Annals of Arid Zone 42(3&4): 309-331, 2003

Desertification Studies in the Sudan

Tarig El Gamri and Maria H. El Nasikh
Desertification Research Institute, PO Box 6096, Peoples Hall, Khartoum, Sudan

Abstract: Sudan is a vast country with an area of about 2.5 million square km (2/3rd of the area is arid or semi-arid) and hosts an estimated population of about 31 million people. It is concluded from the findings of various studies that 12,000 years ago natural deserts constituted only small fraction of the Sudanese territories. However, recently, especially during the second half of the previous century the arid and semi-arid regions of the country were subjected to different forms of land degradation. The area affected by drought and desertification is amounting to about 50.5% of the total area of the country. Deforestation is considered by some authors as the main cause of land degradation in the country. This paper presents an overview of the different desertification studies executed in the country. However, special emphasis is put in the studies in the subjects of soil and water resources. Arid land agriculture and biodiversity are also discussed in some detail. The indicators of soil and land degradation are identified and the causative factors are also highlighted. The characteristics of rainfall and the striking advancement of the use of the empirical-statistical rainfall prediction models are also illustrated. Research in water conservation techniques like water harvesting, supplementary irrigation and canal lining is also reviewed. Studies on the impacts of irrigated desert agriculture with special emphasis to Um Jawaseer Project are also discussed. The Project proved to upgrade the livelihood of the beneficiaries and to protect the environment.

Key words: Land degradation, desertification, biodiversity, monitoring, irrigation.

According to United Nations Convention to Combat Desertification (UNCCD,1998) over 250 million people are directly affected by desertification and about one billion are at risk. During the World Summit on Sustainable Development (WSSD), which was held in Johannesburg, South Africa, in August 2002, the UN Secretary General revealed that now about one billion people are actually living under the influences of the process of desertification. It has been estimated that about 70% of the world's dry lands (excluding hyper-arid deserts) are degraded. On the other hand, land degradation in marginal dry lands covers about 30% of the total area of the globe.

The latest definition of desertification is adopted by UN Conference on Environment and Development UNCED 1992 in Rio de Janeiro, Brazil: Desertification is land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities. The five major causes of desertification are: deforestation, climate variability, overgrazing, poor irrigation practices and over-exploitation of land resources.

UNCED called for the adoption of integrated approaches for sustainable development at the community level for

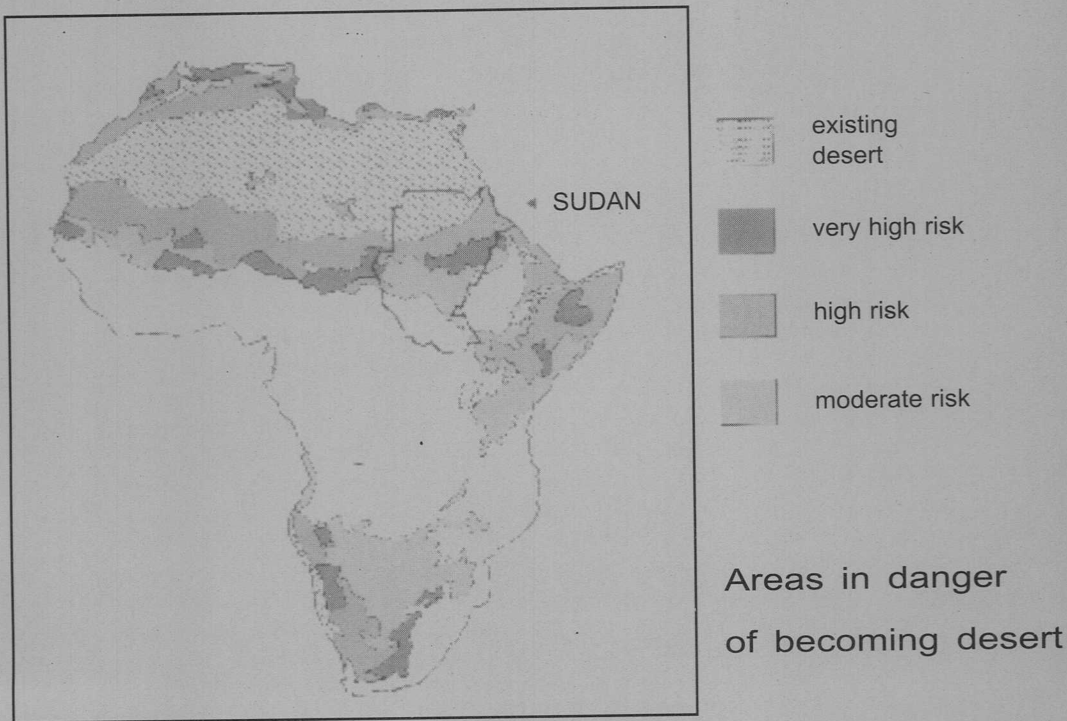

Fig. 1. Areas under threat of desertification.

combating desertification. The conference also called on the UN General Assembly to prepare, by June 1994 a Convention to Combat Desertification. The Convention was adopted in Paris on 17 June 1994, opened for signature on 14 to 15 October 1994 and entered into force on 26 December 1996, three months, after the 50th ratification.

As exhibited in Fig. 1 the African Continent is seriously influenced and endangered by the process of desertification and hence UNCCD laid special emphasis in combating desertification in Africa. Efforts at the international, regional and national levels to combat desertification are numerous. One major action in this respect was the adoption of the Plan of Action to Combat Desertification (PACD) by the UN in the year 1977. Despite this and other efforts, the UNEP concluded in 1991 that the problem of desertification had been intensified, although there were some examples of local success. Fortunately in August 2002 during WSSD the Global Environment Facility (GEF) was mandated to finance desertification projects and large funds were allocated for the coming four years.

Sudan with an area of about 2.5 million square km (2/3 of the area is arid or semi-arid) hosts an estimated population of about 31 million people. During the second half of the last century, the arid and semi-arid regions of the country were subjected to different forms of land degradation like sand encroachment, recurrent droughts and degradation of the vegetative cover. Salih (1996) pointed out "the area affected by drought and desertification is amounting to about 50.5% of the total area of the country". Deforestation is considered by Gamal (2000) as the main cause of land degradation in the country. Recent studies carried out by Food and Agriculture Organization of the United Nations (FAO) showed that Sudan witnessed high rates of deforestation during the period 1996 to 2000.

Sudan has signed and ratified the UNCCD and submitted its National Action Plan to Secretariat UNCCD in the year 2002. By doing so the country is eligible to receive finances from the international community for its' desertification control projects.

