Nile Basin Initiative
Nile Transboundary Environmental Action Project
Micro-Grants Program

Soil Erosion Mitigation in the Nile Basin of Sudan

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Acronyms

ADS	Area Development Schemes
ARC	Agricultural Research Corporation
CBO	Community-Based Organizations
DNP	Dindir National Park
FRC	Forestry Research Center
GNPOC	Greater Nile Petroleum Operating Company
HRS	Hydraulic Research Station
LA	Lower Atbara
MAAWI	Ministry of Agriculture, Animal Wealth and Irrigation
MCM	Million Cubic Meter
Md.c.m	Milliards cubic meters
MGLS	Micro-Grants Lead Specialist
NBI	Nile Basin Initiative
NFC	National Forest Corporation
NGO	Non-Government Organizations
NIS	National Irrigation Schemes
NMGC	National Micro-Grants Coordinator
NRB	Nile River Basin
NTEAP	Nile Transboundary Environmental Action Project
SECS	Sudanese Environment Conservation Society
UA	Upper Atbara
UK	University of Khartoum
UNSECO	United Nations Science, Education and Culture Organization

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1. Background

The Nile Transboundary Environmental Action Project (NTEAP) aims at supporting basin-wide sustainable economic development by addressing high priority transboundary environmental issues within the context of the Nile Basin Initiatives' (NBI's) Strategic Action Program. The project assists the Nile Basin countries to develop practical tools to deal with transboundary environmental threats at the national and regional levels. Additionally, the project promotes more mutual cooperation between the stakeholders on transboundary environmental issues by supporting the implementation of the actions identified and prioritized by the Transboundary Environmental Analysis Document in the field of: i. institutional strengthening to facilitate regional cooperation, ii. Community-level land, forest and water conservation, iii. Environmental education and awareness, iv. Wetlands and biodiversity conservation and v. Basin-wide water quality monitoring.

The community-land, forest and water conservation component, the theme of this study aims at development of appropriate pilot activities in certain geographic and thematic areas of transboundary significant impact. The study should identify and demonstrate the appropriateness of the local approaches and indigenous knowledge to improve and enhance land and water conservation including erosion mitigation action.
The second component, however, is subdivided further into three sub-components that deal with: i. Facilitating and enhancing basin-wide cooperation and collaboration in the management of activities and provision of support to conduct a series of training workshops for the NGOs and government staff, ii. Preparation of priority action for addressing soil erosion and iii. Identifying community-driven interventions to address transboundary environmental threats linked with sustainable livelihood opportunities on a local level to be implemented through fund availed by the micro grants program.

The transboundary Environmental Analysis Document recognizes that soil erosion is the top environmental threats that facing Sudan with complexity of consequences and impacts. The threat has severe consequences not only at the national level but also at the transboundary level, which warrants thoroughly investigations. It is believed that general data and information on soil erosion are available and but scattered and insufficient. Therefore, the current study was proposed by the Steering Committee of the Nile Transboundary Environmental Action Project to perform rapid survey assessment to collect and review data to upgrade, validate and consolidate information to identify the extent and magnitude of the erosion with the view of using it to develop erosion mitigation activities.

2. Objectives of the study

1. To conduct rapid field survey and assessment to identify soil erosion threats.
2. To carry out a desk review to collect relevant available data and information on environmental threats related to land, soil, water and forest from government institutions and other agencies.

3. Compilation and analysis of data and information to identify the magnitude and extend of the problem that requires actions.
4. Formulation of replicable mitigation interventions for the hotspots to help in arresting the deteriorating situation and improve the livelihood of vulnerable communities.
5. Examine successful previous promising mitigation initiatives/activities being undertaken at the local and transboundary levels to be scaled up and to identify stakeholders (NGOs and government institutions) that would have stake on implementing mitigation measures.

3. Introduction

3.1 Nile River Basin General:

The Nile River, has an estimated length of over 6800 km, with greater of its length is in the Sudan. It is the longest river flowing from south to north over 35 degrees of latitude. Ten African countries namely Egypt, Sudan, Ethiopia, Eritrea, Kenya, Uganda, Rwanda, Tanzania, Burundi and Democratic Republic of Congo (DRC) share the Nile basin. The Nile River Basin (NRB) covers 3 millions km^2, which is about one tenth of Africa's total land area. In the NRB several network of rivers and water courses drain the humid equatorial region into extensive natural system of lakes including the Lake Victoria (the second largest fresh water body on earth), Kyoga and Albert as the source to the White Nile, as well as the Ethiopian plateau, which is the source of Lake Tana, Blue Nile, Sobat and Atbara rivers and vast wetlands known as Sudd. Despite of large amount of annual runoff outflows into these natural drainage systems, very little of this water resource is presently utilized for irrigated agriculture and runoff is causing soil erosion, flash floods and sedimentation in downstream bodies of water. Out of the 300 million people that constitute the population of the 10 countries sharing the Nile waters, about 160 million people live within the boundaries of the basin.

Despite of rich natural endowments and potentialities, its inhabitants face considerable development challenges. Presently, the basin is characterized by poverty, rapid population growth, environmental degradation, lack of economic development and instability. Six of the Nile riparian countries are among the world's ten poorest. Population is expected to double within the next 25 years, placing additional pressure on the scarce water and other natural resources. Yet, the Nile basin holds significant opportunities for development that could enhance food production, environmental conservation, transportation and industrial development and other development related activities.

3.2 Nile River Basin in Sudan:

The Nile River in the Sudan is fed mainly by two main river systems, the Blue Nile and the White Nile with sources from the Ethiopia Highlands and Equatorial lake plateau and numerous tributaries. The Blue Nile with its tributaries Dinder and Rahad together with Atbra flow from the east providing about 65 milliards cubic meters (Md.c.m). Bahr el Jebel, tributary of White Nile starts from Lake Victoria with greater part of its flow lost in the Sudd area inside Sudan, brings some 15 Md.c.m at Malakal. The Sobat River, that flows into the White Nile just upstream of Malakal, is fed by the Baro and Akobo Rivers and other tributaries outside Sudan (Ethiopia) brings about 13 md.c.m of which about 8 md.c.m are lost in the Sudd area of Sobat and Mashar. Almost all the water flow of Bahr El Ghazal River estimated at14 md.c.m are lost in the Sudd area of Bahr el Ghazal, leaving only half md.c.m to flow into the White Nile at Lake Noo.

The big variation in the Nile River flow between the flood time (rainy season) and the low river flow during the dry months (March to May) has necessitated construction of dams to store water for irrigation and for the generation of hydro-electrical power. At present they are four dams in Sudan. Two of them were built on the Blue Nile viz Sennar and Roseires reservoirs, the other two are ElGriba and Jebel Awlia, which are respectively Atbara River and White Nile. The storage capacity of these dams is as follows: Sennar (1 md.c.m), Roseires (3.024 md.c.m) and Khashm El Girba (1.3 md.c.m). However, the accumulated silt in the dam lakes has reduced the design storage capacity of Rosaries, Sennar and Khashm El Girba dams by significant amounts. The Sudan is planning to increase its storage capacity to 7.3 md.c.m by heighten Rosaries dam level by 10 m and constructing Siteit dam across upper Atbra River to store additional water for irrigation purposes.

In order to bypass the Sudd region where significant amount of water is lost to evaporation and evapotranspiration in the swamps, the construction of Jonglei Canal had been planned with objective of making more water available for irrigation and other downstream uses (4 md.c.m). The construction of the Canal began in 1978 for a planned total length of 360 km, has stopped in November 1983 with the eruption of the civil war in the south. Although, these losses are beneficial to pasture and fisheries resources and other aquatic habitats in the swamps, it is believed that draining of the swamps by the canal causes enormous human and environmental problems in the area. Nevertheless, people must become aware of how much water must be drained from the Sudd area through the construction of the canal without causing serious damage to the local environment and economy. Sudan is now using about 14.6 md.c.m of the Nile water for irrigation of which 9.5 md.c.m are from the Blue Nile, 1.7 md.c.m, from Atbra river, 1.8 md.c.m from the White Nile and 1.6 md.c.m from the main Nile. Irrigation potential in Sudan has been estimated at over 4.8 million hectares. The irrigated area was increased from about 1.6 million ha in 1979 to 1.9 million ha in 1990. There are plans to increase irrigated area to about 2.8 million ha by the year 2000 almost all by the Nile water, but this not yet accomplished.

Large and small numerous seasonal water courses draining the catchments areas within the basin in the Sudan are flowing from mountains, outcrop rocks, plains and valleys providing significant amount of stream runoff water which might or not reach the Nile. So far they are not fully utilized, with the exception of use for domestic purposes and limited agricultural water supply. Often owing to the physical limitations of climate, geology and the hilly nature of the terrain and access to plain, seasonal streams and wades have assumed an important role in the livelihood of sedentary farmers and pastoralists. It is particularly along the beds, banks and catchments of these water courses, that animals are grazed, agriculture is practiced and open shaft wells and boreholes, the main source of water supply are located. This makes streams (khors) and wadis the main focus of human activities and settlements. The pressure on the khors and wades has, however, increased drastically in recent years as a result of drought and the large scale degradation of the plains that previously provided good grazing grounds for the pastoralists during the rainy and summer seasons.

In the arid regions off the draining ephemeral network courses, rainwater is the main source of water for existence, since it is the primary and sometimes the only source of drinking water as well as for dry land agriculture. Like other basin countries, rainfall has a high unreliability and spatial variability, which related to low productivity of rain-fed agriculture. Rainfall however, is characterized with large variation; in distribution as well as in timing and locations thereby magnifying the risks of crop failure. Autumn (Kharif) is the main rainy season, extending from June to October in the north and from April to December in the South. The annual rainfall varies from zero - 50 mm in the extreme north to 800 - 1500 mm in the extreme southwest and 400 – 800 mm in central clay plains.

4. Methodology:

A rapid field survey and assessment in the form of questionnaire and general basic field data information's and sampling format pertaining to soil erosion were developed and submitted to the (MGLS). Information used in the attainment of this diagnostic survey included both primary and secondary data. The approach taken to conduct this survey included:

1. Collection and review of secondary data mainly from published and unpublished reports, aerial photographs and land sat images.
2. Direct observation: direct field observations and assessment of visual indicators (landscape, soils, vegetation cover, degradation, river bank, wind and water erosion, water resources and agricultural activities).
3. Key-informants:
    - Group discussion with farmers, villagers and local leaders.
    - Interview of households using questionnaire with various quantitative and qualitative aspects.
    - Interview and group discussion with CBOs and NGOs.
    - Official meeting with government staff.

The rapid field survey and assessment and desk review of primary and secondary information are derived from the study terms of reference. Field survey and desk review general key indicators pertaining to the objectives of this study include the followings:

- Erosion hazard (wind, water, river bank, and flood) in the area.
- Agriculture lands and settlement threatened by the sand movements.
- Methods of farms and settlement protection against wind erosion.
- Reasons for not using proper tree shelterbelt for protection.
- Source of knowledge about village and farm protection.
- Role of CBOs, community, projects and government stakeholders in erosion control.
- Agricultural lands and properties threatened by river bank erosion.

- Causes of river bank erosion.
- Methods for controlling river bank erosion.
- Reasons for not using control measures against river bank erosion.
- Water erosions and conservation practices and impact.
- Vegetation covers status.
- Sources of energy and use.
- Wind and rainfall records.
- Sedimentation.
- Flood and drought.
- Irrigation and cropping pattern practices and management.
- Surface sources of drinking water.
- Distribution of respondents according to their major and secondary jobs.

The field survey covers most of the Nile Basin Rivers and tributaries in the northern part of the Sudan, namely the Main Nile River, Blue and White Niles, Atbara, ElRahad and Linder Rivers in 13 days **(NRB map, Annex 1)**. The consultant started the field survey of the basin area on March 28, 2005 after collection and reviewing of relevant information from the secondary sources to the Main Nile River and the lower Atbara River (LA) for 4 days. The second part of the field trip covers the Upper Atbara River (UA) to Ethiopian border, ElRahad and AlDindir rivers, Blue and White Niles for 9 days. During the field survey, a total of 30 random villages were selected and village community was gathered in a large group of not less than 10 people for meeting where important questions of general nature, regarding various aspects of erosion threats and impact and community livelihood status were asked in a form of focused group discussion. A sample of 5 individuals were then randomly selected from the large group and interviewed to answer the specific questions contained in the questionnaire formats. Key informants, including community leaders, CBOs and local administrator (Sheikhs) were also interviewed in order to add more information and to further check on information already gathered, i.e. as a process of triangulation. Discussion with the government staff from Irrigation and Water Resources, Agriculture, Forestry, Range, Soil Conservation and Research Departments and NGO's in the visited areas was also taken as an integral activity to this survey. The main activities and the timetable for the survey are presented in **Annex 2**.

