NILE RIVER BANK EROSION AND PROTECTION

2010

Nile Basin Capacity Building Network

NBCBN-RE

NILE RIVER BANK
EROSION AND PROTECTION

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Project Title

Knowledge Networks for the Nile Basin

"Using the innovative potential of Knowledge Networks and CoP"s in strengthening human and institutional research capacity in the Nile region"

Implementing Leading Institute

UNESCO-IHE Institute for Water Education, Delft, The Netherlands (UNESCO-IHE)

Partner Institutes

Nine selected Universities and Institutions from Nile Basin Countries.

Project Secretariat Office

NBCBN-SEC office, Hydraulics Research Institute – Cairo - Egypt

Beneficiaries

Water Sector Professionals and Institutions in the Nile Basin Countries

Short Description

The idea of establishing a Knowledge Network in the Nile region emerged after encouraging experiences with the first Regional Training Centre on River Engineering in Cairo since 1996. In January 2002 more than 50 representatives from all ten Nile basin countries signed the Cairo Declaration at the end of a kick-off workshop was held in Cairo. This declaration in which the main principles of the network were laid down marked the official start of the Nile Basin Capacity Building Network in River Engineering (NBCBN-RE) as an open network of national and regional capacity building institutions and professional sector organizations.

NBCBN is represented in the Nile basin countries through its nine nodes existing in Egypt, Sudan, Ethiopia, Tanzania, Uganda, Kenya, Rwanda, Burundi and D. R. Congo. The network includes six research clusters working on different research themes namely: Hydropower, Environmental Aspects, GIS and Modelling, River Morphology, flood Management, and River structures.

The remarkable contribution and impact of the network on both local and regional levels in the basin countries created the opportunity for the network to continue its mission for a second phase. The second phase was launched in Cairo in 2007 under the initiative of; Knowledge Networks for the Nile Basin. New capacity building activities including knowledge sharing and dissemination tools, specialised training courses and new collaborative research activities were initiated. The   different new research modalities adopted by the network in its second phase include; (i) regional cluster research, (ii) integrated research, (iii) local action research and (iv) Multidisciplinary research.

By involving professionals, knowledge institutes and sector organisations from all Nile Basin countries, the network succeeded to create a solid passage from potential conflict to co-operation potential and confidence building between riparian states. More than 500 water professionals representing different disciplines of the water sector and coming from various governmental and private sector institutions selected to join NBCBN to enhance and build their capacities in order to be linked to the available career opportunities. In the last ten years the network succeeded to have both regional and international recognition, and to be the most successful and sustainable capacity building provider in the Nile Basin.

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FOREWORD

This report is one of the final outputs of the research activities under the second phase of the Nile Basin Capacity Building Network (NBCBN). The network was established with a main objective to build and strengthen the capacities of the Nile basin water professionals in the field of River Engineering. The first phase was officially launched in 2002. After this launch the network has become one of the most active groupings in generating and disseminating water related knowledge within the Nile region. At the moment it involves more than 500 water professionals who have teamed up in nine national networks (In-country network nodes) under the theme of "Knowledge Networks for the Nile Basin". The main platform for capacity building adopted by NBCBN is "Collaborative Research" on both regional and local levels. The main aim of collaborative research is to strengthen the individual research capabilities of water professionals through collaboration at cluster/group level on a well-defined specialized research theme within the field of River and Hydraulic Engineering.

This research project was developed under the "Cluster Research Modality". This research modality is activated through implementation of research proposals and topics under the NBCBN research clusters: Hydropower Development, Environmental Aspects of River Engineering, GIS and Modelling Applications in River Engineering, River Morphology, flood Management, and River structures.

This report is considered a joint achievement through collaboration and sincere commitment of all the research teams involved with participation of water professionals from all the Nile Basin countries, the Research Coordinators and the Scientific Advisors. Consequently the NBCBN Network Secretariat and Management Team would like to thank all members who contributed to the implementation of these research projects and the development of these valuable outputs.