Desertification Indicators in the Sudan

According to Fadul and Osman (2000) the primary desertification indicators in the country are:

- Degradation of soil fertility, which leads to crop failure or a declined in productivity
- Degradation of the vegetative cover both in terms of quality and quantity
- Change in animal ratios
- Change in wild life due to environmental degradation and illegal hunting

On the other hand the authors mentioned the following permanent desertification indicators:

- Disappearance of the vegetative cover
- Wind erosion and the associated mobile sand dunes
- Water erosion and the appearance of gullies
- Drying of wells and sand deposition in wadis and irrigation channels
- Tribal disputes and conflicts over land resources for range and agriculture (such problems are aggravated by the weakening of the traditional tribal institutions)
- Displacement of rural people to the outskirts of cities and towns where they usually live in bad environmental conditions
- Rises in price rise due to insufficient production
- Famines, malnutrition and increased infant mortality

Studies in Desertification Monitoring

Twelve thousand years ago natural deserts constituted only small fraction of the Sudanese territories (Abu Shama, 2003). As mentioned earlier nowadays natural deserts and desertified lands occupy about 50% of the country's area (Fig. 2). Desertification studies in the Sahel zone during 1970s' claimed that human activities and not climatic variations, are the causative factors of desertification. However, this is in contrast with the recent findings that no wide-scale change in vegetation can occur without changes in rainfall. In the year 1975 Lamprey investigated the extent of desertification in North Kordofan, North

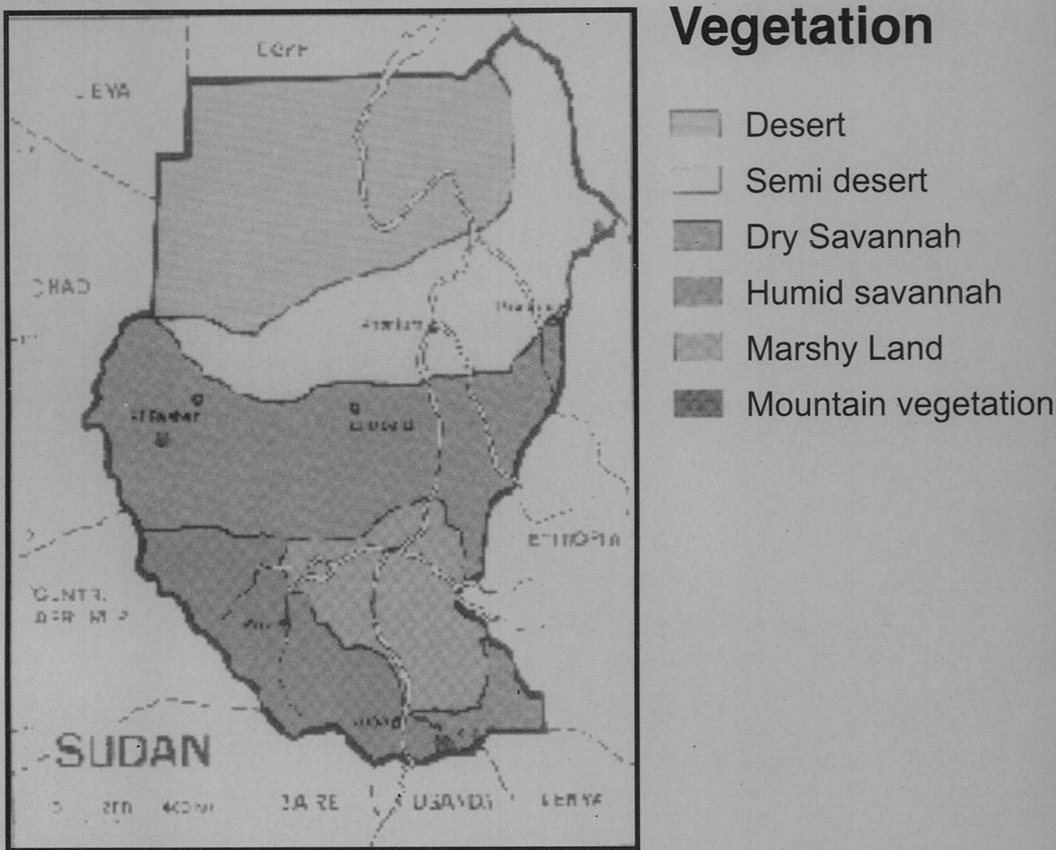

Fig. 2. Extent of desertified land in Sudan.

Darfur and the northern part of the Northern State. His main findings can be summarized as follows:

- Between 1958 and 1975 the desert crept about 90 to 100 km to the south at a rate of about 5.5 km per annum
- The vegetative cover, besides being degraded, has been cleared up to Lat. 15°N except species like *Acacia mellifera*. Lamprey also argued that *Acacia senegal* (Arabic gum) has also been replaced by other species
- Traditional agriculture has been abandoned gradually up to Lat. 14°N, especially in areas where sand deposition occurred
- Sand encroachment invaded the fertile lands of the River Nile banks and he expected that by the year 1995 such fertile lands would disappear
- Drastic erosion of wild life

Lamprey attributed this severe degradation to: (a) lack of national natural

Table 1. Drought influence on animal maturity

Animal	Sexual maturity (Month)		Physical maturity (Month)	
	Normal	Drought	Normal	Drought
Cattle	38.4	46.8	38.4	48.0
Goat	8.6	15.4	15.0	17.0
Sheep	7.8	11.8	12.0	14.0-15.0

Source: Yassin and Alamin (2000).

resources plan, (b) lack of policies and legislations, and (c) population increase.

Abu Shama (2003) discounted the findings of Lamprey because of the short duration of his study (only 21 days) and exaggeration made by Lamprey about sand encroachment around the River Nile.

Hellden (1991) monitored desertification using remote sensing techniques in North Kordofan, North Darfur and the Northern State. The study was conducted during 1972 to 1979 and the main findings were: (i) there is no evidence that desertification is creeping southwards, (ii) desertification does not occur around villages and water as points was believed for along time, (iii) the decline in the vegetative cover and agricultural productivity in the rain fed sector was due to drought in the Sahel zone during 1964-1974.

Hellden (1991) concluded that the influences of droughts were temporal and conditions improved when normal rainfall occurred. This was also confirmed by remote sensing studies using data for the year 1984 (dry year) and 1994 (wet year) and by Abdel-Salam (2003) who studied an area west of Khartoum. Other studies carried in North Kordofan agreed with the findings of Hellden with regard to the recovery of the vegetative cover and build up of soil organic matter.

Rainfall characteristics

Rainfall plays a key role in the environment and the socio-economic conditions of the Sudan. Rainfed agriculture, which is considered vital in the Sudanese economy, is directly affected by the amount and distribution of rainfall. During drought years the growth of farm animals are severely retarded because of shortage of feed available (Table 1).

During wet years, the animal population tends to increase and hence animal losses and overgrazing during dry years increase. Flexible management practices and marketing policies can be used to regulate the herd size.

The main factors that influence the rainfall in the Sudan are (a) annually the Inter-Tropical Convergence Zone enters the southern borders of the country in early March and reaches its ultimate northern position (Lat. 20°N) in August. During September ITCZ starts its return movement and goes outside the Sudanese borders either in the end of November or late December, (b) the four sub-tropical high pressure systems, these are namely the Mascarene, the St. Helena, the Azores and the Arabian high pressure systems, (c) the inter hemispherical monsoonal wind systems, (d) the Mediterranean depression, (e) easterly and westerly waves and associated jet streams, (f) Meso-scale systems, and (g) reconnections with El Nino – Southern Oscillation (ENSO).

According to the Ministry of Irrigation and Water Resources (MOI/WR) (1999) the country is divided into three distinct rainfall zones.