Data collected through various methods were then analyzed and categorized to provide in-depth analysis and indicators of the present situation to guide formulation of future mitigation activities and interventions for appropriate sustainable livelihood opportunities to communities.

5. Study findings

5.1Gully erosion

Gully erosion is an advance stage of rill erosion, which is the creation of shallow channels by washing away the soil in them by the running water i.e. when rills become wider and deeper are called gullies. A gully is a trench dug by moving water. In surveyed areas, gully erosion was obvious along Upper Atbra River from south of New Halfa Town into Ethiopian highlands and Blue Nile from Elmaseed Town, 50 Km south of Khartoum Town to Ethiopian boarder. Kerib land was also observed with less variable intensity along ElRahad and AlDindir Rivers. The detachment of soil particles by the running water to form runoff are linked to the intensity and duration of rainfall, as well as the slope and roughness of the landscape, soil properties, plant cover and human activities. In these areas the topography has steep gradients and deeply incised in the substratum and the natural vegetation cover has been removed for agricultural and energy purposes and by overgrazing, which accelerated water erosion leading to loss of arable land and the development of badly degraded land locally known as Kerib land. Kerib is a name given to a typical undulating landscape that has developed and characterized by intensively dissected steep gullies. The Kerib lands are usually found between the clay plains and the alluvial flood plains bordering streams and watercourses.

Most of the Kerib lands are normally devoid of tree cover or with sparse vegetation as a result of tree cutting for fuel wood and building purposes. In areas such as Al showak where some conservation practices by restocking of Kerib land using several tree species was undertaken by the Forestry Department, the distribution of tree is in such way that the tree cover in the gullies and side slopes is better and denser than in the top ridges and upper slopes. Indigenous grazible trees species like *Acacia tortilis* (seyal), *Acacia millfera* (Kitir), *Balanite aegyptiaca* (Hegleeg) and *Salvadora bersica* (Arak) are generally performing well. The planted Kerib land constitutes reserved forest for livestock grazing and browsing and well controlled by the local community on this area. This is a linking of conservation measures with community livelihood needs. The community believes that without this control, vegetation had no chance to recover when the dry season extends for 7 months and grass are lacking. In this area, grazing was intensive to extend that only few tree stands are existing before tree planting and management program were introduced. The bottoms of the gully floors are sometimes cultivated to millet, sorghum, okra and maize crop, making use of higher water content, which provides better conditions for both trees and crop growth such as at Umrabya in AlShowak and Abu Ramad in Damazin areas **(Plate No. 1)**.

Plate No. 1: Cultivated gully floors in the Blue Nile area (UmRamad)

A study and survey conducted by Hassan M. Fadul, et. al (1999) using Land sat images of TM to monitor and map the area from Alshowak to Khashm ElGirba Dam and upstream of Atbara River and along Setit and Basalam tributaries during the periods 1985, 1987 and 1990 showed an increased development of Keirb land. The rate of arable land loss was found to be 13.4 km^2/year during the period 1985 to 1987, and 9.8 km^2/year during the period 1987 to 1990 **(Table 1)**. According to this rate, the total land covered by the gullies during 1987 along Atbara River was estimated by them about 2070 km^2 and 761 km^2 and 73 km^2along Setit and Basalam tributaries, respectively. Hence the total gross area of Kerib land in the Atbara valley was about 2904 km^2. Beside the loss of this arable land, the Kerib land represents one of the main sediment sources of Atbara River, where the eroded silt and clay materials end up in the nearby Khashm ElGriba Dam and reducing its storage capacity.

In the study area of Atbara River, the intensity of Kerib land increases from north to south, which is largely, influenced by the climate, slope, plant cover and cultivation practices. The climatic zones along Atbara River vary from deserts in lower Atbara to humid zone in Upper Atbara (including Ethiopian highlands) with annual rainfall ranges between 75 mm to 1000 mm, which indicates the high variability. The variation in climate has led to marked pattern of land use practices. At the lower Atbara where rainfall is not sufficient for rain-fed agriculture, so natural vegetation is less cleared and thus has profound effect on reducing runoff, despite of its marginality. On the Upper part to the south of Alshowak into Ethiopian border, erosivity of rain is considerable due to its torrential behavior, high intensity and annual amount (400 – 1000 mm). Therefore, at this part, clearances of vegetation cover to expand on rain-fed agriculture where rainfall is favorable and to secure energy sources are continued and exposing the soil surface to accelerate water erosion. Field observation in the southern Blue Nile area reveals that Kerib land has caused by similar complexity of factors which make the site more susceptible and liable to accelerated water erosion than the northern parts.

Table (1): The extent of degraded land (Kerib) and water bodies between Alshowak and Khashm ElGirba Dam

Date	Total area (km^2) (Kerib + water bodies)	Water bodies (km^2)	Kerib land (km^2)	Rate of land loss (km^2/yr)
1985	335.8	96.4	242.2	-
1987	362.6	93.6	269.0	13.4
1990	391.9	105.4	298.3	9.8

Source: Hassan M. Fadul et, al. (1999). Use of remote sensing to map gully erosion along the Atbara River, Sudan.

5.2 River bank erosion

River bank erosion is a natural phenomenon governed by many factors of climate, hydrology, soil characteristics and human practices. Because of these factors, river generally is continually changing its position and shape as a consequence of hydraulic forces acting on its bed and banks. These changes may be slow or rapid and may result from natural climatic fluctuations (floods, drought) or response to man-induced changes. The response of river to these influences may be modification of channel characteristics such as position and morphology (dimension, shape and pattern). Once the river deviates at any point from its linear course, the resulting unbalanced erosive force tends to increase the local deviation producing meandering pattern which may lead to a serious changes within the influenced reach such as deviation from the main flow path, creates sand bars and appearance and disappearance of islands.

Subjecting these influences to Nile River and its tributaries under study, certain river behavior and effects were depicted. The Nile River and its tributaries within the Sudan are passing through alluvial plains along most of their reaches, which yield easily to the factors of erosion. Grain size analysis of the main Nile and Blue Nile bank soil as apart of hydrological and morphological study performed by UNSECO Chair in Water Resources (2002) showed variable differences in bank soil composition from one location to another. The mean clay content ranges from 30 to 40 %, silt contents are 30 to 35 %, while sand ranges between 26 to 46 %. Bank soil is dominantly clay and silt in the Blue Nile and silt and sand in the main Nile.

Human interference and influences in the proximity of the Nile was experienced in the excavation of soil for brick making, and building, cutting of trees, cropping pattern management and dumping of solid materials, mostly close to urban centers (Khartoum, ElDamar, Atbara, AlSuki, Roseiries). The soil excavation is expected to undermine and loosen the bank soil, thus distorting the river equilibrium. Dumping of the materials is expected to form a sort of isolated groynes causing condition conducive to deflection of flows and change in the bed level and water slope. A direct result is contraction of the width of the river and the river behaves by redistribution of the flow in the area to increase the dimension of the channel most probably through bank erosion in the opposite direction.

A big change in the river bank erosion magnitude in the southern Blue Nile area may be explained by the changing of the cropping pattern and management of the orchards along the Blue Nile. Initially these orchards are planted mainly to deep rooted trees such as mangoes and citruses and with good soil binding characteristics occupying 80 % of cultivated land and the remaining 20 % for banana trees. However, with the increase in the prices of banana, the growers tried in vain to increase their economic returns have removed or decreased the mangoes and citruses trees ratio to only 30 % and replaced them by banana (70 %) - **Plate No.** 2. The increased rate of bank erosion appears to have been influenced by this new cropping pattern.

Plate No. 2: Banana plantation on the Blue Nile banks (Roseiris area)

The hydrographs of maximum and minimum flows of the Nile River and its tributaries show great variation in discharges throughout the year. In the main Nile at Merowe for example, discharges vary from a minimum of $75x10^6$ m^3/day during summer period to $1140x10^6$ m^3/day during peak flood time (UNESCO, 2001). Similarly velocity variation is in the order of 0.6 m/s to 3 m/s. The highly seasonal pattern of flows of the Nile River is produced by the heavy rainfall in the catchment area of Ethiopian highlands and Equatorial plateau, especially the Blue Nile, which accounts for some 60 % of the Nile total discharge and only about 10 % of the annual discharge originating from Lake Tana.

The large flow causes flood problem, bank overflow and surface drainage difficulties during the rainy season, and these flows are also responsible for bank erosion and sediment transport. The rapid drawdown of the Nile as a result of dam operation or seasonal drought is believed also to accelerate bank slides problem. Thus, these flows are believed to significantly influence the changes that may take place within the Nile course. In the process and attempt to restoring its equilibrium either aggradations or degradation, or both usually occurs. These are related to meandering pattern as an ultimate result of bank erosion along many reaches in the Nile. Nevertheless, the important areas experiencing serious bank erosion threats are the Northern regions of Sudan from Khartoum to the border of Egypt along the main Nile River. Condition of river bank erosion in the Northern region is not an exceptional. It is also depicted and documented along Atbara River and Blue Nile. At Atbara River the hot points are downstream of Khasm ElGrib dam. **(Plate No. 3)** The Blue Nile is exhibiting active bank erosion at different locations. The most serious suffering areas are downstream of Roseires dam, Singa to AlSuki, AlMseed, along Tuti's and Shambat area banks. Along the White Nile all banks seem to be stable or with little erosion. The river bank erosion was manifested into a number of damages and constraints that include:

Plate No. 3: River bank erosion along the Main Nile River (Barber area)

5.2.1 River widening

The river widening causes a lot of damages along the Nile such as bank erosion. In the bank erosion process, valuable irrigable land is lost. One of the survey information obtained from unpublished data by the Forest National Corporation (FNC) in the main Nile and Atbara River areas showed that large cultivated areas are lost to river bank erosion with remarkable economic loss of mature date palm trees **(table 2)**. The case of active river bank erosion was observed in many areas along the rivers reaches and the result of data collected during the survey was presented in **table 3**. The total land loss was ranged from 13 to 52 % with an annual loss estimated to be in the order of 0.1 – 1.0 feddan, a local land area measure (one feddan equals 0.42 ha).

Table (2): Effect of river bank erosion on loss of agricultural lands and date palm trees in some villages in Nahr ElNeil State (1980 – 1997)

Province	Village	Lost land (feddan)	No. lost date palm trees	Estimated cost of lost trees ($ US)
ElDamar	Safari Alamarap	240	-	-
ElDamar	Al Hylab	18	500	250,000
Eldamar	Um Altour	20	425	212,500
Barber	Enabis	53	490	245,000
Barber	Albawaga	-	485	242,500
Abu Hamd	Alkarw	150	740	370,000
Shindi	Um Ali	-	20	10,000
Total	**-**	**481**	**2660**	**1,330,000**

Source: FNC, Nahr Elneil State, ElDamar.

Table (3): Agricultural land threatened by river bank erosion in Lower Atbara and the main Nile in some villages

Region	Village	Farm area (feddan)	Lost area (feddan)	Percent lost	Number of years	Lost area (feddan/yr)
Lower Atbara	Alhoodi	73	10	14	10	1.0
“ “	Abusonoon	2	1	50	15	0.1
“ “	Gozalhalag	8	1	13	8	0.13
“ “	Alamarab	23	12	52	20	0.6
Barber	Enibis	18	5	28	9	0.6

5.2.2 Water recession

It is normally intricate to have both erosion and recession occurring simultaneously near each other. When river increases its width in order to minimize the amount of work done, high energy is saved to transport huge amount of sediment delivered from upstream and the channel banks. Deposition and accumulation of sediment materials lead to appearance and disappearance of islands in the Nile course, which might extend to the river banks and prevent water flow and cause water recession. River bank inspection during the survey in the Northern regions of Sudan showed recession extension for a length of 0. 2 – 3 km and a width range of 100 – 400 m are most common. The recession forced the local people to abandon their field or to resort to dig wells to provide irrigation water or extend pipe to convey irrigation water from far distances. Occasionally, the length of conveying pipes is relatively long, which increases friction losses and shortened the live of the pumping units by half.