Special thanks are due to UNESCO-IHE Project Team and NBCBN-Secretariat office staff for their contribution and effort done in the follow up and development of the different research projects activities.

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EXECUTIVE SUMMARY

Along the Nile River and its tributaries, bank and gully erosion represent an important phenomenon. The impact of this problem is widely spread within the Nile basin countries causing a great set back for their socio-economic development. The Nile Basin Capacity Building Network for River Engineering (NBCBN-RE) was initiated in year 2000, with the objective to create an environment where professionals from the River Nile Basin Countries can exchange their ideas, practices and learn from each other. This report is prepared by Group 2 of the River Morphology Cluster and present the progress made by the team and the way forward to finalize the objective of phase II of the project. The names of the group members are written at the end of chapter one. The report is organized in seven chapters. The achievements of phase II of the project and research problems are identified in Chapter one. The literature review is provided in Chapter two. Chapter three presents the methodology adopted in the preparation of this report including the schedule followed from start to end.

Five case studies from different countries within the Nile Basin were compiled and presented. Among the five cases, four studies are dealing with the Nile Erosion mitigation plans in the respective countries of Ethiopia, Kenya Rwanda and Sudan. The four countries potential erosion was assessed at a basin scale. They were addressed in chapter four.

Chapter five discusses the work done at a reach scale. It includes Singa case study, HEC-RAS and Khartoum Bank Protection case study. The Use of modern technology and advanced modeling techniques in evaluating and assessing morphological changes and erosion problems on the Nile river were addressed in two case studies in the Sudan. Singa case study reach of the Blue Nile Rivers which lies between the two dams of Sinnar and Roseries. The study results showed that the sediment deficit water released from the Roseires Dam caused river bed degradation. The degradation of channel bed coupled with the cohesive nature of the bank material and its steepness caused loss of stability of the channel bank associated with bank erosion. Changes in bed elevation as a results of channel aggradations or degradation were determined on an annual basis. The use of Remote Sensing technology in monitoring the impacts of Bank and Gully Erosion in Sudan is highlighted. .

Chapter six includes the assessment of river bank erosion at a section scale. It shows a study carried out in Egypt, a rapid assessment of bridge site river section stability in Northern Sudan, and a bridge pier scour study in Sudan. The case study from Egypt addresses the problem of bank erosion in a pilot area at Salaam Village, downstream of High Aswan dam. The study aimed to investigate causes of bank failure using hydrodynamic modeling approach. The rapid assessment of bridge site river section stability in Northern Sudan covered the geomorphic assessment and stability analysis for a bridge site across the main River Nile at Aldaba (North Sudan). The results identified the geomorphic factors that can affect channel stability near the bridge. In the bridge pier scour study, theoretical and practical procedures were adopted clarifying the problems of local scour, its estimate and related empirical equations

Chapter seven reveals the lessons learned from the reported studies and the practical experience gained though discussions and field visits as well as meetings. It also gives the recommendations and conclusions of the study.

Despite the fact that some case studies are dealing with broad objectives on soil erosion and do not focus on the specific targeted objectives, all studies contributed to the understanding of the phenomena involved and showed possible different approaches. This report tries to accommodate and compile all the available contributions from researchers on the field of river morphology and erosion mitigation measures, in a single document. It is anticipated that, the compiled information provided in this report would be helpful in the development of a guideline or a manual dealing with bank erosion in the River Nile Basin. Most of the techniques for erosion protection, and river bed and bank restoration measures were extensively addressed as part of the cases presented in this report.

1

INTRODUCTION

1.1.   Background Information

The Nile Basin Capacity Building Network for River Engineering (NBCBN-RE) was initiated in year 2000, with the objective to create an environment where the professionals from the water sector sharing the River Nile can exchange their ideas and practices as well as learn from each other. The goal was that of reaching a common vision to manage the use of the water resources of the basin efficiently and in a sustainable manner. Within this framework the second phase (2007 – 2009) is now in its final stage and this report represents the results achieved by Group 2 of the River Morphology Cluster.