The Northern half of the country extends from Khartoum where rainfall is about 200 mm per annum to the Sudanese-Egyptian borders where rainfall is almost nil. In this region the rainy season is limited to 2 to 3 months with the rest of the year virtually dry. Rainfall usually occurs in isolated showers. The coefficient of variation of the annual rainfall could be as high as 100%.

The southern half of the country receives rainfall of about 700 mm annually and the rainy season extends for 4 months from July through October. Rainfed agriculture is mainly practiced. Since the coefficient of variation of the annual rainfall is about 30%, there are large fluctuations in area cultivated and the productivity. In the extreme south annual rainfall exceeds 700 mm and the area is dominated by extensive wetland, inhabited by the tsetse fly and other insects hazardous to humans and livestock.

Rainfall predictability

According to Abdalla (2003) the Sudan Meteorological Authority (SMA) started to issue seasonal rainfall forecast from the year 1999, the most important of which is the rainfall forecast for the period June-September, which is the main agricultural season in the country. Using the Principle Component Analysis the country was first divided by SMA into 6 homogenous rainfall zones. Table 2 shows a summary of the predicted and actual rainfall received during the period 1999 to 2002.

Table 2. Summary of the rainfall forecast vs the actual rainfall for the years 1999-2002

Year	1999		2000		2001		2002	
zone	Forecast	Actual	Forecast	Actual	Forecast	Actual	Forecast	Actual
Three	NA	A	NB	N	NB	B	NB	B
Four	NA	A	BN	B	NB	N	BN	N
Five	AN	N	BN	N	N	A	BN	B
Six	AN	A	BN	B	NA	B	AN	A

Source: Abdalla (2003); Legend: A = Above normal, B = Below normal, and N = Normal.

Abdalla (2003) concluded that the results of sea surface temperature (SSTs) – rainfall regression models are reasonable and can be used in strategic planning for food security, environmental protection and disaster mitigation. On the other hand, early warning of favorable climatic conditions can be useful to improve productivity in the rainfed agriculture, since the usual practice is to apply low inputs and to plant drought resistant crops and hence, the full benefit of the favorable climate is not obtained.

Water harvesting

Water harvesting is an ancient practice, which was in use almost over 4000 years ago during the Bronze Age when agricultural civilizations first developed in regions with an annual average rainfall of about 100 mm, which was inadequate for conventional agriculture (NAS, 1974). Besides utilization in crop production, the technique is also used for erosion control, range improvement, afforestation and ground water recharge for human and animal consumption. Table 3 shows the effect of water harvesting on growth of some trees in the Sudan.

Collection of runoff water from rooftops is another historical method of harvesting rainwater. However, the development of central domestic water supply systems has caused it to be abandoned and forgotten in many parts of the World.

An amount of 50 to 80 mm average annual rainfall seems to be the lowest limit for water harvesting. However, usable runoff from only 24 mm average annual rainfall is also reported.

Advantages of water harvesting includes (i) no energy input or intervention in the ecosystem is required, (ii) it is easy to modify and adapt to changing local conditions, and (iii) can help in controlling erosion and recharging ground water aquifers, and the main disadvantage is its unreliability during drought year.

In the Sudan the total flow from non-Nile streams (Wadis) varies from 3 to 7 Milliard m^3 (following the erratic nature of rainfall) (MOI/WR, 1999).

There are many ephemeral streams in the country with high potential. They may flow for a few days or hours depending on duration and intensity of rainfall.

Orev (1986) illustrated the difficulties facing engineering works on very large desert wadis (with catchments of >1000 km^2) due to lack of adequate hydrological data, large volume of water and sediment, and the high cost of structures needed to control such volumes. However, for many countries, the development and efficient utilization of the renewable sources of water in wadis is the only optimal solution for addressing water shortage problems (Salih, 1998).

Table 3. The effect of water harvesting techniques on the growth of some trees

Tree	Water harvesting technique				
	10 x 10	5 x 5	Semi-circular	Traditional	Average
	Growth rate (cm per month)				
Acacia mellifera	24.6	24.6	9.2	1.7	14.8
Acacia seyal	65.4	41.3	36.3	13.2	39.0
Grewia tenax	37.2	12.2	21.4	7.0	19.4
Average	42.4	26.0	22.3	7.3	

Source: Farah and Ali (2000).

Design of suitable water control and conservation structures requires that the following factors should be taken into consideration:

- Equitable water resources allocation between the upstream and the downstream communities
- For most purposes it is often more economical to have a periodic failure than to design for the highest rainfall that has ever occurred (Schwab *et al.*, 1992)
- When human life is endangered, however, the design should handle runoff from storms even greater than recorded in the past
- Environmental factors

Khalafalla *et al.* (2003) considered the discharge data (maximum, minimum and average) at a properly selected location as the most important data for the development of wadi through which the storage capacity and cost of the hydraulic structure can be determined. In addition to that and for successful development of the seasonal wadis the topography, soils, geology, climate of the area and close supervision of the construction are to be considered.

El Khidir (1998) discussed the design, construction and durability of small earth dams in the Sudan and attributed the frequent failure of such dams to the disregard of sluice gates and spillways. Small dams are to be equipped with sluice gates to prevent silt deposition during the first few floods while spillways regulate the amount of stored water to the design capacity.

According to Al Latif *et al.* (2003) the traditional water harvesting techniques vary with the hydrological conditions. For instance in large wadis usually the bed is cultivated after the recession of the flood. On the other hand simple obstructions like branches or small earth bunds were put across low discharge wadis. Some of the traditional systems like wadi water spreading, storage dams, hafeers (cistern), etc., have been improved

Fadul *et al.* (2003) illustrated the use of remote sensing and GIS for planning water harvesting in North Darfur State and recommended the use of parameters like hydrology of the area, soil texture and depth as related to the adaptable crops.

The use of micro-catchments for tree planting reduced runoff by more than 50% and consequently sediment load has been reduced. Survival rate of trees was increased by about 80% and crop production was increased by 25 to 300% (Salih *et al.*, 2003). The authors suggested that agronomic practices to be given equal attention and recommended planting of early maturing crops, optimum plant density and timely weeding and thinning.

Sirelkhatim and Al Rahman (2003) investigated the effects of water harvesting on the productivity of fodder crops in the degraded lands of the Sudan and found that the productivity can be increased from 0.32 to 2.3 t per feddan. Al Latif (2003) suggested that Gardoud soil (naturally compact soil) which constitutes about 20% area of North Kordofan State has appreciable agricultural potential provided water harvesting techniques and chisel plough were used. Table 4 shows the effect

Table 4. The effect of tillage on crop productivity

Tillage	Productivity kg ha^{-1}
Good	705
Medium	528
Poor	368
Average	428

Source: Latif (2003).

of tillage (chisel ploughing) on crop productivity in such soils.

Supplementary Irrigation

Supplementing rainfall by irrigation from surface, ground, treated sewage, harvested water or any other source is found to increase considerably the efficiency of utilizing water for the production of food and fiber. It has been found that a linear relationship exists between cereal yields and the amount of rainfall during the growing season (Arar, 1994). This relationship is represented by the following regression equation:

$$Y = C\,(R - Ro)$$

where,

Y = yield of grain (t ha^{-1}),

C = coefficient of crop water use efficiency varying from 0.014 to 0.016,

R = total water (rain or irrigation) up to 600 mm, and

Ro = minimum amount of water varying from 100 to 150 mm required to produce cereal vegetative growth with no grains.