Poor drinking water quality and quantity is mostly associated with water recession as a result of water being stagnant in isolated pools in rivers, canals and surface dug-out structures (hafirs) during summer times, where flows are either low or absent. Such type of water was depicted in Atbara, AlDindir and ElRahad Rivers and canals in white and Blue Niles and Hafirs in dry land areas. Health hazard, migration during summer time (e.g. White Nile and Alshowak areas) and increased expending money to purchase water are the major impact of the lack and poor drinking water resources associated with water recession. Both the lack and poor water quality prevail under water recession condition are caused by one or more of the followings:

- Drought conditions.
- Policy in O & M of dams and irrigation canals.
- Lack of O & M and maintenance of drinking water supply facilities by the benefiting community and concerned local government.

5.2.3 Pumping units operation

The river bank erosion was found jeopardizing the pumping stations sitting sites and their operation by undermining the stable pump site and blocking or allows low level of water flow, which increases the pumping cost. The Ministry of Irrigation and Water Resources records and reports in the Northern region showed that many Nile pump's irrigated schemes have drastically reduced their irrigable areas because of difficulties encountered in pumps operation due to blockage of the inlet channel. At Al Arak scheme near Karima and UmSiyouf, for example only 400 and 250 feddans out of 600 and 700 feddans were cultivated now, respectively, while AlGoled scheme has stopped completely where the pump site is 700 m away from the Nile course.

5.2.4 Physical properties

The real threats and adverse impact for the bank erosion was experienced on physical damage to buildings and other properties in the vicinity of its course. Typical example was the Forestry Department Rest House at AlSuki **(Plate No. 4)**. The rest house which used to be about 120 m away from the shore is now nearly to collapse. Similarly pumping houses of many irrigation schemes and private buildings were reported collapsed under the influence of the bank erosion.

Plate No. 4: River bank erosion undermining property close to the bank (AlSuki)

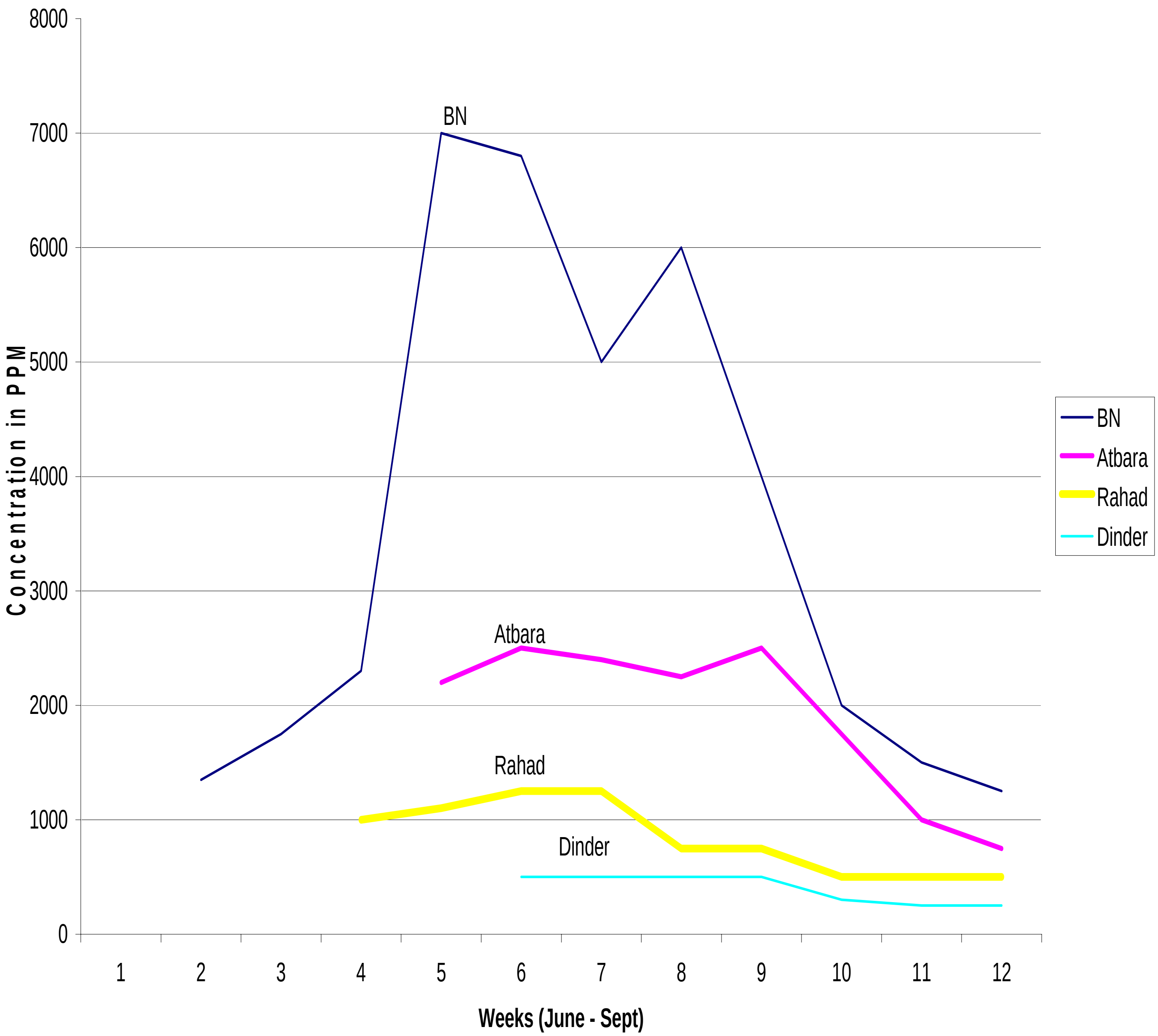
5.3 Sedimentation

With exception of some tributaries of White Nile all rivers in the Nile Basin of Sudan are originated from the Ethiopian highlands. The agricultural expansion, removal of trees cover and overgrazing and burning of grasslands and succession of drought years necessarily disturbed the natural conditions. The intense rains and steep gradients in the upper catchment area in Ethiopia keep the silt in suspension ready to be transported to deposit further downstream. This resulted in speeding up the erosion process and accordingly these rivers carry tremendous amounts of sediment brought annually by the flood during the rainy season. Because these rivers possess the necessary properties to carry sediment load, large volume of suspended sediment is encountered in their waters. The most important rivers are the Blue Nile and Atbara River.

Sedimentation studies in irrigation systems carried out by the Hydraulic Research Station (HRS) and documented by Salih Hamad Hamid (2001) showed that the sediment materials are almost of similar characteristics and sediment concentration inputs are mainly from the Blue Nile and Atbara River and minor from ElRahad and AlDindir rivers **(Fig. 1)**. Because of these two rivers, the sediment deposition has become the major problem for operation and management of the hydraulic structures as well as the irrigation schemes in the Sudan. At Khashm ElGriba dam, for example, the storage loss to sedimentation was estimated to be more than the 50 **%** of the reservoir design capacity (HRS, 1990). While in Roseires dam, it is about 38 % **(table 4)**, with the remaining storage capacity up 2000 is 2036 MCM out of 3024 MCM design capacity at a level of 480 m above sea level (a.s.l). The monitoring of sediment accumulation development at various levels from 465 m to 481 m for the years 1966, 1976, 1981 and 1985 conducted by HRS (2001) showed that all the dead storage volume below the minimum operating level upstream the reservoir (467 m) is almost completely filled and the live storage is depleting gradually as ascertained by the subsequent analysis in recent years. Moreover, this siltation problem causes serious difficulties in the intakes of the power generation facilities.

Fig. 1: Sediment concentration input from the Blue Nile, ElRahad, AlDindir and Atbara rivers (PPM)

Fig:SEDIMENT CONCENTRATION INPUT FROM THE BLUE NILE, ATBARA, RAHAD AND DINDER RIVERS (PPM)



Source: Sedimentation study by HRS.

Table (4): Sediment accumulation at Roseires Dam during 1970 - 2000

Year	Level (m)	Design capacity MCM	Actual capacity MCM	Sediment MCM	% loss of design capacity
1970	480	3024	2724	300	**10**
1975	480	3024	2474	550	**18.2**
1980	481	3300	2324	976	**29.6**
1985	481	3300	2227	1073	**32.5**
1990	481	3300	2106	1194	**36.2**
1995	481	3300	2036	1264	**38.3**
2000	481	3300	2036	1264	**38.3**

Sources: Ministry of Irrigation and Water Resources.

The concentration of the sediment entering the irrigation systems is virtually the same as that of the source rivers, especially during the peak flood when the storage dams are operated at their lowest retention levels. Records of sedimentation deposited in the National Irrigation Schemes (NIS) by the same study showed distribution in the canalization network in the following manner; 4, 23, 35 and 38 % for the main canal, major and branch canal, minor canal and field, respectively. The result also showed that between 70 – 80 % of the sediment entering the irrigation systems was during the period of mid July to end of August. Records of quantities of sediment removed from the Gezira Scheme for example showed an enormous increase since it is first commissioned in 1925. Estimates for annual desilting requirement range between 4 – 10 million m^3 with remarkable increase since the seventies. Recently the total annual sediment to be removed from the NIS is more than 15 million m^3 distributed among considerable long canalization network (17244 km) and drainage system (10650 km).

Monitoring program of sedimentation in irrigation canals of Gezira Scheme conducted by Ministry of Irrigation and Water Resources in collaboration with the Gezira State Ministry of Agriculture, Animal Wealth and Irrigation showed similar increased rate of sedimentation **(table 5)**. The table clearly shows that the sedimentation load varies from year to another with an obvious correlation to the amount rainfall. A significant increase in the average sediment concentration entering the Gezira during August from 700 ppm in the period 1937-38 to about 3800 ppm during the period 1988-89 has been noted by The HRS in collaboration with the Hydraulic Research Ltd. (HRL, 1990), Wallingford of U.K. This was attributed to the increase in the rates of soil erosion in the Blue Nile catchment enhanced by the effect of successive drought events hit the Ethiopian plateau.

The adoption of crop intensification and diversification policy since mid sixties is believed to be one of the causes. One important factor also affecting the sedimentation process is the design and operation of the irrigation system. This is clearly shown by the design of the minor canals for night water storage and irrigation is only provided during daylight hours, a condition viable for sediment deposition. Additionally, minor canals are designed with large cross-sectional areas, small gradients and thus very low flow velocities, a design feature that made them having very limited sediment transporting capacities and practically to act as a sediment trap. These problems are further accelerated by the effect of noxious weeds growth stimulated by the silt deposition particularly in the minor canals.

Table (5): Sedimentation in irrigation canals system of Gezira Scheme

Year	Sedimentation (million tons)	Remarks
1981	5.8	
1982	6.6	Dry year
1983	11.8	Above average year
1984	6.1	Drought year
1987	4.6	" "
1988	10.3	Very wet year
1989	4.7	Dry year
1990	6.6	Dry year
1991	7.7	Average year
1992	4.2	
1996	10.5	Very wet year
2000	5.3	
2003	13.5	Wet year

Source: Ministry of Irrigation and Water Resources.

Generally the sediment deposition in the storage reservoirs has the following implications:

- Reduces the reservoir capacity.
- Lack of irrigation water i.e. not enough to meet irrigation requirements.
- Difficulties in power generation.
- Sediment passed in to canal system will raise canal bed and water levels, drowned control structures and hence overflow causing damages to canal structures.
- Increased cost of operation and maintenance of reservoirs and canalization network in the removal of sediment.
- Enhance noxious weeds growth by inherently fertile silt soil, which slow down the flow.
- Deterioration of water quality and increased cost of treatment for drinking purposes.