In the first phase, Group 2 completed a report entitled "Towards the improvement of the protection methods against bank erosion".   The original plan for the second phase has been based on the outputs and recommendations of the first phase, as well as on the output of the workshop held in Cairo on 22-23 May 2005. Some adaptations to the original plan have been agreed during the work with the Scientific Advisor. The main change is that the work that originally focused on "river bank erosion" has been extended to the more general "erosion problem", to take into account also the interests of the countries of the upper Nile basin, where soil erosion, gully excavation etc. are major problems. In this way all erosion factors responsible for excessive sedimentation are taken into account. Considering the global problem of erosion and sediment input in the river system, Group 2 complied with the work of Group 1, dealing with the sedimentation problem.

The Nile flows 6,600 kilometers, drains an area of 3.1 million square kilometers, and covers one-tenth of the African continent. The Nile basin is home to about 160 million people and includes parts of ten countries, viz. Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda as shown in Figure 1.1. The Nile‚s most distant source is the Kagera River, which flows from Burundi through Rwanda and Tanzania into Lake Victoria NBI- SVP, 2001). Famine, extreme poverty, instability, rapid population growth, and deteriorating natural resources are characteristic features of the Basin today. It is shared by ten riparian countries, half of which are among the 10 poorest in the world. The Transboundary character of the Nile Basin poses a great challenge impeding efforts towards achieving truly sustainable management. The challenge is intensified by the Basin‚s increasing populations, urbanization, and industrialization. To face these challenges, the Basin states require the will and courage in participating as partners for collaborative and visible actions as well as the emergence of a regional perspective on management and development of the River.

Cooperative management of the Nile River basin requires focusing on transboundary issues, which provide the riparian countries with opportunities to make significant progress towards their economic and environmental goals in ways that have proved difficult to achieve independently. These include, among others, the environment development synergies, and the sustainable development opportunities in the basin.

Nile Transboundary Environmental Action Program (TEAP) encourages effective basin wide stakeholder cooperation on transboundary environmental issues by supporting the implementation of the actions prioritized by the TEAP.

Figure 1-1: The Nile Basin (Source: NTEAP/Ethiopia)

Environmental Action document. Within these areas/components of the prioritized actions are Community-Level Land, Forests and Water Conservation, supporting pilot activities in geographic and thematic areas of Transboundary significance. It will demonstrate the feasibility of local level approaches to land and water conservation, including mitigation action for erosion and other activities. Priority Action for addressing soil erosion, which will support carrying out rapid assessment studies in regions where soil erosion have been identified as high priority during project preparations.

NTEAP involves priority actions for addressing soil erosion through providing supports to carry out rapid assessment studies in regions where soil erosion have been identified as high priority during project preparations. This specific study is intended to address activities in the sub-component that relates to rapid soil erosion studies within the Nile Basin parts of Ethiopia. There are many causes for the depletion of soil fertility including erosion due to wind and water. The impact of soil erosion includes decreased food production leading to a decline in food security and increased poverty. In connection with this, the Transboundary Environmental Analysis (TEA) Document, jointly prepared by NBI, GEF, UNDP and the WB, has highlighted soil erosion as one of the primary environmental threats to the country and reflects on the main causes and the impacts thereof. This threat has been recognized to have severe consequences not only at the national level but also at Transboundary level.

1.2. Statement of the Problem

Along the Nile River and its tributaries, erosion represents a serious problem. The impact of this problem is widely spread within the Nile basin countries causing a great set back for their socio-economic development. Soil erosion mainly occurs in the upper catchments, whereas bank erosion, which can be extended to gully formation and excavation, occurs along the upper river network.