It becomes evident from the equation that the first 100 to 150 mm water (Ro) will produce no grains, and every mm of water above that (whether from rain or irrigation) will produce about 14 to 16 kg of grain ha^{-1}. This is confirmed by the findings of Arar (1984) in the Near East, where supplementary irrigation increased the productivity of cereal crops, particularly wheat. A minimum yield of more than 3.5 t ha^{-1} of wheat was guaranteed in areas receiving 350 mm or more annual rainfall for which supplementary irrigation of 50 to 200 mm was given. The extent of increase in yield was 100% as the normal average yield was within the range of 1.5 t ha^{-1}.

According to Farah and Ali (2000) supplemental irrigation is used in the Middle East for 6000 years, but such uses in the Sudan are recent. Supplementary irrigation has been shown to increase sorghum productivity and prevent crop failure in dry years. Another research revealed the benefits of combined application of supplementary irrigation and the organic matter (Table 5).

Arid Land Agriculture

El Gamri (2002a) discussed the constraints and prospects of desert agriculture with special reference to west Omdurman.

The overall constraints of agricultural development in the region are difficulty and complexity of dry land management, paucity of data, confusing definitions of drought and desertification, lack of solidarity, peace and appropriate priorities at the global level; poverty; global economic situation; the price policies for export trades; inequitable terms of domestic trade; moisture variability, limited soil resources wind and water erosion, lack of efficient

Table 5. The effect of supplementary irrigation and organic manure on the productivity of sorghum in Abu Habil Scheme

Supplementary irrigation	Organic manure (t ha^{-1})				Average	% increase
	0	4	8	12		
	Productivity kg ha^{-1}					
Nil	431	88	726	712	688	-
1 irrigation	1305	1126	2045	1895	1593	132
2 irrigations	1162	1807	1660	1638	1567	128
3 irrigations	1252	1540	1793	1769	1588	131
Average	1038	1340	1557	1505	-	
% increase	-	29	50	45	-	

Source: Al Latif and Al Amin (1996).

and appropriate extension services; and land tenure system.

Impacts of Irrigated Projects

Sudan like most African countries is basically organized on the tribal system especially in the rural areas, and the country is estimated to consist of about 570 tribes. Each tribe inhabit and own specified piece of land. During the Condominium (Anglo-Egyptian) (1898-1965) era this land ownership has been legalized and delineated on official maps. Each tribe practices a different land tenure system as stemmed from its culture and modified by the modern Condominium administration system. In the year 1927 El Sheikh Ordinance Law was issued. Although the system has been weakened due to different factors like the instability of policies, MAF (2002) concluded that the system still plays an important role in protecting natural resources. At each level land ownership and natural resource utilization are governed by certain laws and institutions. It is worth mentioning that such institutions play an important role in the resolution of conflicts especially within the same tribe. Um Jawaseer Desert Farm Project, which is located in Wadi El Magadam, the Northern State was established in the year 1989 for the settlement of the nomads of El Hawaweer Tribe. The project harnesses water from an aquifer of about 40 m below ground surface for irrigation and other purposes. Evaluation studies showed that the project is successful in creating better livelihood for the people of the area. It utilized the traditional tribal system in the planning and management of its functions and proved to be very influential in conflict resolution (El Gamri, 2002b).

Planning and Management of Um Jawaseer Project

The project adopted the participatory approach and the beneficiaries are strongly involved in all the stages of the project. The planning and management structure created made use of the traditional tribal institutions with some modifications to suit the project objectives. The beneficiaries were selected so as to represent the different clans of Hawaweer Tribe in the vicinity of the project. In addition to that the project allocated 20% area for women.

The project is managed at two levels. Technical and supervisory role, that is carried out by ADRA, usually phased out in about 5 year after the project commencement. Field operations that are carried out by the community that will lead the whole process after donor phase-out.

On the other hand the community is organized under farmers' committee, well committee, and women development committee.

Before phasing out of the project the beneficiaries were trained in farm management under participatory conditions, revolving fund management, and training of youth in pump operation and tractor driving. A women development center was established to train women in cooking, food processing, soap production, and sewing and tailoring.

Socio-economic Impacts of the Project

- Food security.
- The inhabitants of the area are the most marginalized group in the Northern State. The project assisted them to stay in their land as indicated by the in- migration from towns and villages along the banks of the River Nile.
- One of the most striking benefits of the project is training and enlightenment of women and their involvement in the decision-making process.
- Improved nutritional status in terms of quantity and quality.
- Improved hygiene and housing environment where mud houses replace the huts of the nomads.
- Provision of education and basic healthcare facilities.
- The project sustains the livelihood of 200 farmers (households) with a very high production potential since they are provided with the appropriate technical packages and extension services.
- Women are able to generate income from food processing, soap making and sewing and tailoring.
- Improved livestock production due to the increased availability of feed and the introduction of an improved goat breed (Sa'anin). Consequently daily milk production in the project site increased from 0.5 L to about 2.0 L per goat. On the other hand the number of livestock increased from 6 per household in the year 1990 to about 8 per household in 1999.

Environmental Impacts

- Shelterbelts in the project area have markedly reduced the wind speed, sand movement and dust storms.
- Temperature drop of about 3°C was recorded inside the project area.
- The availability of animal feed has alleviated pressure on the natural rangelands.
- Increased environmental awareness that is reflected in the commitment to protect the environment and to plant shelterbelts across the wind direction.
- Land reclamation of about 800 feddans and sustainable ground water utilization.

Studies in Rainfed Agriculture

Rainfed agriculture plays a key role in the Sudanese economy. The farming is accused by many authors to induce desertificaiton due to the clearance of the vegetative cover and for the improper production packages adopted.

Crop production in this sector is characterized by generally low productivity due to rainfall variability and negligence of the recommended improved production practices (Farah and Ali, 2000).

The following are the research recommendations developed by the Agricultural Research Corporation (ARC) to improve productivity in this sector.

Sowing Date

Sowing during July results in the highest productivity. However, this demands 100 mm precipitation during June to fill the cracks and for mechanical weed removal before planting crops. This consequently reduces the need for manual weeding during the season. It has been reported that one day's delay in sowing results in a loss of 1 to 2% of the productivity. Since rainfall is erratic in nature this recommendation is difficult to adopt.

Crop Density

Usually the farmers in the rainfed cropping maintain low crop density as it suits their traditional sorghum varieties. Research findings showed that the optimum plant density is 160,000 plants ha^{-1}, which is achieved by a spacing of 60 cm between lines and 10 cm between plants. Low plant density increases weed infestation further decreasing the productivity.

Crop Rotation

ARC recommended the following crop rotation: 50% sorghum, 25% sesame and 25% fallow or cotton, sunflower or legumes. Table 6 exhibits the effects of crop rotation in the productivity of sorghum in rainfed agriculture.