5.4 Resource degradation in AlDindir National Park

AlDindir National Park (DNP) is located in the South-East of Sudan between longitude 34^0 30' to 36^0 00' E and Latitude 11^0 00' to 13^0 00' N. The Park covers an estimated area of about 9000 km^2. Both AlDindir and ElRahad Rivers and their tributaries flow through the park. Hydrologic ally, these rivers with their tributaries and numerous natural ponds form an extensive drainage system network. These natural surface water bodies constitute the major source of water supply for drinking and grazing requirements during the long dry season (November – June) for the wildlife. Nevertheless, during the last 2 decades, people working in the park have indicated that the park is experiencing a serious problem of natural resources degradation that affects its potentiality to restore and sustain the ecosystem that the wildlife is enjoying. The resource degradation is attributed to drought in terms of decreased rainfall and river discharge coupled with human-induced factors of agriculture expansion, tree cutting for fuel wood, fire hazard associated with charcoal making and honey extraction and competition from domestic livestock for water and food. As a result of these factors the catchments areas have been deteriorated drastically, which manifested into:

- **Decreased storage capacity of surface water structures (ponds and meandering streams).**

This is entirely due to soil erosion (sedimentation). The natural ponds locally known as Mayas play an important role in the ecosystem of the park from the fact that, the major rivers flow for a few months and thereafter Mayas become the only source of drinking water and grazing resources. As Mayas and feeding streams drainage pattern changed by sedimentation over time they become dry and desirable grasses were replaced by tall unpalatable annual species (Salwa et.al., 1996). It was also found that the fish productivity and other biotic activity of soil fauna are adversely affected by the loss of nutrients and soil moisture storage due to surface runoff.

- **Gullies development**

Increased rate of water erosion in the steep areas of catchments has impaired gully development. Soil erosion from gullies removing 1 to 16 m annually has been reported by the Wildlife Research Center (1999). Variations in the rate of erosion are due to characteristic of rainfall, soil and topography and vegetation cover intensity prevailing in the area.

- **Reduced vegetation cover**

Grazing grasses and browsing trees resources were remarkably reduced with fires outbreak and tree removal by human interference and heavy pressure from domestic animals invasion. Land degradation as attributed to increased human and animal populations and pressure have resulted in over utilization of land resources. The extensive expansion of cultivated area not only affected land and crops but also wildlife. Their habitats have been adversely affected and their number decreased, certain species completely vanished and those remaining were endangered.

5.5 Runoff water erosion in dry land agriculture

Many parts of surveyed areas in the central and eastern Sudan are the driest of the African continent and rains are concentrated in short wet seasons and soils have low water holding capacity. Under this condition runoff erosion after rain storms is inevitable. High –intensity rains concentrated in a few months normally cause a severe water erosion hazard. When rain falls on loose dry soil, the soil particles are suddenly washed away and collect on the surface quickly and flow away instead of penetrating through the soil. The problem of water erosion is aggravated by poor practices in rain-fed agriculture and introduction of mechanized farm operations that lead to soil compaction. Soil compaction reduces water infiltration rate, causing depletion of soil fertility, loss of plant available water reserve, and further degradation of soil quality. Research on similar arid zones indicates that the organic matter levels, clay content and the concentration of plant nutrients in eroded sediments are usually 2 to 5 times higher than those in the parent soil. Field investigations indicate that overland and rill runoff water on the cultivated clay plains is the initial stage to enhance gully growth in the local farms and grazing lands, or might extend to form kerib land in the vicinity of rivers' banks.

Accelerated soil erosion has been shown to cause severe and often irreversible reduction in crop yields. In fact, the root cause of the chronic famine in parts of Sudan and other Nile basin riparian countries can be traced to misuse of soil and water resources. Much of unsustainable land use practices can be attributed to overgrazing, deforestation and cultivation of marginal lands. These practices and conditions are normally linked to increased population density, with more people living on diminishing natural resource base, and generally having few opportunities for alternative employment and income. With prolonged drought, asset depletion, poor agricultural production, low food supply, poor health, water shortage, migration and environmental damaging survival strategy would become more prominent and it's difficult to recover from when the rainfall returns to normal.

People in their struggle to produce more food; and as a survival strategy, farmers continue to strip away and remove vegetation cover in increasingly arid and semi-arid lands. By doing so, they unwillingly fuel environmental degradation that perpetually undermines the agro-ecological capacity and potential of the land to support the human existence. The resultant flush floods, wind erosion, high surface runoff and reduced soil infiltration capacity have contributed to declining soil fertility and water retention and hence poor crop yields. A typical example of such human interference, where expansion in agriculture has been the main reason for land degradation is in the Blue Nile State. It was noted during the survey discussion by the State and FNC officials that the forest cover is now reduced to about only 17 %. Areas experiencing overland water erosion with typical influences and adverse effects are the followings:

- The traditional rain-fed areas (Upper Atbara, central Blue and White Niles and north Gadref).
- Mechanized farming schemes (south and central clay plains in Gadref, Blue Nile, AlDindir, ElRahad and White Nile).
- Marginal cultivated areas (Butana, north of White Nile and Blue Nile).

Dry land agriculture has a very important role in the national economy and food supply as it provides a large share of the staple food (90 %). The current survey data analysis shows that it employs over 80 % of the total respondents and off-farm employment and economic opportunities are very limited. Dry land agriculture, of very low productivity is practiced on 90 % of the total cultivated area. The challenge is now how to develop a sustainable natural resource base management for self–sufficiency agricultural economy and livelihood. Therefore, controlling soil and water resources degradation will specifically address improving dry land agriculture output for large population. The target areas in addition to Sudan should include upper catchments of the Nile Basin, where low-inputs, poor rain-fed agriculture and pastoralism predominate in harsh environments of fragile natural resource bases and variable climates.

In most of these areas crops are usually planted with no or limited conservation practices **(Plate No. 5)**. Conclusion drawn from the field survey concerning conservation practices indicates that over 95 % of the respondents did not use any conservation methods. Few traditional practices of terracing were employed by farmers in Alshowak, Butana and north of While Nile areas (AlDweim). A study to test the effects of water conservation compared to flat planting was conducted by (Farah, Ali and Inanaga, 1996 and Salih and Farah, 1999) in the Gadref and Butan areas **(table 6)**. The results showed that tied ridges increased yield over the control by 38 % and 86 % for Gadref and Butana, respectively. The earth boundaries attained the lowest yield over the control (14 %), probably because of inefficiency of surrounding the field by distant earth boundary bunds.

Table (6): Effect of water conservation on sorghum crop yields (kg/ha) under rain-fed conditions in central clay plains of Sudan

Area	Tied ridges	Earth boundaries	Flat
North Gadref	1252	-	904
Butana	1659	-	890
Gadambalia	-	1361	1196

Plate No. 5: Lack of conservation practices on rain-fed agriculture

5.6 Wind erosion

Wind erosion as natural phenomenon has been based on physical principle that soil movement occurs in response to forces generated by the flow of wind. Wind erosion occurs when soil aggregates subject to removal by wind are present in the soil surface and wind velocity is strong enough to detach soil particles when the soil surface is not protected. As the wind speed exceeds the threshold velocity required to initiate soil movement, individual soil aggregates become aerodynamically unstable, picked into wind stream, and are transported down wind. The distance traveled by the air carried particles depends on the velocity of the wind and the shape and density of the soil particles.

Wind erosion is caused by several climatic and human-induced factors. In the area covered by study, the process is influenced by a variety of factors that yield serious environmental degradation. The factors influencing wind erosion are well experienced in the Main Nile north of Khartoum into Egypt, north of White Nile and Lower Atbara north of Sydoon town. In these areas, wind erosion is one of the most wide spread form of land degradation.

5.6.1 Wind speed

Wind speed is one of the main climatic factors that affect erosion process. Wind direction during the rainy season (June – October) is SW and N to NE for the rest of the year. Average wind speed ranges between 5 – 8 mph, which is enough to initiated soil particles movements. During the summer time, when the soil is predominately dry, high speed dust storm locally known as Haboub prevails through much of north Khartoum area. The mean daily temperature ranges between 22 to 36 C^0, which is relatively high resulting in dry soil surface. In the north region of Sudan, the number of dust storms each year has been mentioned by the inhabitants for various locations during the group discussion. The greatest number was encountered northward of Shendi in both west and east of the main Nile course with intensity of wind erosion increased regularly from November to May.

5.6.2 Rainfall

The area experiencing wind erosion has desert to arid climate, in which rainfall starts from June/July and ends September/October with annual value ranges less than 50 mm in the north desert to 250 - 300 mm in the arid zone represented by Aldoweim town along the White Nile. Frequency analysis for rainfall undertaken by various investigators indicates high variability of rainfall, which characterized by sporadic distribution, amount, intensity, fluctuation trends and return periods. Example of large extreme variability is given by (Environment & Development Services, 1999) for three stations in the north area **(table 7)**. The table clearly indicates a general declining trend in low mean annual values from south to north reflecting drought condition. In such dry area, a few years of poor rainfall with low exceeding probability can lead to deterioration in vegetation cover, which is not always possible to recover in succeeding wet years.

Table (7): Annual rainfall variability in some stations in north Sudan

Station	No. of years observation	Mean annual rainfall (mm)	Highest (mm)	Lowest (mm)	Standard deviation
Atbara	69	64.4	238.9	1.1	41.2
Shendi	38	72.2	205.4	3.0	56.3
Khartoum	30	124.1	415.5	4.4	99.8

Source: Water Resources Development Study. ADS Lower Atbara, Environment & Development Services (EDS)

5.6.3 Vegetation cover

The area vegetation cover consists of desert, and arid type Acacia scrub, shrubs and annual grasses. The vegetation is extremely sparse and the land is virtually barren area, because it is ineffective in controlling wind erosion. The vegetation composed mainly of *Acacia tortils, mellifera* and *nubica, Balanites aegyptiaca* and grass species such as *Aristida, panicum spp., Andropogan gayanus* and *Cenchrus ciliaris*. The vegetation density increases along Khors, Wadis beds and rivers course. Trees dry out during summer time and in years of bad rains. It is particular along the bed and edges of wadis that rain-fed agriculture is practiced, animal are grazed and open shaft wells are dug. Thus, the land is further degraded by heavy pressure from both human and livestock in terms of cultivation, overgrazing and deforestation for fuel wood purposes and ultimate outcome is extending desertification. Assessment survey about the sources of energy indicates that the majority of population depends basically on wood and charcoal **(table 8)**. However, there is increasing number of households tried using gas for home cooking by better-off individuals promoted by some active CBOs such as in LA. In areas where the use of fire wood and charcoal is relatively lower (Lower Atbara) than other areas is notably indication of trees depletion or at far distant and alternatively relied on crops residues as a source of energy. The table also shows that none of the households surveyed are relying on kerosene.

Table (8): Source and energy use percentages

Area	Fire wood & charcoal	Crop residues	Gas	Kerosene
Lower Atbara	60	32	8	0
Upper Atbara	95	0	5	0
Blue Nile	94	5	1	0
AlDindir	80	20	0	0
White Nile	70	28	2	0
Mean	**80**	**17**	**3**	

5.6.4 Implication of wind erosion in the area

Wind erosion has been serious in many parts of the surveyed areas. General areas most endangered and susceptible to wind erosion include the Main Nile, lower Atbara and north White Nile regions. Wind erosion damages in several ways.

5.6.4.1 Endangering agricultural land and settlements

Result of field survey assessment about the wind erosion effect on some agricultural land on Lower Atbara indicates serious threat by the sand dunes movement over less than 10 years period**(Plate No. 6**). A large number of villages on those areas were found endangered, susceptible or even some dislocated such as Gozalhalag in 1988. The **table (9)** below presents a few examples of typical agricultural areas cover by sand. The table clearly indicates that in most sites about 30 % of cultivated area is invaded by sand dunes movement. At Lower Atbara and Main Nile the limited agricultural land stretched along the rivers course was significantly reduced and hampered by wind erosion deposition action.

Plate No. 6: Desert encroachment on arable lands (Alshigla village, north of Atbara town)

Table (9): Some of agricultural land threatened by sand dunes movement

Village	Cultivated area (ha)	Threatened area (ha)	Percent coverage
Alhoodi	80	25	31
Kenidra	12	3	25
Abusounon	6	2	33
Gozalhalag	100	27	27
Alamarab	22	6	27

5.6.4.2 Reduce soil fertility and crop yield

Wind erosion physically removes from the field the most fertile portion of the soil and changing the soil composition to more sandy texture, and thereby lowers its productivity. Some research shows that in almost all arid and semi-arid areas affected by or threatened with desertification, the soils are deficient in organic matter, low in phosphorous and nitrogen.