Erosion is a natural phenomenon governed by many factors, including climate, hydrology, soil characteristics and human practices. River bank erosion, in particular, is affected by the excavation of soil for brick making, and building materials, cutting of trees, cropping pattern management and dumping of solid materials, mostly close to urban centers. Valuable irrigable lands are lost because of riverbank erosion along the Blue Nile and the main Nile River. The total irrigable land loss in Sudan was estimated to range from 13 to 52 % (unpublished data from the Forest National Corporation, FNC). The major factor currently affecting the magnitude of riverbank erosion in the Blue Nile area has been identified in the change of the cropping pattern. The large flows cause floods, bank overflow and surface drainage difficulties during the rainy season, which cause bank erosion. The rapid drawdown of the Nile as a result of dam operation or seasonal drought and sand encroachment enhance bank failure. Thus, changes in the river hydrodynamics can significantly influence the changes that may take place within the Nile course. Soil erosion occurring in the upper catchment is mainly caused by deforestation practices. The results are local losses of arable land, deep gully formation and a large increase of sediment input to the river system, leading to sedimentation problems more downstream

1.3. Purpose and Achievements

During phase 1 of the study, bank erosion problems were identified along the main River Nile in the reach downstream Aswan High Dam and between Khartoum and the Third Cataract. During Phase 2, the importance of the erosion problem occurring in the upper catchment and having a major influence on the river morphodynamics more downstream was recognized.

The major purpose of the NBCBN project is capacity building. The project offered the opportunity of exchanging ideas, evaluating different approaches and methodologies to researchers and professionals from the different countries in the River Nile basin.

Research projects on water erosion were carried out in different countries with the aim of increasing the knowledge on the entity and characteristics of the erosive phenomena along the Nile River system and evaluating the consequences. The results of Phase 2 of the project dealing with the river morphology were presented and discussed during the Workshop held In Khartoum in April 4-7 2009. The workshop included both the "erosion" and "sedimentation" groups (Goups 1 and 2 together), so in this special occasion the entire community of scientist involved in the Morphology Cluster of the project could benefit from the work carried out, fully evaluate the consequences of some human practices on local erosion and sedimentation elsewhere. Given the large number of works dealing with soil erosion in the upper catchment, it has been decided to include all the results of these works in this report so that the erosion problem could be fully represented. The works have been classified by their spatial scale.

1.4. Nile River System Description

The Nile River is the longest rivers in the world. It has two major tributaries, the White Nile and Blue Nile, meeting at the Sudanese capital Khartoum. The Blue Nile is the source of most of the Nile's water and sediment. It starts at Lake Tana in Ethiopia, flowing into Sudan from the southeast. In Ethiopia the river, especially the upper reaches, is called the Abay. The Abay portion of the Blue Nile rises at Lake Tana and flows for about thirty kilometers before forming the Tis Issat Falls. The river then loops through the Ethiopian Plateau in a deep canyon into Sudan. The flow of the Blue Nile reaches its maximum volume in the rainy season (from June to September), when it supplies about two thirds of the water of the Nile. The White Nile is the longer Nile River tributary. It originates in the Great Lakes region of central Africa, with the most distant source in southern Rwanda, and flows north from there through Tanzania, Lake Victoria, Uganda and southern Sudan.

Downstream of Khartoum, the Nile River flows almost entirely through desert into the artificial Lake Nasser in Egypt. The Nile ends in a large delta that empties into the Mediterranean Sea.

The Atbara River rises in northwest Ethiopia, approximately 50 km north of Lake Tana and 30 km west of Gondar. It is about 800 km long and joins the Nile in north-central Sudan, at the city of Atbara. The Atbara River is the last tributary of the Nile before it reaches the Mediterranean. For most of the year, it is little more

than a stream, but during the rainy season (generally June to October), the Atbara River rises about 5 m above its normal level. Important tributaries of the Atbara River include the Tekezé River, the Shinfa River which rises west of Lake Tana, and the Greater Angereb which has its source north of the city of Gondar.