As illustrated by Farah and Ali (2000) the recommended crop rotation is rarely adopted because (a) the difficulty of sesame harvesting and the large losses due to delayed harvesting, (b) high cost of cotton production, (c) nonavailability of seeds of

Table 6. The effect of crop rotation on the productivity of sorghum in rainfed agriculture

Rotation	kg ha^{-1}	Reduction (%, based on first year)
First year	1736	–
Second year	771	56
Third year	664	62
Fourth year	536	69
Fifth year	450	74
After fallow	1543	11
After sesame	1178	32

Source: Farah and Ali (2000).

sunflower, and (d) susceptibility of legumes to pests and diseases.

Consequently the farmers are not able to adopt this recommendation and sorghum monoculture is taken year after year. This has led to decreased fertility, severe Buda (*Striga hermonsica*) infestation and reduced productivity. This reduced productivity has been compensated through the horizontal expansion of crop area at the expense of forests and rangelands. This has led to land degradation.

Water Harvesting and Supplementary Irrigation

In the Sudan rainfed agriculture is usually practiced in flat areas. This has not only led to wastage of rain water, but exposed crops to drought and water logging. On the other hand water harvesting was found to improve this situation and to increase crop productivity. Table 7 exhibits the effects of water harvesting and fertilizer application on the productivity of sorghum in rainfed agriculture in northern Gadarif State.

Soil Degradation Studies

Soil is a vital resource and is exposed to degradation due to various natural and human factors. According to Ayoub (1998) several global and regional attempts to assess land degradation and desertification assessments have covered, among other countries, the Sudan. These studies indicate that about 120 million ha of land, are degraded at varying degrees (Table 8). The most degraded areas in the Sudan are the arid and semi-arid zones, where 76% of the human population lives.

Soil conservation research is comparatively weak in the Sudan. Idris (2000) attributed this due to the lack of adequate funds, lack of researchers and trained personnel, lack of equipped laboratories, and the legislations governing land use.

According to Idris (2000) research in soil conservation aims at: reclamation of salt affected soils, desertification control, and determination of the impact of land use systems on soil characteristics and the remedy measures.

Table 7. The effect of water harvesting and fertilizer application on the productivity of sorghum in north Gadarif, Sudan

Treatment	Productivity (kg ha^{-1})	Increase over control (%)
Control	890	–
Nitrogen (N)	1690	90
Phosphate (P)	1781	100
N + P	1660	86
Water harvesting (WH)	1931	116
WH + N	1631	83
WH + P	2340	163
WH + P + N	2379	166

Source: Farah and Ali (2000).

Table 8. The extent and severity of soil degradation in the Sudan (million ha)

Degradation severity	Hyper arid	Arid	Semi-arid	Dry sub-humid	Moist sub-humid	Total
Very high	8.0	24.7	8.8	2.1	2.3	45.9
High	0	4.7	5.4	0	0	10.1
Medium	0.2	0.5	2.1	2.2	1.7	6.7
Low	0	0	0.9	0.2	0.2	1.3
Total	8.2	29.9	17.2	4.5	4.2	64.0

Causes of Soil Degradation

Soil degradation is a result of a number of factors like removal of vegetation cover due to overgrazing, deforestation, intensive cropping and fires.

Improper land management

In mechanized agriculture mono-cropping and lack of manure application has led to the depletion of the soil nutrients. Use of heavy agricultural machinery has led to soil compaction. All these malpractices have led to declining yields. Most of the crop fields in Sudan were not protected through wind breaks and shelterbelts, which improved the land productivity and secure other benefits like wood, forage, honey and fruits.

Increased population

The growing population is considered as a primary factor for soil deterioration, as it increases the pressure on land resources used for agriculture. This led to shortening of fallow period and inadequate regeneration of soil fertility and planting of crops on marginal lands.

Indicators of soil degradation include increased wind and water erosion, increasing parasitic plants in agricultural land, decline in vegetation cover, reduced carrying capacity in natural range lands, reducing infiltration rate and increasing surface run-off, ground water degradation both in terms of quality and quantity, increased salinity and sodicity, and increasing silt in the torrents.

Soil degradation has numerous economic, social and ecological consequences such as: reducing organic matter content in the soil, reducing soil moisture retention, decline in soil permeability, lowering soil fertility, impairment of the activities of soil microorganisms, decline in land productivity leading to reduced agricultural or forest produce, and decline in income generation.

Types of Soil Degradation

Wind erosion

Erosion is the major cause of soil degradation in Sudan and may result in loss of 27 and 18.2 million ha of soil by wind and water erosion, respectively (Table 9). Wind erosion is wide spread in the arid zones. It prevails in areas where strong winds lift and carry fine soil particles for long distances leaving behind only the coarse textured infertile soil. According to

Table 9. Soil degradation types in the Sudan (million ha)

Aridity zone	Wind erosion	Water erosion	Chemical deterioration	Physical deterioration	Total degraded
Hyper arid	5.8	2.4	0	0	8.2
Arid	20.0	6.9	3.0	0	29.9
Semi-arid	1.2	7.7	5.3	3.0	17.2
Dry sub-humid	0	0.7	3.8	0	4.5
Moist sub-humid	0	0.5	3.7	0	4.2
Total	27.0	18.2	15.8	3.0	64.0

Source: Ayoub, 1998

Hassan (2001) the action of wind erosion is more apparent between latitudes 12° and 14°N where about 20% of the area has changed into shifting sands due to the destruction of the natural vegetation cover, over-grazing and fires. Areas that suffer from wind erosion include Northern Kordofan, Northern Darfor, White Nile and Gezira States.

The movement of soil particles by wind in sandy or silty soil led to formation of unstable dunes of varying heights, which become a serious threat to agricultural lands, settlements, roads, irrigation canals, railway lines and seasonal water courses. Moreover, wind erosion causes dust storms which not only reduces visibility, but causes health problems especially those related to the respiratory system. The dust storms occur throughout the year but are more intense in summer.

In the Gezira scheme (the largest irrigated scheme under one management in the world), which occupies an area of about one million ha between the Blue Nile and the White Nile in a 250 to 400 mm annual rainfall zone. It was used to be the backbone of the Sudan economy and form the source of food security of the Sudan during seasons of crop failure during famine years.

Moving sands invaded crop field and affected the physical and chemical properties of the soil and changed it from a soil characterized by clayey texture, prismatic moderately developed structure, with brown color, alkaline pH and 4.0 to 4.5 cm h^{-1} infiltration rate, to silty sand and sandy silt, massy poorly developed or massive, yellowish brown, neutral or slightly acidic and 8.0 to 15.5 cm h^{-1} infiltration rate (Fadul and Mohammed, 2000). Also the moving sands filled the irrigation canals with sand and decreased the command required by the gravitational irrigation system. Therefore thousands of hectares of productive land in the scheme were thrown out of production. To counter this *Eucalyptus* shelterbelt, 12 km wide and 300 to 500 m long, facing the wind direction was established to protect the land from sand encroachment.

Studies of Mohammed (1991) after 10 years of shelterbelt establishment revealed that the wind speed reduced by 20 to 2% (with an accuracy of 2%) at distance between 1.5 and 3 times the shelterbelt height. Wind speed within the shelterbelt was further reduced by 15, 25, 40 and 65% at distances of 2.5, 7.5, 12.5, 17.5 m inside the shelterbelt, respectively, compared with the already reduced wind speed at 2.5 m in front of the belt. Hardly any sand was observed to move beyond 25 m inside the shelterbelt. Without the shelterbelt this trapped sand would have been deposited inside the field. The belt made it possible to get the irrigation water flowing again to the land that had been taken out of production. In addition to that the land itself was rehabilitated (Mohammed and Stigter, 2000).