5.6.4.3 Burying roads and highways

Blowing soil covers roads and highways along many sections in Nahr AlNeil, Northern and White Nile States. Dust particles in the air reduce visibility and with sand accumulation usually lead to increased road accidents.

5.6.4.4 Filling ditches and irrigation canals

The burying of irrigation channels in the northern region, White Nile and Lower Atbara schemes causes many problems in irrigation water management, where the delivery of water is jeopardized by higher gradient level and seepage losses. Long hours of pump operation were required to convey irrigation water to rather short distance through sand buried irrigation channels were noticed in many small-scale irrigated units (Mataras) at Lower Atbara and Northern Region.

5.6.4.5 Reduce plant growth and survival

The direct mechanical actions of wind erosion reported by the farmers on damaging of plants were torn of the leaves, bending of stems and up root plants or even kill them. The hurling grains particles of hot sand against plants were observed sometimes damages them sufficiently to kill them. A plant having its leaves shredded may loss some of its photosynthetic capacity and thus reduced growth and survival. Dust blown by wind may increase their susceptibility to diseases. The most harmful indirect action of wind erosion during dry season causes great desiccation of soils and vegetation, and thus increased evapotranspiration. The crops appear to be stressed within very short period from irrigation and thus farmers tend to irrigate more frequent. Survey results about irrigation frequency of three major crops in Lower Atbara and the Main Nile showed that, sorghum, wheat and onion received 5-9, 8-10 and 14-21irrigations during the cropping season. However, these are rather high irrigation frequencies and above recommended frequencies. The optimum frequency is therefore, bound to reduction of wind erosion effects and improved field irrigation and cropping practices management.

6. Erosion mitigation activities

This part of the study describes some of the interventions that can be implemented to control different kinds of erosion threats. These interventions range from physical barriers to biological soil conservation and management measures. The importance of these structures and how they control erosion has been discussed. The methods proposed here are easy and they do not involve much work. They can easily be adopted by beneficiaries. Based on type of the erosion threats being identified in the above findings and CBOs and stakeholders priorities the followings could be proposed:

6.1 Gully erosion control

Gully erosion (Kerib) can be controlled in many ways. The most practical and simple means were rehabilitation of the Kerib land by construction of small check dams and planting of trees. Rehabilitation by planting trees was already initiated by the Forest National Corporation (FNC) with the participation of community in upper Atbara River, where the indigenous trees were found performing well. However, these initiatives need some improvement with respect to the type of enriching trees, density and associate conservation measure. The type of tree species such as *Acacia mellifer* and *tortilis* presently growing, although are indigenous, they are of low growth and density. Enriching of these trees by fast growing high density trees like *Acacia seyal* (Tilah), *Zizyphus spina Christi* (Cidir) and *Acacia nubica* (Laoat) can grow several times faster to reduce flow velocities and sediment load due to their soil binding properties and roughness effect.

Experimental work with the same tree species planting and linked with cut-off drains water harvesting technique documented in the Alskowak area by (Hussein Awad S. Ahmed, 2001) showed significant increased plant growth and improved survival rate of 65 – 95 % after 15 months growth monitoring period and 3 years mean soil loss was reduced by 72 % from 1.6 t/ha for control to 0.93 t/ha for treatment.
The restocking of degraded Krib land by tree planting treatment could be of significant impact if this area is reserved as natural forest with controlled livestock grazing and tree removal for fuel wood, particular during the first years of establishment. The conflict between forestry and animal husbandry is a major problem during early stage of establishment. Once this stage is passed the tension is greatly reduced. If we increase the management of trees and adopt measures, including rotational grazing at the right time, both forestry and animal husbandry can benefit.

The gullies, although unfavorable for agricultural development, but they were used for this activities by enormous number of farmers in Upper Atbara and Southern Blue Nile areas as home/back yard gardens (locally known as Jubraka). With the loss of soil and water from the gully, the productivity of these gardens is declining. Often the loss of soil and water from the gully systems is very high, the sediment concentrations of flood water can be very high and scouring may be a serious problem to be harnessed by trees alone. Therefore, placing of small earth/stone check dams barriers, along the bed (furrow lines) and terracing and strip cropping in the side slopes and ridges can reduce runoff intensity in the deep gullies and produce economic benefit in terms of improving crop yield. Other than the earth/stone check dams, wooden and gabion check dams could be used, depending on the availability of construction materials.

Check dams are structures built across the gully and the slope. The check dams trap soils and water, which allow water to soak into the ground easily. The spacing of the check dams and terraces depends upon the steepness of the land. A steep slope will therefore have more dams and terraces, which are close together than a gentle slope.
In strip cropping, land is divided into long narrow pieces along the contour. Different crops are planted on these strips, which help to reduce the speed of runoff. The upper strip should have closely planted crops such as grass and sweet potatoes. This strip, which covers the soil completely, could be followed by widely spaced crops such as maize, millet and okra. When water from a strip with a crop that does not cover the soil reaches a strip of a crop with a good cover, its speed is reduced. The water spreads out and the crop traps the soil. In this way, we can not only effectively control soil erosion, but produce greater economic income.

The extension of typical gully induced factors such as rainfall, landscape, topography, soil properties, plant cover and cultivation practices into Ethiopian highlands along Atbara River basin would likely to produce similar impact of gully erosion depicted in Sudan. In view of this assumption, we suggest the same kind of interventions could be implemented as transboundary mitigation action. In this way, we may succeed in significantly reducing the sediment and runoff influx into the Atbara River in its upper catchment basin. The practice may be afforestation of gullies, structural barriers (dams and terraces) and strip cropping, that is not in the sequence gully floor, ridge and slope.

6.2 River bank erosion control

Generally options for controlling bank erosion are well known among professional engineers and recommendations were provided. However, most of these deal with engineering solution and used in limited scale, because of cost involved. The HRS (1990) recommended the following protection measures for bank erosion.

- Revetments to stabilize the banks following a stable slope.
  This is used to protect the bank against the erosive power and wave's action of the flow.
- Groins to deflect strong current from the bank and enhance better conditions for deposition.
  Groins are principally used to deflect strong current from the bank and provide conditions conducive to silt deposition, provided that groin characteristics such as length, angle and spacing are determined.

The use of traditional method in bank erosion was found at two locations throughout the Nile basin. In the Northern region of Sudan, tree branches spaced closely and tied with wire were installed by orchards growers in the Nile banks in an attempt to trap silt and create a natural wall to protect the endangered bank. It is a sort of revetments structure to stabilize the bank against erosion, but ineffective and used in a very limited scale and not popular among farmers. The role and response of farmers to bank protection was investigated during the field survey. **Table 10** reflects the farmers' views on reasons for not using protection measures against river bank erosion. The figures displayed in this table show that with exception of Blue Nile the traditional methods were ineffective where tried or when natural grasses are left grown in the bank such as halfa plants in LA. The survey results also revealed that, the traditional practice and natural growing of grasses depend primarily on indigenous trial and error and technical know-how or improved simple techniques are lacking. At the Main Nile and Blue Nile areas some information and improved technical methods of tree planting are availed by specialized institution such as the FNC and Ministry of Irrigation and Water Resources. In the Blue Nile planting of some appropriate tree species such as *Oxytenanthera abyssinica* (Gana), *Tamaris abhylla/nilotica* (Trafa) and *Acacia nilotica* (Sount) are proved to be effective. These species are believed to have long flexible branches protruding in the water to reduce and absorb the current force. The survey results also showed that no such single farmer had practiced any form of protection in the Upper Atbara and AlDindir. In the latter area the problem is not serious. However, the majority of respondents have indicated willing and interest to adopt protection practices, particularly in areas where bank erosion is serious like, Main Nile, Lower Atbara and Blue Nile. Almost all the respondents have cited unavailability of suitable tree seedlings and the high cost discouraged them to be involved in the process of protection.

It is clear from the above documented trials, biological stabilization of river bank using suitable tree species is likely more acceptable and simple to be adopted by farmers and desire some propagation and launching with extensive awareness campaigns in collaboration with the FNC. Other options of river bank protection technology could be generated through research and development (R & D) pilot project with a technical assistance and guidance from Irrigation and Forestry Departments, particular in the Main Nile and Atbara River. An important point emerged from the negative effect of banana plantation on bank erosion is that, the awareness campaign should explain to farmers the importance of planting big fruit trees in front of banana trees as land use arrangement necessary to protect the bank. The FNC could play an important role of providing the suitable natural and fruit trees seedlings as incentives in addition to technical services to be provided in relation to this issue.

A number of Community-Based Organizations (CBO's) and NGO's were identified in the Main Nile, Atbara River and Blue Nile that they could work together with researchers and other concerned institutions in the implementation of R & D programs. Generally, the government institutions or NGO's could be sub-contracted by the CBO's to provide specified technical services from project formulation, implementation to monitoring and evaluation phase. Lack of implementing research findings by community is a capacity building gaps. This capacity building gap could be bridged and enhanced when this component is taken inline with the research requirements.

Table (10): Reasons for not using protection measures against river bank erosion (%)

Reason	Lower Atbara	Main Nile	Upper Atbara	Blue Nile	AlDindir
Ineffective traditional methods	60	100	NA	20	NA
Lack of knowledge	100	30	100	50	100
Lack of improved method	100	80	100	70	100
Not interested	50	20	50	25	100
Not serious	20	10	40	45	100
Costly	100	100	100	75	NA

6.3 Sedimentation control

The findings of this study showed that the sediment material originating mainly from heavy erosion in the upper catchments area in Ethiopia highlands. Therefore, upper catchment looses valuable soil, while lower basin in Sudan looses valuable storage capacities in reservoirs and canals carrying capacities. A part from the high economical cost brought by sediment deposition, there are social and environmental impact of this watershed degradation and sedimentation. Therefore, the problem of sedimentation should be worked out on both national and regional levels, as they are so inter-related in the watershed management and sediment.

6.3.1 Sediment control at the national level

This is mainly are preventive measures to account for sediments entering the irrigation systems. The magnitude of sedimentation problem in the irrigation systems of Sudan has limited the options to manage its seriousness. However, despite of that, genuine efforts so far have found to lay some feasible sediment management. Of these, the HRS using data collected and analyzed from the sediment monitoring program study has proposed two categories, which are dealing with operation and management of irrigation facilities. It is identified as the most promising solution.

6.3.1.1 Sediment exclusion measures

This is attained through two options:

a. Sediment exclusion by closing the main supply system

Closing of the main supply system is intended to reduce the flow through the system during time of high sediment concentration. Their results from the sediment monitoring indicate that closing the gates at the head-works of the Gezira Scheme main canal for a period of 6 weeks between 20th of July to 31st of August has led to the exclusion of about 75 % of the sediment entering the scheme annually. Although, this method seems to be effective, but it bears some implications with respect to the current crop and water management practices:

- The closing of the main system coincides with the optimum planting date, which would be delayed and hence possible reduction in crop yield.
- Delaying of planting date would mean that many crops need water at the same time i.e. conjunction in water delivery, which would lead to reduction in cropped areas.

b. Introducing settling basins

The settling basins are performed by construction of large basins along selected canal sections at the head of the irrigation systems for sediment deposition and trap. This method was implemented through simulation models to determine the settling basins size and to assess their performance. The prediction model concluded that relatively large size basins are required to be effective. For example the predicted size was found to have the dimensions in the range of 2.7 – 7.5 km long, 0.4 – 10 m wide and 1.5 – 4 m deep. However, the relatively large size basins impose some practical constraints that include:

- Loss of some area for the construction of disposing system.
- Cost involved.

6.3.1.2 Changing current irrigation and sediment removal practices

a. Changing the current irrigation practices

This option involves changing the design of canals and irrigation practices. The change in canal design calls for deep and narrow cross-section so that a large portion of the sediment is conveyed through to the field, while changing the current practice of night storage system to a continuous one. However, this proposal faces certain difficulties to be implemented.