The Nile Basin is divided into four topographic divisions. These are: the main Nile from Khartoum to the Mediterranean sea, the River Atbara, the Blue Nile and its tributaries and the White Nile, including the rivers Sobat, Bahr el Jebel, Bahr el Ghazal and Lake Plateau.

The basin of the Nile includes the Equatorial Lakes Plateau of East Africa, the Al-Jabal (El-Jebel), the White Nile, the Blue Nile, the Atbara, the Nile north of Khartoum in Sudan and Egypt, and the Nile delta (Figure 1.2).

 Information and characteristics of the Equatorial Lakes Plateau are listed in the following tables: the Victoria Lake in Table 1.1; the Kioga Lake in Table 1.2; the George Lake Table 1.3; the Edward Lake in Table 1.4; Albert Lake in Table 1.5. The general characteristics of the Bahr El Ghazal Basin are given in Table1.6. The important rivers flowing from the Ethiopian Plateau are the Sobat (Table1.7); the Machar Marshes (Table1.8), the Blue Nile and Atbara Rivers.

Table 1-1: Characteristics of Victoria Lake

Item	Description	Information		
1.	Basin Area	$262000 - Km^2$		
2.	Surface Area of the Lake	$67000 - Km^2$		
3.	Maximum length of the Lake	$315 - Km$		
4.	Minimum width of the Lake	$275 - Km$		
5.	Average depth of the Lake	$40 - m$		
6.	Maximum depth of the Lake	$70 - m$		
7.	Basin rainfall intensity / year	$1190 - m$		
8.	Lake rainfall intensity / year	$1150 - m$		
9.	Lake Surface evaporation intensity / year	$1120 - m$		
10.	Basin Inflow to Lake (with 8% rate/year)	$18 \times 10^9 m^3$		
11.	Lake Direct rainfall/ year	$77 \times 10^9 m^3$		
12.	Lake total inflow / year	$95 \times 10^9 m^3$		
13.	Lake evaporation losses / year	$75 \times 10^9 - m^3$		
14.	Lake Net yield / year	$20 \times 10^9 - m^3$		
15.	Lake average natural discharge at Ripon falls	$20.4 \times 10^9 - m^3$		
16.	Lake Maximum 10 days mean discharge/day	$92.7 \times 10^6 - m^3$		
17.	Lake Minimum 10 days mean discharge/day	$28.0 \times 10^6 - m^3$		
	Gauge	**Entebbe**	**jinja**	**kisumu**
18.	Zero	$1122.17 - m$	$1121.65 - m$	$1121.54 - m$
19.	10 days average maximum	$1133.60 - m$	$1133.60 - m$	$1133.73 - m$
20.	Date of maximum	June	June	June
21.	10 days average minimum	$1131.94 - m$	$1131.87 - m$	$1131.97 - m$
22.	Date of minimum	Feb	Feb	Jan

Table 1-2: Characteristics of Kioga Lake.

Item	Description		Information
1.	Basin Area		$75000 - Km^2$
2.	Surface Area of the Lake and Swamps		$6270 - Km^2$
3.	Basin rainfall intensity / year		$1.3 - m$
4.	Lake Surface evaporation intensity / year		$1.2 - m$
5.	Swamps evaporation intensity / year		$2.0 - m$
6.	Inflow to Lake rate/year		$19.9 \times 10^9 m^3$
7.	Lake Out flow (Kandini)		$19 \times 10^9 m^3$
8.	Lake outflow into Lake Albet/ year		$19.5 \times 10^9 m^3$
	Gauge	**Masindi**	
9.	Zero	$1017.18 - m$	
10.	10 days average maximum	$1030.63 - m$	
11.	Date of maximum	Nov	
12.	10 days average minimum	$1026.82 - m$	
13.	Date of minimum	March	