Another example of moving sand is the study dealing with sand movement towards secondary source near the White Nile in Gezira region. The study investigated the origin of the sand blown over the area (identifying the main source) as well as the mechanisms possibly involved in the transfer of sand over the White Nile. Another objective was monitoring desertification in terms of sand removal and deposition and dune movement over the past 35 years.

Soil surveys and interpretation of historical remote sensing pictures revealed that between 1972 and 1985 the sand invaded the secondary source area at an average rate of about 34 km^2 per year. The origin of the blowing sand appears to be the desertified area of north Kordofan (Alamin, 1999). The sand is transported by the southern and southwestern winds through a corridor across the White Nile to the eastern bank, where the most likely water transported sediment is reworked by wind and transported further to the northeast. Moreover, the study indicated that soil conditions have degraded over the past 40 years and the area is subjected to wind and water erosion and sand deposition. Soil properties are not conducive for natural regeneration of vegetation without adopting appropriate management practices. Moreover, rainfall is neither sufficient nor reliable enough to sustain rainfed agriculture without supplemental watering.

It can be concluded from questionnaires distributed among residents that wood demand in the study area exceeds the available forest resources. Human communities in the study area appear to be forced by generate income through wood cutting and charcoal making. In addition, there is a general lack of awareness among the rural people on how to combat desertification. Studies on desertification, rainfall and growing season patterns showed that the situation was aggravated by recurrent droughts.

Alamin (1999) used the calibrated sand catcher in the study area to quantify the moving sands. She showed that the northern winds prevailed for a longer period, but carry lower quantities of soil particles, while southern winds carry sand over shorter periods, but in larger amounts. The latter period coincides with the rainy season. The sand catcher measurements indicated a sand flow of something like 50,000 kg over a width of 100 m in one month at the peak of the season. This clearly reflects the seriousness of the problem. The main protection against the blown sand into the area from the southwest (the desertified area of North Kordofan) is the White Nile. The researcher argued that the disappearance of vegetation is the main cause of further wind erosion and recurrent droughts is another.

Alamin (1999) showed that at the beginning of the southern wind (June) there was a violent removal of the sand, resulting in a small size dune and new slip-face, which was built-up again during the months of July, August and September (still southern wind), to attain bigger sizes compared to that of previous April after the northern winds. The rate of dune movement in this area can be expressed in terms of meters per year. This result confirms the effectiveness of the southern and southwestern winds in blowing sands and the building of dunes.

Water erosion

Water erosion is the most wide-spread erosion hazard in the semi-arid regions of the Sudan. The most common form of water erosion is the loss of topsoil through sheet erosion and a more extreme form is the formation of gullies. According to Ayoub (1998) overgrazing and over-exploitation of vegetation coupled with deforestation in the semi-arid zone have led to sheet and gully erosion. About 80% of the soils affected by water erosion are found in the arid and semi-arid zones and about 13% are found along the River Nile banks in the hyper arid zone. Ayoub (1998) stated that the arid loamy soil of the Butana area (8 million ha) between the River Nile and Atbara River are affected by water erosion. Also the Nuba Mountains in southern Kordofan and Jebel Marra volcanic soils in Darfur, which are rich soils in an area of about 10 million ha suffering loss of top soil through water erosion and this, can be attributed to their sloppy terrain coupled with the removal of the vegetative cover.

Gully erosion has been observed in many places in Sudan such as central Sudan, around Suki Project on the Blue Nile and eastern Sudan along the banks of Atbara River, Setite and Basalam Rivers on both sides up to 2.0 km in width (Seid Ahmed, 2001). Furthermore, Musnad and El Rasheed (1978) mentioned that there is severe gully erosion on the clay plains and main river banks. The two words Haddam and Kerreb lands are used locally to describe this type of soil degradation in Northern and Kassala and the Blue Nile States, respectively. In Suki area water erosion has spoiled more than 50,000 ha land (Musnad, 1975).

In eastern Sudan the agricultural lands are threatened by gully erosion especially around Atbara River, irrigated Khashim El Girba Scheme and Gedarif area, which is one of the most important areas where rainfed agriculture is practiced. Some farmers in these regions observed that the area of their fields decreased by approximately 15 m adjacent to gullies every two years. This process aggravates silting problem of Khashm El Girba Dam, which was established without adequate shélterbelt and wind breaks for the protection of crops and canal. It is worth mentioning that in this area sand deposits were further carried by runoff and aggravated siltation problems. Also the New Halfa Agricultural Scheme at present is suffering from reduced water in ditches and canals (Seid Ahmed, 2001). A remote sensing investigation in this area revealed that gully erosion along Atbara River covers about 2070 km^2. It affected about 761 km^2 along Setite and 73 km^2 along Basalam tributary (total 2904 km^2). The rate of arable land loss was about

14.3 km per year during 1985 to 1987 and 9.8 km per year during 1987 to 1990 (Seid Ahmed, 2001).

Chemical deterioration of soil

The soils of Sudan are inherently poor in nutrient content. Moreover, they experienced chemical deterioration affecting about 16.8 million ha (Ayoub, 1998). Two types of chemical deterioration are recognized:

Fertility depletion: Generally soils all over the Sudan experienced nutrient depletion. However, this is critical in the arid and semi-arid parts in southern Kordofan and Darfur. Agricultural activities and deforestation are the main factors responsible for nutrient depletion. Ayoub (1998) recorded that nutrient depletion in Sudan is about 3 times higher than the world. He attributed this to the very low fertilizer input in Sudan (< 5 kg of nutrient ha^{-1}). According to Hassan (2001) fertility depletion is more evident in rainfed areas, especially in Kassala, South Kordofan and Blue Nile states where it caused 50% drop in yield.

The main factors responsible for fertility depletion are: insufficient use of fertilizers and/or manures, absence of proper crop rotation since most of the farmers grow the same crop year after year, shortening of fallow periods, in irrigated agricultures which enhance decomposition of the organic matter and soil compaction, and ignorance or improper adoption of the shifting cultivation.

Salinity and sodicity: As mentioned earlier about two-thirds of the area of the Sudan is located in arid and semi-arid regions, such situation favors the formation of salt affected soils (Mustafa, 1986). About 2 million ha area in the Sudan is affected by salinity. Generally saline-sodic soils are found in the northern part of the country flanking the River Nile, Khartoum area, Gezira clay plain and along the White Nile. These soils need reclamation before salt sensitive crops are cultivated.

Distribution of Saline and Sodic Soils

Gezira clay plain

Most of Gezira soils which are classified as Vertisols did not suffer from salinity or sodicity although it is under irrigation for more than 75 years. This can be attributed to the high quality irrigation water with low salt content (less than 200 ppm), growing of salt-tolerant crops such as cotton, poor permeability and deep ground water. Saline soils were observed in western and northern parts of Gezira scheme while in eastern part, sodicity is prevalent and salinity increases with depth. According to Mustafa (1986) soils of the Gezira clay plain consist of 3 groups namely, the flat plains which constitute the most extensive part (Suleimi series), soil of depression which is located in southern Gezira and Managil extension (Hosh series) and soil of levees (of limited extent) the first two groups were reported to have sodic phase.