- Big capital investment is required to redesign over 8500 km of canalization.
- Change in the field level profile (gradient) by allowing huge sediment passed to the field (field irrigation water management problem).
- Extra operation burden on farmers and irrigators in the supervision of the continuous flow system.

b. Changing the current silt clearance practices

These are mechanical practices to remove the accumulated sediment and restore the original design cross-sections of canals. The mechanical work is effective in removing both the sediment and the aquatic weeds, but the question of the current practice of restoring the design cross-section of canals as the design sections are not the optimum ones as far as efficiency in suspended sediment transport is concerned. Nevertheless, the cost of sediment clearance is expensive and steadily increasing.

6.3.2 Sediment control at regional level (catchment/watershed control)

The procedure of catchments treatment when possible is most effective in sediment control. The basic principle is to arrest and prevent sediment movement and transport at the source through a number of management procedures. The source of silt causing sedimentation is originating basically from severe erosion in the upper catchments areas in Ethiopia. The selection of appropriate catchments/watershed management procedures however, depends on particular boundary conditions, characteristics and deterioration level within the watershed area. For the purpose of rehabilitating degraded watershed and arresting sedimentation, soil erosion can be controlled by biological soil conservation measures.

Integrated watershed and natural resources management and production models have been tested and proved in countries of East and West Africa region, can immediately be transferred and adapted.

The proposed intervention would be integrated R & D activity that will test, adapt and transfer an 'already proven' technological model for integrated natural resource and agricultural production improvement at the watershed level in Ethiopia and Sudan. It will develop conjunctive rational use of natural resources (rains, forest, soils, and rangeland) with crop and livestock productivity enhancement and ultimately farmers' income in the target watersheds. It is expected to contribute effectively to sustainable resource management and productivity improvement, and would have good impacts on erosion hazards, food security, poverty and the livelihood of the rural poor, and the environment in general. It is a community-based activity, uses multidisciplinary approaches to R & D, with effective participation of resource-user communities. The interventions are meant to be simple, and work on basis of small easily manageable watersheds. The intervention focuses on forest management (improved vegetal cover, afforestation and control of forest fires), controlled grazing and water harvesting techniques (mulching, contour/strip farming, terraces and check dams) to reduce soil and water loss with due attention to crop/livestock productivity and sustainability consideration.

6.3.2.1 Vegetation cover/afforestation

The soil can be kept under cover by maintaining natural vegetation cover, planting cover crops and enriching the existing trees in areas where trees are removed or do not exist. A natural vegetation cover of grass trees and bushes should be maintained in areas which are not under cultivation or marginally cultivated. In area experiencing severe erosion as a result of high terrains, trees also should be planted in steep areas such as hill slopes and mountain sides. If trees are planted in areas where they have never existed before, this is called afforestation. The vegetation cover prevents rain drops from hitting and loosening the soil, slows speed of running water and trap soil, and thus no soil detachment and transport. Control of forest fires is also an important forest management component to conserve the environment and maintain naturally balanced ecosystem.

6.3.2.2 Contour/strip farming

This simply means that the land is plowed along the contour, which facilities interception of runoff water and maintenance of soil. The crops are also planted along the contour. Strip cropping with the same objectives follow the same principle, where different crops are planted in an alternating manner in long narrow pieces of land.

6.3.2.3 Mulching

When soil is covered with dried plant remains, this is called mulching. Example of plant remains are sorghum, maize, wheat stems, leaves and stalks, banana leaves and sunflower stalks and heads. Mulching benefits crop growth by improving soil physical properties such as total porosity and infiltration rates and by adding plant nutrients. In addition mulch also conserves soil water by decreasing losses due to runoff and soil evaporation. Mulch also enhances the activity of soil fauna, which improves soil structures. Mulches are suitable in areas of relatively flat terrains to control soil erosion in many ways by intercepting the impact of raindrops and increase the surface roughness to resist erosion. Experiments conducted in eastern Africa have shown that even for plantation crops on highlands (tea and coffee) mulch farming techniques are the most appropriate for controlling runoff and erosion and increasing production.

In addition to soil and water conservation, crop residue mulch also regulates soil temperature. When cleaned and cultivated soil with coarse-textured sandy surface horizons experience temperatures of 40 – 50 ^{0}C at depths of 1 to 5 cm for as long as 3-6 hours a day. Germination and seedlings establishment of crops are adversely by high soil temperatures. These high temperatures are both the cause and consequence of the low level of soil moisture. Use of crop residues mulch of 4 to 6 t/ha regulates soil temperature by decreasing the maximum soil near-surface temperature by as much as 5 – 10^0 C. Mulches are cheap and easy to get because crop remains and residues are always available on the farm. However, there is limitation of acquiring the mulch material that makes mulching practically difficult innovation. This constraint is particularly true for arid and semi-arid regions with prolonged dry season and a large livestock population. Crop residue for mulching can be provided by introducing crop rotations and fallow system to produce enough biomass from crops for animals, while fallow grasses could be preserved completely for mulching or subject to light grazing. Thus, this system could be an alternative strategy to optimize the use of limited resources in semi-arid environment between farming and conservation needs.

6.3.2.4 Controlled grazing

This means controlling the number of animal feeding on a given area of land to avoid overstocking. When land is overstocked most probably left bare which lead to overgrazing and soil can easily be eroded. To avoid over grazing, the number of animals grazing in a given area of land should be controlled to match the optimum carrying capacity of land grazing resources. Such management practice would likely to keep the land under vegetation cover, which reduces soil erosion.

6.3.2.5 Terracing (channel and ridge)

Channel and ridge terraces reduce the length of the slope by breaking it into small sections. In this way the distance covered by the runoff downhill is reduced. When the runoff is covering a short distance, the speed of water downhill is reduced. The reduced speed of runoff allows more water to soak into the ground and collection of sediment on terraces and ridges. This water can be used by plants when dried up. In high rainfall areas a lot of water collects on the ground when the rain falls. On this case, it is important to construct slightly graded channel and ridge terraces in these areas. These structures help to retain much of the runoff water for deep percolation. The excess water which can not be absorbed by the ground moves out slowly along the graded terraces. Grasses are usually planted on the banks of terraces. The grasses protect the terraces from erosion. The water soaks into the ground increases soil moisture, which can be tapped and used by trees with deep root system during the dry season.

Because the catchment area of treatment lies partly in Sudan and largely beyond its national borders, this project could be of transboundary nature. This off course requires a high level of cooperation for effective complementary catchment control measures. It is hoped that the NBI project currently operating between the riparian countries of the Nile would make and facilitate such level of cooperation.

6.4 Control of resource degradation in the AlDindir National Park

Management activities to prevent deterioration of catchment and to improve the productivity of the resources necessitate the control of elements envisaged in the degradation. These briefly include the followings:

- Flood regulation and control using water cross-regulator in appropriate river tributaries and feeding streams.
- Enhance the storage capacity of some badly deteriorated pools and feeder channels by desilting of sediment.
- Control expansion of agricultural schemes into the park area.
- Improvement and establishment of surface water storage structures (dug-out reservoirs and dams) outside the park territory for nomads to reduce invasion pressure on park's water resources.
- Establishment of fire lines to reduce fire outbreak hazards.
- Improvement of vegetation covers through planting of palatable and desirable under- and over story species.

Because of extension of AlDindir National Park into Ethiopian borders with typical degradation elements and similar hydrological pattern, the upper catchment of DNP in Ethiopia is very attractive to transboundary mitigation program.

6.5 Controlling runoff water in dry land agriculture

Due to convective characteristic of rainfall, lack of conservation practices, poor vegetation density and nature of clay and soil compaction low permeability of soils and consequently runoff is unavoidable. Runoff does not allow much water to be retained in the root zone. Moreover, excessive evaporation from the soil surface accelerates water loss and subject crops to water deficit. In order to reduce runoff and increase the available soil moisture, some water conservation methods and eliminating unsustainable land use practices could be beneficial. Hence providing support to proper land use planning and utilization and sustainable practices to enhance protection and conservation of natural resource base can be a strong drought mitigation strategy.

The use of a simple sustainable community-driven least costly targeted interventions benefiting as large numbers of beneficiaries as possible utilizing potential natural resources are appealing for prompt intervention by the NBI project. Although, technological options differ among soils and ecological regions, perhaps water-harvesting intervention is more appropriate in addressing water erosion and availability and supply of water for agriculture use. Available water resources in the area liable to water harvesting harnessing comprise rainfall/ overland water flow, seasonal watercourses flow and water bodies (lakes and ponds). Based on topography and soils prevalent in the area, the type of available water resources potential and local building materials, several interventions/activities of the water harvesting techniques could be used.

6.5.1 Modifying of Indigenous Terrace Water Harvesting Techniques

The proposed modification is to control water erosion and enhancing rain-fed crop production presently under traditional terrace cultivation aimed at increasing soil moisture to alleviate the effect of most common long dry spells (3 – 4 weeks) during the cropping season for improving and stabilizing crop yield. The farmers traditionally build up terraces to harvest water for crop production purposes in limited scale (Aldoweim, ElRahad and Butana). However, these terraces are improperly designed and thus either washed away or proved to be inefficient in harvesting adequate water to be retained for sufficient time duration to sustain plant growth for successful cropping season.

The proposed intervention is to modify these terraces using simple contour alignment instrument (Water Tube-Level) and build them according to the standard design procedure and compactness to ensure uniform water distribution, moisture retention and durability of terrace structures. The terrace system will be built up of earth/stone bunds on its three sides to collect water from its fourth upslope open side with inner arms to provide control of water between the cultivated plots and draining ditch to discharge excess water out of cropped land at its lower end. The terraces are raised manually by hand or animal drawn implements. Each farmer household is expected to treat about 0.5 – 1.0 ha with either earth or stone terraces, depending on the availability/ suitability of building material and suitability and size of his holding. The participating farmers need training assistance to upgrade their technical skills on structure layout and building technique and improved agronomic practices, establishing water users associations, provision of improved drought tolerant seeds and hand tools for cultivation process.
Research conducted on sorghum in Sudan rain-fed (Omer, 1997) showed application of modified terrace technique resulted in significantly increased yield.

6.5.2 Tillage methods

Mechanical manipulation of soil provides protection against water erosion because it does prevent detachment of soil particles by leaving rough surface. However, soil management in combination with crop practices can most effectively control water erosion. Among soil management and cropping practices, tillage and crop residues have important bearing on water erosion. Tillage is primarily performed to prepare seedbed for seed germination and optimum crop stand, and to control weeds. However, faulty, improper and excessive tillage can lead to increased soil erosion. Typical example of this practice is the use of wide-level disc in the mechanized farming schemes in Sudan rain lands and Ethiopian clay plains year after year, which has developed shallow hard clay pan of restrict downward water movement and increased water loss through evaporation and runoff. Keeping these things in view, conservation tillage systems like deep tillage, reduced or no-tillage have proved to be successful with respect to soil water conservation.

6.5.2.1 No-tillage

It includes tillage practices which least disturb the soil surface and sowing is done without plowing in narrows strips or slots. This practice has been found to be very effective in controlling runoff and soil erosion than the conventional tillage. Reports form tropical areas such as Nigeria and Ghana have indicated that no-tillage practices effectively control erosion on sloping cultivated fields. The data of Free and Bay (1969) illustrates the benefits of no-tillage **(table 11)**. Moreover, it was found that no-tillage practices in sorghum conserved 20 % more moisture in the profile than that of conventional tillage. This is attributed to higher rainwater infiltration and structural conditions.

Surface residues are an essential component of no-tillage system; therefore, effectiveness of these practices greatly depends upon the amount of crop residues present at the surface. Crop residues dissipate energy of falling raindrops, reduce surface sealing and help to maintain higher infiltration rates and reduce runoff velocity. At the local level the no-tillage system has been adopted over the last few years as important soil conservation practices in Southern Blue Nile by the Arab Authority for Agricultural Development and Investment. In this trial crop is planted directly into the previous season plant stalks. Results obtained were very promising and emphasized that with good surface crop residues, no-tillage practices were very effective in controlling erosion, increasing soil moisture and improving crop yield. Sorghum average grain yield (2.38 t/ha) were claimed by this Authority. This is a much better improved yield compared to the current average yield normally obtained in these mechanized areas (0.714 t/ha). However, the machines employed in the no-till operations are very expensive and mostly beyond the farmers financial capability and technical knowledge.

