and the high conveyance efficiencies in the Sudan's clay plains. The future water demand projection prepared by the Ministry of Irrigation and Water Resources under the Long term agricultural strategy (02 – 07) projected the irrigation needs to be about 42.5 bcm by the year 2027, human and animal usage and other domestic and industrial needs to be about 10.1 bcm (Table 1). If the evaporation from the reservoirs of the proposed hydropower development projects is added (6.6 bcm), the total demand would be 59.2 bcm.

Table 18. **Water demand Projection to 2027 (bcm)**

Year	Irrigation	Domestic Supply	Animals & Others	Total
2010	27.1	1.1	3.9	32.1
2020	32.6	1.9	5.1	39.6
2025	40.3	2.5	5.3	48.0
2027	42.5	2.8	7.3	52.6

Water demand according to 25 years strategy is far beyond the available water, even, if the water flowing in the seasonal streams is harvested, the ground water is pumped to its recharge limits. The Sudan's population at that time is expected to be 56 million, and accordingly, the per capita water stress margin. It is worth noting that the above mentioned study assumed that the irrigated area would be 7.487 million Feddans (3.15 million ha) which is less than 4.0% of the arable land of the country.
The future development projects are based on different assumptions and cropping patterns. Obviously, it would not be possible to meet the demands of all these projects as planned and major changes in the policy or demand and/or choices from the possible projects will need to be made.

Institutional and Legal Framework:

Institutional Framework:

The responsibility of water resources monitoring, assessment, development and management in Sudan was not under one institution. The major part was under the responsibility of the Ministry of Irrigation and Hydroelectric Power now the Ministry of Irrigation and Water Resources (MIWR). The Ministry of Irrigation and Hydroelectric Power was entrusted for management of water resources in Sudan including monitoring, assessment, planning, development of the Nile Water

Resources and the major Wadis of Gash, Baraka and Jebel Marra, for irrigation, hydropower and partly drinking water. The monitoring, assessment, development and management of the small Wadis in central clay plains of Sudan for drinking water and also the monitoring and development of ground water drinking was the responsibility of the Rural Water Corporation which used to be part of the Ministry of Agriculture for sometime and the Ministry of Energy for the other. There was national water resources policy for each of the above water sectors separately. Sewage and sanitation is only up to now limited to Khartoum town and is under the municipality as it is the case with most countries of the world. Measurement of evaporation was and is still the responsibility of the Meteorological department which is part of the aviation as in many countries in the world. There was coordination between the Meteorological Department and the other agencies involved in the use of water resources. There is also some degree of coordination between the Ministry of Irrigation and Water Resources, the Ministry of Agriculture and Forestry, the Ministry of Electricity and the Ministry of Industry, through the high committee of utilization and optimization of the Blue Nile waters.

Realizing these drawbacks, the Government started in the last decade some major steps for rectifying the situation. One of these major steps is bringing down the responsibility of all the water resources, surface (Nile and Wadis) and ground water resources, under the umbrella of the Ministry of Irrigation and Water Resources (MIWR). Another major step is the formulation of the National Council for water Resources (NCWR) with the objective of formulating common water resources policies and coordinating the activities of all water sector agencies and stakeholders. The NCWR has the Technical Water Resources Organ (TWRO) as its executing arm. These can be considered as significant steps towards the integration of activities in this important sector.

Another major change in the setup of the management of the water sector was brought about by the restructuring of the management of the national economy and the adoption of the federal system and privatization. The restructuring of the management of the instate water resources to the States and also the irrigated agriculture to the farmers including the financing of the water delivery cost. The Federal system of Government is major step in decentralization. Its associated local government acts gave the village and town councils full responsibility of financing and managing domestic and industrial water supplies.