White Nile

Both banks of the White Nile within the arid and semi-arid zone were affected by salinity. The soil of the White Nile can be divided into those of the active flood plain (non saline, non sodic), inundated flood plain (slightly saline to slightly or moderately sodic) and the upper terraces (strongly saline) (Mustafa, 1986).

Khartoum

Salt affected soils in Khartoum were located in the south and north-east part of the State. The area south of Khartoum between the Blue Nile and the White Nile and extended as far south as the north-west boundary of the Gezira scheme (total area estimated at 81,000 ha) is predominantly saline and/or sodic. In addition to that four types of soils were found to be affected. These are Esailat sodic series, Bagair which is generally non-saline, but sodic series, Eilafun saline-sodic series and Gureir series (El Karouri, 1978).

Northern Sudan

The soils of northern Sudan are more affected by salinity than the central clay plains, particularly the area from Khartoum northward along both banks of the Nile. It is divided into two main groups, namely soils of the Recent Flood Plain and soils of the High Terraces. Soils of the Recent Flood Plain include the Gerif, Gureir (local names) and the basin soil. Only the latter one is salt affected and characterized by low salinity and occasionally high sodicity (El Karouri, 1978). Most of the soils of the Recent Flood Plain particularly the Gerif and Gureir soils are fully exploited for agricultural production, and any envisaged agricultural development in the northern provinces will depend mainly on the utilization of High Terrace soils (El Karouri, 1978). Salinity and sodicity are among the most important factors, which limit production in the High Terrace soil. In these soils there is a considerable variation in salt content not only between the different sites, but also with depth in one profile. The sources of salt in these soils are the parent rocks with the most dominant cation and anion are sodium and sulphate and chloride, respectively.

Mustafa (1986) reviewed studies conducted in eighteen areas having salt affected soils. The results of the study revealed that salinity rarely occurs in the top soil and that most salt accumulation observed at the depth of 0.3 to 0.6 m. Generally salinity is positively correlated with aridity and occurs where the annual average rainfall is less than 200 mm per annum and in most soils increasing with depth. The cation dominance was studied in seven selected areas along the Blue Nile and the main Nile from Managil (average rainfall about 330 mm per annum) to Wadi Elkhowi (average annual rainfall about 50 mm per annum) at three depths 0 to 0.3, 0.3 to 0.6, 0.6 to 1.0 m. It was found that sodium was the dominant cation at all depths in most areas. Furthermore, sodicity was found to be associated with salinity.

The salt affected soils in Sudan belong to three orders, Vertisols, Aridisols, and Entisols. Most of these soils have a relatively low nutrient content, especially phosphorus, which is below the critical levels for most crops. The capacity for phosphorus retention in these soils increases with salinity and decreases with sodicity (Elmahi and Mustafa, 1980).

Studies in the reclamation of the salt-affected soils were carried out using chemical and organic ameliorants and different crops as indicators. The result of crop yield showed that farmyard manure is superior to gypsum and green manure. Although there is no increase in yield due to gypsum application it increased hydraulic conductivity, reduced mechanical resistance and crust strength and increased seedling emergence (El Karouri, 1978).

Physical Deterioration

As shown in Table 9 about 3 million ha of the degraded soils in the Sudan experience physical deterioration. The heavy clays of central and eastern Sudan are suffering from physical deterioration due to the inappropriate mechanized farming and mono-cropping.

Sudan has signed the Convention in June 1992 and ratified in Oct. 1995 and consequently the country developed its National Biodiversity Strategy and Action Plan (NBSAP) which was completed in May 2000 and approved by the Council of Ministers. The overall objective of the strategy is to conserve and enhance biodiversity for the prosperity and development of the Sudan.

A biodiversity assessment of the country shows the richness and the diversity of the country in the biological resources and ecosystems (Mohamed *et al*., 2003). However, desertification is considered to threaten the biodiversity, specially that of plant species. According to El Wakeel (2000) dryland ecosystems of the country contain a rich biota, including plant and animal species not found elsewhere.

Crops like sorghum and millet, which are of principle importance in Sudan were reported to originate in dry lands. Recently, forced by the influences of drought and desertification there is a marked shift for using early maturing and improved crop varieties and by doing so many important genetic traits of adaptation are being sacrificed. In the northern parts of the country sand encroachment has led to the depletion of the vegetative cover and consequently wildlife had migrated to the south. Due to over grazing and desertification several rangeland plant species (both herbs and shrubs) have disappeared and many are under threat (El Wakeel, 2000).

Salih (2000) reviewed the diversity, adaptability and productivity of the mammals of the dry lands of the Sudan. The author put special emphasis on camels, which he considered as the best domestic animal in such areas. He attributed that to the grazing habits of the camel this suits dry lands and because of its physiological traits and milk and meat production merits. Salih discussed other herbivorous and carnivorous species and concluded that such distinct diversity enriches dry land environment. He recommended more concentration in animal census and research, and the creation of sanctuaries.

References

Abdalla, A.K. 2003. *Evaluation of the Sudanese Experience in Rainfall Seasonal Forecast*. Workshop in the use of meteorological data in disaster control. Sudan Meteorological Authority. Khartoum, Sudan.

Abdel-Salam, A. 2003. Monitoring desertification using remote sensing techniques. *M.Sc. Thesis*, Desert Cultivation Studies Institute. University of Khartoum, Sudan.

Abu Shama, F.T. 2003. *Desertification Monitoring in the Sudan*. A paper presented at the National Centre for Research.

Alamin, N.K. 1999. The physical potential of indigenous vegetation and other means to supress sand movement in a secondary desertification source area near the White Nile in the Gezira scheme region, Sudan. *Ph.D. Thesis*, University of Gezira.

Al Latif, M. 2003. Evaluation of the techniques of the water harvesting and runoff irrigation model: Food security project. In *Workshop on the Evaluation of the Food Security Project*. Fedral Ministry of Agriculture and Forestry, FAO.

Al Latif, M. and Al Amin, E.M. 1996. The effect of supplementary irrigation and the addition of organic matter in the productivity of sorghum in Khor Abu Habil area, (in Arabic). *Scientific Report of El Obied Research Station* (1995/1996).

Al Latif, M., Salih, A.A., Farah, S. M. and Fadul, H.M. 2003. The Sudanese experience in the field of water harvesting. A paper presented at the *Conference on Water Harvesting and the Future of Development in Sudan*, UNESCO Chair in Water Resources, Sudan.

Arar, A. 1984. The role of supplementary irrigation in rain-fed agriculture. *A Report on a Consultancy to ICARDA*, Aleppo, Syria.

Arar, A. 1994. Optimization of water use in arid areas: Satisfying future national and global water demands. *IWRA Congress on Water Resources*, Proceedings Vol. 7: 21-25, Cairo.

Ayoub, A.T. 1998. Extent, severity and causative factors of land degradation in the Sudan. *Journal of Arid Environments* 38(3): 397-409.

Birch, D.R. and Lockette, N.J. 1993. Alternative materials and construction techniques for lining tertiary level irrigation canals. In *Proceeding of the International Workshop on Canal Lining and Seepage*, pp. 371-382. Lahore, Pakistan.