Table 1-3: Characteristics of George Lake

Item	Description	Information
1.	Basin Area	$800 - Km^2$
2.	Surface Area of the Lake	$300 - Km^2$
3.	Basin rainfall intensity / year	$1.365 - m$
4.	Lake Surface evaporation intensity / year	$1.200 - m$
5.	Average water level of Lake	$912 - m$

Table 1-4: Characteristics of Edward Lake

Item	Description	Information
1.	Basin Area	$1200 - Km^2$
2.	Surface Area of the Lake	$2200 - Km^2$
3.	Basin rainfall intensity / year	$1.365 - m$
4.	Lake Surface evaporation intensity / year	$1.200 - m$
5.	Average water level of Lake	$912 - m$

Table 1-5: Characteristics of Albert Lake

Item	Description	Information
1.	Basin Area	$17000 - Km^2$
2.	Surface Area of the Lake	$5300 - Km^2$
3.	Basin rainfall intensity / year	$1.260 - m$
4.	Lake rainfall intensity / year	$0.810 - m$
5.	Lake Surface evaporation intensity / year	$1200 - m$
6.	Inflow to Lake (Fajau)	$19.5 \times 10^9 \, m^3$
7.	Inflow Semilki to Bweramoli / year	$3.8 \times 10^9 \, m^3$
8.	Lake average natural discharge at Exit	$22.7 \times 10^9 - m^3$

Table 1-6: Characteristics of Bahr El Ghazal Basin

Item	Description	Information
1.	Basin Area	$526000 - Km^2$
2.	Area of Swamps	$40000 - Km^2$
3.	Basin rainfall intensity / year	$1.300 - m$
4.	Basin rainfall intensity / year	$0.810 - m$
5.	Basin Surface evaporation intensity / year	$2.00 - m$

Table 1-7: Characteristics of Sobat Basin

Item	Description	Information
1.	Basin Area	$187200 - Km^2$
2.	Basin rainfall intensity / year	$0.900 - m$
3.	Basin Surface evaporation intensity / year	$1.420 - m$

Table 1-8: Characteristics of Machar Marshes

Item	Description	Information
1.	Basin Area	$10300 - Km^2$
2.	Basin rainfall intensity / year	$0.800 - m$

The Blue Nile tributaries are fed from the northern part of the Ethiopian hills. The rains falling on the basin, and Lake Tana, are flowing towards Roseires, at Sudan boarder. Between Lake Tana and Roseires ,there is a large drop in the water level, followed by a smaller drop between the Sudan boarder and Khartoum. The Dinder River and Rahad River flow into the Blue Nile on its right side are also originated from Ethiopian Hills.

The Blue Nile flows into Main Nile at Khartoum. From Sennar dam, the Gezira Scheme is irrigated. The Atbara River is fed by Bahr El Saloum and Steit. Steit is the main tributary of Atbara River. The gauge discharge records started in the Nile Basin since the nineteenth century. Table 1.9 shows the gauging stations established in the Nile Basin and its tributaries.

Table 1-9: Gauging stations established in the Nile Basin

River	Date Of Establishment	No. of Stations
Main Nile	From 1869 to 1957	32
Atbara	From 1906 to 1937	3
Blue Nile	From 1903 to 1952	13
Rahad	From 1908 to 1922	2
Dinder	From 1907 to 1922	2
White Nile	From 1906 to 1938	24
Sobat	From 1903 to 1929	6
Baro	From 1905 to 1947	8
Pibor	From 1918 to 1931	5
Bahr El Gebel	From 1906 to 1950	28
Bahr El Zeraf	From 1906 to 1922	9
Bahr El Gazal	From 1911 to 1927	4
Bahr El Arab	From 1932 to 1959	13
Others	From 1904 to 1953	13
Total	From 1869 to 1959	162

Figure 1- 2:Nile Basin Layout from the South to its out fall

2

LITERATURE REVIEW

2.1. Previous Work on Water Erosion and Protection

Recorded Previous works in relation to the Nile River generally could be observed in two reaches based on the scale of bank erosion. The first reach is the part of the Main Nile downstream the High Aswan Dam (HAD) while the second reach is that part between Khartoum and third cataract. After the construction of HAD the downstream river reaches responded in a different manner. The river velocity influences Nile Bank Erosion in Egypt. As the river changes its flow pattern, the location and the riverbank erosion extent also change. **Figure 2**.1, shows typical bank erosion at Luxor.