The ministry of Irrigation and Water Resources (MIWR):

All water affairs are now under one umbrella – the Ministry of Irrigation and Water Resources (MIWR). Section 10 of the Council of Ministers Resolution dated 12 November 1995 defines the powers of the national focal point for water resources, the ministry of Irrigation and Water Resources (MIWR). Its main functions are:

Administrative function:

a. Assessment of water resources by compiling information and data for analysis and evaluation.
b. Formulation of policies for the use of water resources and review and update such policies according to new development.
c. Preparation of new water resources development projects, evaluation of the engineering designs prepared by non governmental agencies and issuing of technical approval and supervision of r implementation.
d. Conducting hydraulic research, as well as systems analysis, flood control and sedimentation studies.
e. Assessment, formulation and development of national plan for irrigation.
f. Operation and maintenance of dams.
g. Development of irrigation systems and operation and maintenance of large irrigation schemes.
h. Development of regional and international cooperation in the various aspects of water resources and irrigation development activities.
i. Development of training activities for the different skills in irrigation and water resources management.

The expected increase in water demand in the near future with the increasing population, technical and environmental difficulties associated with exploitation of other water resources (Wadies, ground water and swamp water and the large rainfall variability necessitates continuous update of water policies for the best management and efficient use of the limited share of the Nile water. This requires continuous strengthening of the capacity of the water management capabilities of the country.

To achieve this objective several issues need to be addressed. These include, but are not limited to:

- Water resource monitoring, assessment and development is divided among many institutions. Similarly water use is managed by different sectors. Adequate coordination among water related sectors is essential for developing an integrated holistic approach needed for sustainable water resources management
- Awareness among the public on the value of water and the importance of its conservation
- Maximization of the returns from water especially in irrigated agriculture which utilizes 90% of our water share in the Nile water. The same yields realized now could be obtained by less than one fourth of the water consumed.
- There is a need to increase the number of trained staff and to improve skills in the efficient and effective management of water. Efficient water management at the field level is especially important.
-

Water Users Associations

The Gezira scheme is the largest irrigated scheme in Sudan, with a total area of 882000 ha. It is the major user of water in Sudan. The total number of tenants is 112000. Major crops are cotton, sorghum groundnuts and vegetables. The irrigation system of the Gezira scheme is divided into upper system (US) which comprises the dam, main, branch and major canals and the lower system that includes the minor, tertiary and field channels. Since its establishment in 1925 the operation and maintenance of US and the minor canals is the responsibility of Ministry of irrigation, the responsibility of the minor canals was handed over to the scheme management in 1999. A pilot project (PP) supported by FAO handed the operation and maintenance of the minor canal to tenants in one of the Gezira 14 Blocks was during 2000-2002. Crop yields (Table) in the PP out yielded neighboring blocks as well as the scheme average during the duration of the project (Abdelhadi et al, 2004).

Table 19. **Crop yields (1999-2000) before and after the PP (tha^{-1}): Abdelhakam block compared with the Gezira scheme average (source: A.W. Abdelhadi, et al, 2004)**

	1999/2000	2000/2001	Increase (%)
Cotton			
Abdelhakam (PP)	1.00	1.88	87
Gezira scheme	0.86	1.6	86
Increase (%)	17	17	

Sorghum			
Abdelhakam (PP)	1.19	2.93	
Gezira scheme	1.55	2.26	
Increase (%)	-29	30	
Wheat			
Abdelhakam (PP)	0.48	2.26	375
Gezira scheme	1.19	1.67	40
Increase (%)	-60	36	
Groundnuts			
Abdelhakam (PP)	1.36	2.12	56
Gezira scheme	2.05	2.05	0
Increase (%)	-29	3	

Economic productivity

Water harvesting techniques were found to be economically feasible for traditional farmers. Table

Table 20. **Average production costs and returns (Sudanese Dinar/ha) for Sorghum under different water harvesting techniques.**

Water harvesting techniques	Total costs[1]	Total costs[2]	Net benefit
1997/1998			
Control	9001.3	8961	-
Chisel plough +Contour Dikes+	21680.3	16948	-
Chisel plough	13868.3	15456	1587.7
Traditional +contour dikes	11561.3	13917	2355.7
1998/1999			
Control	15712	23168	7456
Chisel plough +Contour Dikes+	24215	30702	6487
Chisel plough	22072	35602	13530
Traditional +contour dikes	17232	26742	9532