El Gamri, T. 2002a. Prospects and constraints of desert agriculture: Experience from West Omdurman. Presented at International Symposium on *Alternative Ways to Combat Connecting Community Action with Science and Common Sense*. Cape Town, South Africa.

El Gamri, T. 2002b. Sustainability of small-scale irrigation projects in Africa. A paper prepared for the *Regional Seminar of the Dry Land Coordinating Group (DCG)*. Khartoum, Sudan.

El Gamri, T. *and* Saeed, A.B. 2003. An overview of canal lining and the related research in the Sudan. *Proceedings of the 6th Scientific Conference of the National Centre for Research.*

El Karouri, M.O.H. 1978. Effect of soil salinity on the productivity of arid lands, with especial reference to the Sudan. Proceedings of the *Khartoum Workshop on Arid Lands Management.*

El Khidir, A.M. 1998. *A Report on: Studying the Possibility of Making Use of Wadi's Water in Selected Areas in Northern Darfur, Sudan.* Intermediate Technology Development Group, Sudan.

Elmahi, Y.E. and Mustafa, M.A. 1980. The effects of electrolyte concentration and sodium adsorption ratio on phosphate retention by soils. *Soil Science* 130: 321-324.

El Wakeel, A.S. 2000. Impact of desertification on biodiversity in Sudan. A paper presented at the *Symposium on Drylands Development Challenges.*

Fadul, H.M. and Mohammed, A.E. 2000. The application of remote sensing in monitoring desertification on the agricultural land of Gezira scheme, presented on the *3rd Conference on Desertification and Environment Studies, beyond the year 2000*, Riaydh, Sudia Arabia.

Fadul, H.M. and Osman, O.A. 2000. Desertification in Sudan: Causes, indicators, consequences and mitigation measures. *Proceedings of the Symposium on the Role of Agricultural Research in Combating in the Sudan* (in Arabic). Ministry of Science and Technology, Sudan.

Fadul, H.M., Osman, O.A. and Hamid, A. 2003. Application of remote sensing and GIS for planning water harvesting in Wadi Kutum, North Darfur. A paper presented at the *Conference on Water Harvesting and the Future of Development in Sudan*, UNESCO Chair in Water Resources, Sudan.

Farah, S.M. and Ali, I.A. 2000. The role of improved production packages in combating desertification in the rainfed sector of the Sudan (in Arabic). *Proceedings of the Symposium on the Role of Agricultural Research in Combating Desertification in the Sudan*. Ministry of Science and Technology, Sudan.

Gamal, A. 2000. Case of Um Jawasir: An ecological reality of dryland development intervention. A paper presented at *Dubai International Conference on Deserification*, 12-15 Feb. 2000, Zayed International Prize for the Environment.

Hassan, K.I. 2001. An assessment of the state of natural resources sustainable development in Sudan. *Sustainable Development in Sudan: Ten Years After Rio Summit* (Ed. H.A. Abdel Ati), pp. 99-125. Proceedings of the National Civil Society Preparatory Conference for WSSD- Johannesburg.

Hellden, U. 1991. Desertification: Time for an assessment. *Ambio* 20(8): 372-283.

Idris, M.A.M. 2000. Assessment of some degraded soil series and conservation research priorities in the Sudan. *Proceedings of the Symposium on the Role of Agricultural Research in Combating Desertification in the Sudan* (in Arabic). Ministry of Science and Technology, Sudan.

Khalafalla, M., Ahmed, S.A. and Al Gadir, E.O. 2003. Seasonal wadis, institutions and water security. A paper presented at the *Conference on Water Harvesting and the Future of Development in Sudan*, UNESCO Chair in Water Resources, Sudan.

Ministry of Irrigation Water Water Resources (MOIWSR), 1999. *Sudan Nation Water Policy*, MOIWR, FAO, UNDP.

Mohammed, A.E. 1999. The influence of *Eucalyptus* shelterbelt on sand movement northwest of Gezira (Sudan). *Ph.D. Thesis*, University of Gezira, Wad Madani, Sudan.

Mohammed, A.E. and Stigter, C.J. 2000. The effect of a *Eucalyptus* shelterbelt on moving sand towards Gezira scheme (Sudan). Presented at the *Symposium on Development Challenges in Dry Land*. Khartoum, Sudan.

Mohamed, E.I., Abu Gabr, E. and Osman, M.A. 2003. Priority capacities needed for the implimentation of the National Biodiversity Strategy and Action Plan (NBSAP) in the Sudan. *The National Consultation Workshop on the Steps Towards Implementation of the National Biodiversity Strategy and Action Plan (NBSAP) in the Sudan*.

Musnad, H.A. 1975. Soil conservation and land use in the Sudan. *Sudan Silva* 3: 34-38.

Musnad, H.A.R. and El Rasheed, M.A. 1978. Soil conservation and land reclamation in the Sudan. In *Proceedings of the Khartoum Workshop on Arid Lands Management*.

Mustafa, M.A. 1986. Salt affected soils in the Sudan: Their distribution, properties and management. *Reclamation and Revegetation Research* 5: 115-124.

National Academy of Sciences (NAS), 1974. *More Water for Arid Lands, Promising Technologies and Research Opportunities*, Report of Ad Hoc Panel of the Advisory Committee on Technology Innovation Board on Science and Technology Innovation for International Development Commission on International Relations, Washington, DC, USA.

Orev, Y. 1986. *A Practical Handbook on Desert Range Improvement Techniques*. Interagency Group on Agricultural Biometeorology, FAO, UNEP, UNESCO, WMO. Geneva.

Salih, A.A., Farah, S.M. and Al Latif, M. 2003. The Role of water harvesting in improving agricultural production in Sudan. A paper presented at the *Conference on Water Harvesting and the Future of Development in Sudan*, UNESCO Chair in Water Resources, Sudan.

Salih, A.M.A. 1998. *UNESCO's IHP Programmes and Wadi Hydrology*. UNESCO Cairo Office.

Salih, E.M. 1996. The geographical extent of desertication in Sudan. *AL-Buhuth Scientific Journal* 5: 1.

Salih, M.M. 2000. Mammals of the drylands of the Sudan: Diversity, adaptability and productivity. A paper presented at the *Symposium on Development Challenges in Dry lands*., Kharftoum, Sudan.

Schwab, G.O., Fangmeir, D.D., Elliot, W.J. and Fervent T.R.K. 1992. *Soil and Water Conservation*

Engineering. 4th Edn. John Wiley & Sons, Inc.

Seid Ahmed, H.A. 2001. Control of gully erosion in Upper Atbara River in El showak, Sudan. *Ph.D. Thesis*, Sudan University of Science and Technology.

Sirelkhatim, M. and Al Rahman, M.E. 2003. Water harvesting and its effects on animal resources. A paper presented at the *Conference on Water Harvesting and the Future of Development in Sudan*, UNESCO Chair in Water Resources, Sudan.

Yassin, O.E. and Alamin, S.M.M. 2000. Animal wealth: The economic losses. *Al Buhuth Scientific Journal* No. 1/8 (in Arabic).

UNCCD 1998. *An Introduction to the United Nations Convention to Combat Desertification* (Fact Sheets) *CCD/98/4*, Paris.