Table (11): Runoff and soil loss as influenced by no-tillage practices

Tillage practice	Runoff (% of rain)	Soil loss (t/ha)
No-tillage	23	2.5
Conventional tillage	29	17.5

Source: Free and Bay Published paper

6.5.2.2 Deep tillage

It is specific tillage practice desirable in situation where an impeding layer such as clay pan is present within 30 – 40 cm depth, which reduces infiltration and profile storage and enhances runoff. Such layers not only increase runoff and soil loss but also restrict the root growth and adversely affect the crop yield. Deep tillage has been found to enhance profile water storage (Unger and Wiese, 1979). Effectiveness of deep tillage, however, increased several-fold in the presence of surface mulch. Under rain-fed conditions Verma et al. (1979) found that on sandy loam with 1 % slope, deep tillage with much increased infiltration and decreased runoff (**table 12**). Deep tillage without mulch reduced runoff from 123 mm to 112 mm, whereas when mulch was present the runoff was furthered reduced to 69 mm i.e. almost by half of that of shallow tillage with mulch. The practice of deep tillage is well suited for the intensively mechanized central deep clay plains soils. Deep tillage may be performed every other year, or every season depending on crop requirement and intensity of clay pan development.

Table (12): Effect of deep tillage and mulching on runoff and infiltration

Hydrologic parameter	No mulch		With mulch	
	Shallow tillage	Deep tillage	Shallow tillage	Deep tillage
Seasonal runoff (mm)	123	112	73	69
Infiltration	9.9	11.5	13.4	13.6

(mm/hr)				

Source: Verma (1979)

6.5.2.3 Reduced tillage (chiseling & Tie-ridges)

Alfisols and entisols of semi-arid and arid areas are structurally inert soils. They do not swell or shrink like clay soils and they have compacted and crusted surfaces, which are conducive to runoff. Under such soil condition some form of mechanical tillage is required. Minimum or reduced tillage that cause minimum soil disturbance or create vertical channels such as chisel plow are preferred here. Effectiveness of chisel plow, however, increased significantly in the presence of contour bunds. This is evident from the data of Omer (1997), where chisel with contour bunds has increased water storage and sorghum grain yield by 33 % and 3-folds over the flat traditional, respectively. Land ridging is also considered to be a form of minimum tillage. It holds promise for conserving soil and water in the dry land areas. Ridge cropping has evolved as an integral component of subsistence farming and is well adapted for small, low-input poor resources farmers. Tied-ridging or ridging with the addition of cross ties in the furrows is an improvement over the simple traditional ridge-furrow system. This system is designed to hold surplus runoff water and allow more water for infiltration into soil. Results of experimental work conducted by Agricultural Research Corporation (ARC) and other research institution in west (Burkina Faso) and East Africa (Tanzania) have shown substantial runoff conservation and crop yield increase under the tied-ridge system. The beneficial effects of tied-ridge system reported in Tanzania **(table 13)** show its appropriateness as promising technique (Rattan, 1987).

Table (13): Effect of tie-ridge system on maize grain yield in Tanzania (kg/ha)

Soil	Flat	Simple ridge	Tied-ridge
Vertisol (black cotton soil)	3085	3251 (105)*	3274 (106)
Alfisol (lateritic soil)	2628	3029 (115)	3433 (131)

Figures in parentheses refer to yield as a percentage of that obtained on flat bed.
Source: Rattan

The system of reduced tillage such as tied ridges is recommended for arid and semi-arid areas of the Nile Basin countries. Within the Sudan non-cracking sandy clay to clay loam soils in Butana, North of White and Blue Niles, Upper Atbara are typical suitable areas.

6.5.3 Contour bunds:

Contour earth or stone bunds are used to slow down runoff speed, thereby increasing infiltration and capturing sediment. The water and sediment harvested lead directly to improve crop productivity. The technique is simple and well suited to small scale application on farmer’s fields, given that stones are readily available in the field or the soil has the ability to form resilient bunds, can be implemented quickly and cheaply. Making bunds or just lines of stones is a traditional practice in parts of Africa, particularly Sahelian West Africa, notably in Burkina Faso. Field observation from these areas indicates that stone bunding technique has proved effective, popular and quickly mastered by villagers than the hillside terracing. Improved layout of structures to be aligned along the contour makes the technique considerably more effective. Unlike water spreading structures, the great advantage of systems built from stones is that need for spillways is limited or not required, where potentially damaging flows are concentrated. The stone bunds require much less maintenance compared to earth bunds provided that they are properly designed.

The contour bunds are technically suitable where annual rainfall is 200 – 750 mm; soils are moderately shallow to deep and slope preferably below 2 %. The spacing between bunds ranges normally between 15 – 30 m depending largely on the amount of stones and labour availability. Various areas within the Nile Basins in the central Sudan and the upper catchment in Ethiopian high lands are well suited for contour bunds techniques.

6.6 Controlling wind erosion

Wind erosion can be reduced or eliminated by controlling the factors causing or influencing erosion. Natural factors such as rainfall and wind speed are difficult to tame but they can be effectively influenced by certain management practices.

6.6.1 Tree planting

Tree planting is most important single technique known to effectively control wind erosion. In areas threatened or susceptible to wind erosion, rainfall is scarce and of very poor amount and there is prolonged dry season. Therefore, supplying irrigation water to overcome increasingly erratic rain water supplies is bound to reduce the vulnerability of trees to adverse rainfall conditions in desert, arid and semi-arid areas where wind erosion prevails. Depending on the climatic zone, the use of rainfall and irrigation for tree establishment deserve some attention.

6.6.1.1 Shelterbelt establishment (windbreaks)

Shelterbelt can be established by irrigation in areas close to the Nile River and its tributaries such as the White and Blue Niles, Atbara River and Main Nile using multipurpose tree species to protect the fields, irrigation canals and villages. The potential of establishing irrigated shelterbelt in the areas has been tried recently with good success. The Forestry Research Center (FRC) at Soba has established an efficient shelterbelt plantation using drip irrigation system for protecting Oil Pumping Stations in three sites including Lower Atbara and Khartoum areas for the Greater Nile Petroleum Operating Company (GNPOC).
Research study on wind erosion using sand traps in Khartoum State from University of Khartoum (UK) indicates intensity was remarkably reduced by shelterbelt more than on bare and cultivated soils (Adel, 2003).

In an attempt to control sand dune movement in this area, which is highly vulnerable to wind erosion, farmers, planted Prosopis species (Muskeet) trees. These trees become a problem and invaded large fertile lands **(Plate No. 7)**. Such trees are very tolerant, adapted to harsh conditions and efficient in erosion control, but suppressive to other species and difficult to eradicate. The potential for developing alternative protection system lies in the eradication of Prosopis trees and replace them by multipurpose trees such as Acacia Ampliceps, Conocarpus (Damas) and Ziziphus spina (Cidir). Some incentive such as small irrigation pumping sets could be provided to farmers for replacement purposes. A few farms in small irrigated plots (Mataras) were observed protected with patchy lines of trees. These lines could be enriched and improved by encouraging farmers to plant more suitable and adaptive tree species. In addition to these trials, during the field surveys crops stalks, palm fronds and tree branches were depicted being used traditionally on limited scale as control measures in parts of Lower Atbara and the Main Nile areas. They are generally ineffective techniques. Major effectiveness-related constraints to these initiatives are lack of technical know-how, unavailability of appropriate tree species, insufficient rainfall or irrigation water and the traditional believes geared to fear of birds nesting on trees rather than environmental protection. However; these activities are in separable to community awareness raising programs, participation and training.

Plate No. 7: Prosopis species (Muskeet) invasion and creeping on limited fertile agricultural land (Goz Alhalag, Lower Atbara).

6.6.1.2 Field boundaries and water courses tree planting

Some tree species for example acacias can be grown on the field boundaries and seasonal potential water courses or as shelterbelt to reduce the risks of soil erosion in rain-fed areas. As, it stands today, wades and khors present the key resources in this barren environment. On these regions, although drought is a common occurrence, still wades and khors are the main focus of human activities and settlements. The pressure on the wades and khors has, however, increased drastically in recent years as a result of drought and large scale degradation of the plains that previously provided good agricultural and grazing grounds. Future food security and the social stability of rural population off the

Nile and with meager resources in these zones seem to depend primarily on the efficient utilization of these resources. Thus, protection of these wades and khors resources by tree planting and other conservation practices could add to sustainability and enhancing of food production while maintaining ecological stability and preservation of natural resources. Simple and low-cost techniques of water harvesting and conservation should be given high priority for this purpose.

6.6.2 Management and conservation of natural forests

Forests management and their conservation are specifically important to maintain environmental stability and some economic benefits. This suggests that proper management of forest with involvement of community will not only provide them with fuel and fodder in sustainable manner but realized from various environmental advantages of erosion control. The work and experience of NFC showed that community-based organization participation in the management of their neighboring forests has been both environmentally and economical feasible. Planting of trees in cut and drainage areas in the irrigated agricultural schemes of ElRahad, Gezira, Suki, New Halfa and Blue and White Niles pump schemes has been promising technique to provide valuable trees products to the community, beside its complimentary effects of controlling both water and wind erosion **(Plate No. 8)**.

Plate No. 8: Cut and drainage area planted to trees lot

6.6.3 Replacement of open channel irrigation ditches by pipe conveyance system

This is indirect approach for avoiding the sand burying effect on open channel conveyance ditches. The use of closed conduit system such as (PVC) for water delivery and distribution in the susceptible fields to wind erosion will eliminate completely the burying of irrigation channels and the subsequent substantial seepage and evaporation water losses and the burden of frequent excavation of deposited sand materials. Moreover it improves the irrigation water conveyance efficiency and management in general.

7. Outcomes of the study

7.1 Soil erosion threats

1. Soil erosion in the NRB of the Sudan occurs in variety of ways influenced mainly by climate, soil, topography and human activities.
2. Land degradation by gully erosion is usually extend as a strip bordering the streams and seasonal water courses and also exits in over cultivated and grazed land.
3. Upper Atbara River reach in the Sudan and Ethiopia and some localized reaches along the Blue Nile represent the most intensively degraded land by gully erosion.
4. Land degradation by gully erosion and overland runoff erosion in Sudan and upper catchment deterioration in Ethiopia represents the main sediment sources in Atbara River and Blue Nile and its tributaries.
5. Dam storage loss due to sedimentation was estimated to be about 50 % and 38 % for Khashm ElGriba and Roseires, respectively and their live storage capacity has been depleted gradually.
6. River bank erosion is a natural complex phenomenon governed by inter-related factors of climate, hydrology, soils, O & M of hydraulic structures across the rivers and human irrational practices of land uses.
7. The passing of the Nile River and its tributaries through alluvial plains, great variation in flow discharges and human interference in the vicinity of the river by soil excavation for brick making and building and tree cutting are responsible for undermining the river equilibrium, which force the river to behave differently by redistributing the flow, producing meandering pattern most probably through bank erosion to regain balance.
8. Recent increased rates of bank erosion in the southern Blue Nile appears to have been influenced and accelerated by changing the cropping pattern that replaces big deep-rooted fruit trees by shallow rooted banana trees.
9. Areas experiencing serious river bank erosion threats are the Main Nile, Atbara River and Blue Nile. The White Nile banks are relatively stable with little or no erosion.
10. River bank erosion was manifested into loss of valuable fertile agricultural lands through river widening, irrigation water shortage through water recession by accumulation of sediment material and blockage of inlet channel and damaging of pumping sets and buildings.
11. There is an enormous increase in sediment deposition in the canalization network of irrigated schemes evidenced by huge annual sediment removal (15 million m^3).
12. Sedimentation load varies from year-to-year and generally correlates well rainfall amount.

13. A significant increase in sediment concentration entering the Gezira canalization system from 700 ppm in 1937/38 to 3800 ppm in 1988/89 is the sign of increased rate of erosion in the upper Blue Nile catchment.
14. Sediment deposition in storage reservoirs leads to lack of water for irrigation and hydro-electrical power generation, difficulties in O & M of irrigation hydraulic structures, enhancing weeds growth in canals and deterioration of water quality.
15. Resource degradation in AlDindir National Park (DNP) is attributed to drought and hydrological conditions coupled with human-induced factors of agriculture expansion, tree cutting, fire hazards and competion from domestic livestock.
16. Degradation of the Park's watershed was reflected on decreased natural water collection and storing structures capacity, poor grazing resources, disturbed habitats and decreased number of wildlife.
17. Runoff water erosion in dry land areas is caused by poor management practices in rain-fed and mechanized farming, intense short convective rain events and destructive survival and coping strategies by poor-resource inhabitants.
18. The undermining agro-ecological capacity and potential of dry land to support human welfare are ultimate result of land degradation envisaged in the runoff water erosion that have contributed to declined soil fertility and water retention and hence poor productivity of crops and livestock.
19. The climatic and man-induced factors influencing wind erosion are primarily experienced in the desert and arid zones in the northern region, Lower Atbara and White Nile and secondary in the semi-arid zone in the North Gezira and Khartoum areas.
20. Wind erosion is the most widely spread forms of land degradation in the Northern region of Sudan into Egypt, which seriously endangered limited agricultural lands, reducing soil fertility, its physical quality and yield potentialities, burying of irrigation canals, roads, vegetation cover and damaging plants.

7.2 Mitigation interventions

1. Rehabilitation of Kerib lands by indigenous technique initiated by FNC and community in UA area can be enhanced by improving methods of trees planting combined with construction of small check dam structures and management of forestry and benefiting livestock.
2. In areas where wide bottoms of gully floors are used of cultivation, planting trees alone is not enough to harness runoff water. Addition and arrangement of earth/stone check barriers across the bed, terracing and strip cropping in the side slopes and ridges can effectively reduce runoff intensity to produce both economic and conservation benefits.
3. The treatment of gully degraded land could be of transboundary nature due to extension of typical gullied-induced factors into Ethiopia.
4. Biological stabilization of river bank erosion using suitable tree species is more acceptable, simple and technically and economically feasible to adopted by farmers.
5. Because of limited information on river bank protection technology, appropriate technology could be generated through Research and Development (R & D)

trials with technical inputs and guidance from Irrigation and Forestry Research Institutions with participation of community.

6. Control of sediment load into rivers and irrigation canals system requires handling both at regional level (transboundary) to arrest and prevent sediment movement at is upper catchment source and at the local level through feasible management measures.
7. Mitigation measures at the transboundary level through appropriate watershed management (afforestation, control grazing, mulching, structural barriers, contour/strip plowing) seem more effective than just undertaking remedy and temporal actions at the local level.
8. Control of resources degradation at DNP requires small watersheds management activities that improve the hydrological elements input concerning increasing and conserving water supply and vegetation cover and reducing sediment and management and control of human activities in the vicinity of the park.
9. Because of extension of AlDindir National Park into Ethiopian borders with typical degradation elements and similar hydrological pattern, the upper catchment of DNP in Ethiopia high lands treatment is very attractive to transboundary mitigation program.
10. Water harvesting interventions is more appropriate to address runoff water erosion and availability and supply of water for agricultural use in dry land areas.
11. In areas seriously threatened by wind erosion, rainfall is commonly scarce. Therefore, supplying irrigation water is necessary to overcome increasingly erratic rainwater for establishment of irrigated shelterbelt.
12. Simple low cost technique of rainwater harvesting and conservation could be given priority for field boundaries and potential seasonal water courses tree planting to reduce the risk of wind erosion in barren areas where there is no other source of irrigation water.
13. Planting of cut and drainage areas in the national irrigated schemes or even natural depressions are promising interventions to provide valuable tree products to community, beside its complimentary effects of controlling both wind and water erosion.

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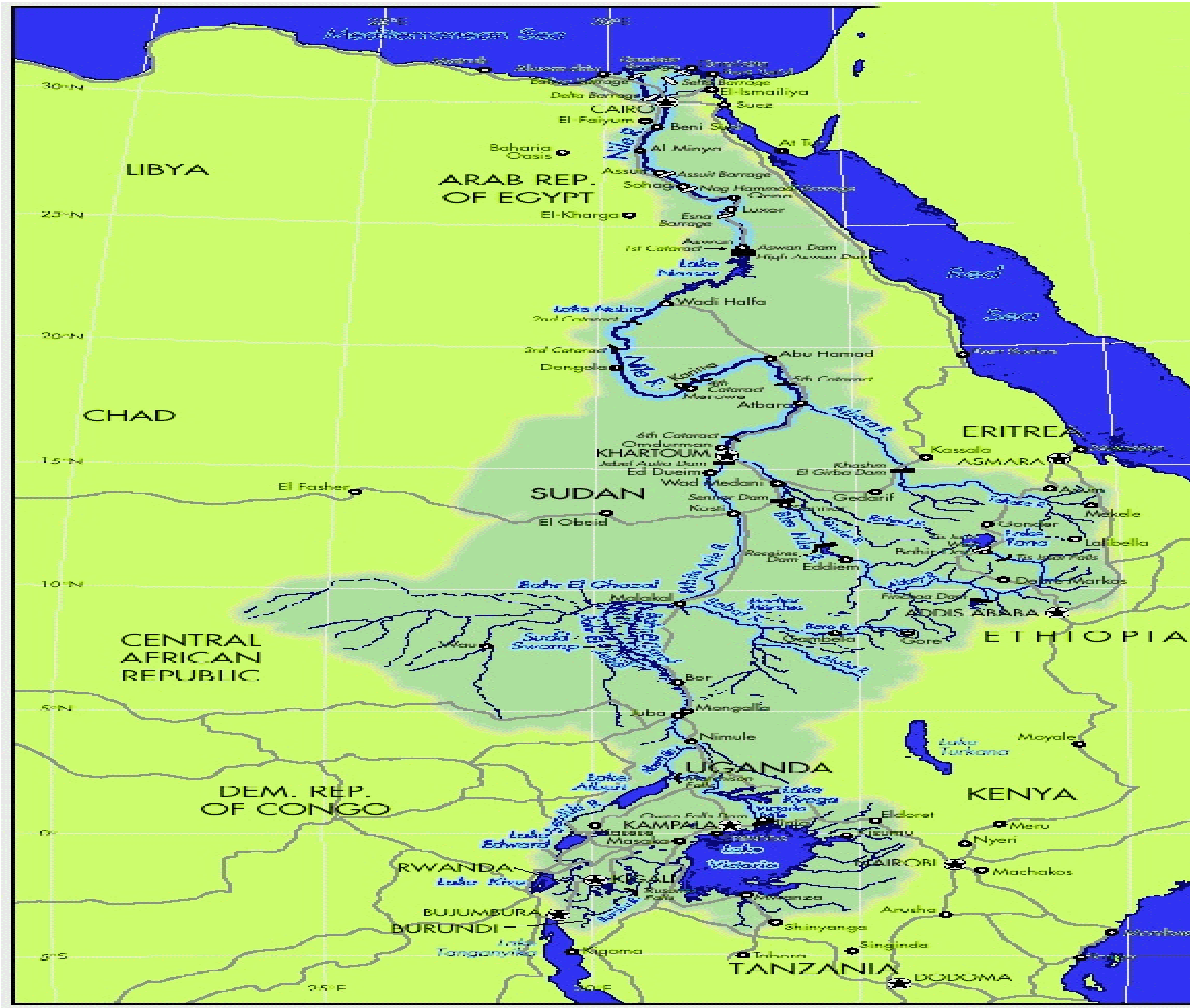

Annex 1: Nile River Basin covered areas during the survey

Annex 2: The main activities and the timetable for the survey activities

Date	State	Village/Town	Institution	Names	Position
28/3/2005	Nahr ElNeil	ElDamer	SECS	Ahmed alrasheed	Manager SECS, El Damer branch
	,,	,,	NFC	Yousif A.Abd alla	Director NFC
,,	,,	,,	Women Development Society	Mrs. Fawiza Gafaar	Member WDS
	,,	,,	,,	Miss. Somia Saeed Jillal	,,
,,	,,	,,	,,	Mrs. Mariam Awad Elsadig	,,
29/3	"	Atbara, Barber	CBOs	Community in 13 villages	Farmers
"	"	ElDamer	MAAWI	Eng. Azhari Khalfaala	H.E Minister of MAAWI
"	"	"	Locality	Eng. Ali Simsaa	Commissioner
"	"	"	Irrigation Department	Eng. Saleh AlMamoun	Director
"	"	"	National Forest Corporation (NFC)	Staff	Employee
"	"	"	Hudeiba Research Station (HRS)	Dr. Mubark Sir AlKhatim	Former ADS Director and HRS Director
4/42005	Algezira	Madani	ARC	Prof. Azhari Abdalazeeim	Director General
5/4	"	"	Hydraulic Research Station (HRS)	Prof. Ahmed Salih	Director HRS
5/4	Gadref	Gadref	Gadref Research Station	Prof. Mohamed Hassan Alesier	Director
"	"	"	"	Hassan Algazoli	Forester
"	"	"	"	Khalfaala A. Ali	Crops
"	"	"	"	AlNeir Ahmed	Insects
"	"	"	"	Ahmed Algada	Soil
6/4	"	AlShowak	NFC	Haishim Hassan	Forester
"	"	"	"	Mahmoud Abass	Director
"	"	"	"	Fadul Musa	Forester
"	"	"	Green Peace Association	Amer Abass	Chairman
7/4	"	"	Farmers Union	Mohamed A. Abdalla	Chairman
"	"	"	CBOs	Community in 10	Farmers/local leaders

				villages	
8/4	Blue Nile State	Eldamazeen	Sudanese Environment Protection Association	Elbagir Suleiman	Director
:	:	:	Research Scientist	Anas M.Awad	Director
:	:	:	Range and forage	Ahmad M.awad	Director
:	:	:	Forestry	Yousif Suliman	Director
:	:	:	Forestry research	Monaim Hassan	Technician
:	:	:	Agriculture-research	.D/Farog elhadi	Researcher
:	:	:	Agriculture-research	Osama Mohmed	Researcher
:	:	:	Ministry of Agric.	Omer abdelkareem	Director of MAAWI
:	:	:	Forestry	M.Ahmad	Technician
9/4/2005	Blue Nile State	Eldamazeen	Horticulture	Abdela A.elgani	Director
"	"	Roseiris	CBOs	Community in 5 villages	Farmers/local leaders
10/4/2005	:	:	Forestry	Musa Suleiman	Director
:	:	:	:	Fatih elrhman	Senior
:	:	:	:	Mohamed elbasher	Senior
:	:	:	:	Abdelgani Moha	Senior
"	"	Eldamazeen	CBOs	Community in 3 villages	Farmers/local leaders
	:	:	Ministry of Agric.	Rehap Ahmad	Women development
"	"	"	Nile Friend Organization	Hadia Abdalla	Administrative Officer
"	"	"	"	Andarowous	Member

Date	State	Village/Town	Institution	Names	Position
10/4/2005	Blue Nile State	Eldamazeen	MAAWI	Ehssan elmaki	Women development
:	:	:	:	Eatidal Hassan	Eng.
11/4/2005	Sennar State	Aldinder	Forestry office	Anass Awad	Director of forestry
11/4/2005	:	:	N G O	Mohamed Ali	Director
:	:	:	Forestry office	Sohair mansor	Senior Forester
"	"	AlSuki	Agric. & Forestry	Staff	Employee
12/4	Algezira	Wad Madani	ARC, Land & Water Department	Prof. Mustafa M. Idris	Director
"	"	"	"	Prof. Osman A. Altoum	Soil Scientist
"	"	"	"	Dr. Abd Alla Alhagoa	Soil Scientist
"	"	"	"	Prof. Hassan Fadul	Desertification & Remote Sensing Scientist
"	"	"	"	Prof. Saed M. Farah	Irrigation Scientist
14/4/2005	White Nile State	Eldeweim	MAAWI	Abdelazez Seid	Director of forestry
:	:	:	:	Awad elkareem	Horticulture
:	:	:	:	Abdelkareem	Extension officer
:	:	:	:	Eng. Balla Ahmed	Irrigation Eng.
"	"	"	CBOs	Community in 4 villages	Farmers/local leaders