Figure 2- 1: Typical Bank Erosion at Luxor

2.2 Typical Bank Erosion at Luxor

The Nile in Sudan is known to be well confined to its valley. The average suspended sediment concentration is in the range of 12 to 15kg/m^3. At the beginning of the flood this value reaches 25 kg/m^3 as reported for River Atbara.

With respect to bank erosion, the Nile reach in Sudan can be divided into four reaches. The first one is between Khartoum and the fifth cataract. Second reach is from the fifth to the fourth cataract. Third reach is between the third cataract and fourth cataract. The last reach is from the fourth cataract to HAD Lake. The first and the third cataracts are reported to have noticeable bank erosion. The large and rapid drop of the water level and the high velocities are the main reasons for bank erosion of the Nile in Sudan. Figure 2.2 shows typical severe erosion in the third reach.

Figure 2- 2: Very Severe Bank Erosion Dongla – Merowi Third Reach

GIS, satellites images, old and recent aerial photographs and survey maps are important for determining erosion rate of banks and lateral shifts of natural channels. In general the NRI in Egypt and HRS in Sudan believe that the erosion rate of the Nile banks and lateral channel shift rates are very low and usually unnoticeable. Table 2.1 gives the bank erosion rates for some river basins.

Table 2- 1: Rates of Lateral Bank Erosion (NRI –Egypt)

River	Period	Shift Rate m/year	Source
Ramganga (India)	1795- 1805 1806 – 1833 1833 - 1845	80.5 4.3 4.0	Gola and Chitale (1966)
Kosi (India)	1736 - 1950	540	Gola and Chitale (1966)
Jamuna (Bangladesh)	1974	1300	Galay (1980)
Larami (USA)	1851-1954	0.3	Ackers and Charlton (1970)
Missouri (USA)	1833 - 1903	76	Ackers and Charlton (1970)

2.3. Causes of Bank Erosion

An alluvial river is a dynamic system, which is subjected to continuous change throughout its flow course. Often, bank erosion occurs in conjunction with bed degradation, local scour, undermining and nick point migration. The main factors and forces that cause bank erosion are:

❖ **Shear Stress**,. The induced flow shear stress contributes significantly to instability of river banks. For non-cohesive soil the flow shear drags the soil particles by rolling and sliding causing direct erosion of the soil mass. The induced flow shear is a function of the near-bank flow velocity.

❖ **Quick variation of water level**. In general, stage variation of natural river flows results in large water drops in short period of time which causes significant bank erosion. At high stage these waves erode the top part of the bank giving staggered geometry of the bank slope.

❖ **Seepage**. Seepage flow through the bank soil usually happens as a result of increasing pore water pressure within the soil. Drainage water causes under caving of the banks as shown in Figure 2.3.

❖ **Structures**. Downstream of flow deflectors such as groins, bank erosion takes places unless special treatment is added. As the flow detached away from the deflector large eddies generated downstream cause bank erosion.

❖ **Bank heightening**. Bed lowering due to local scour or bed degradation results in increasing the bank height hence reducing the stability of the bank slope (reduced factor of safety).

❖ **Ship waves**. Ship waves erode banks at the water level as illustrated in Figure 2.3.

❖ **Steep bank slope.** Bank steepness reduces the stability of the banks. This is usually observed at the bank of outer bends where the induced flow shear acts over the entire bank slope giving steep slope, with reduced factor of safety, as shown in Figure 2.4,
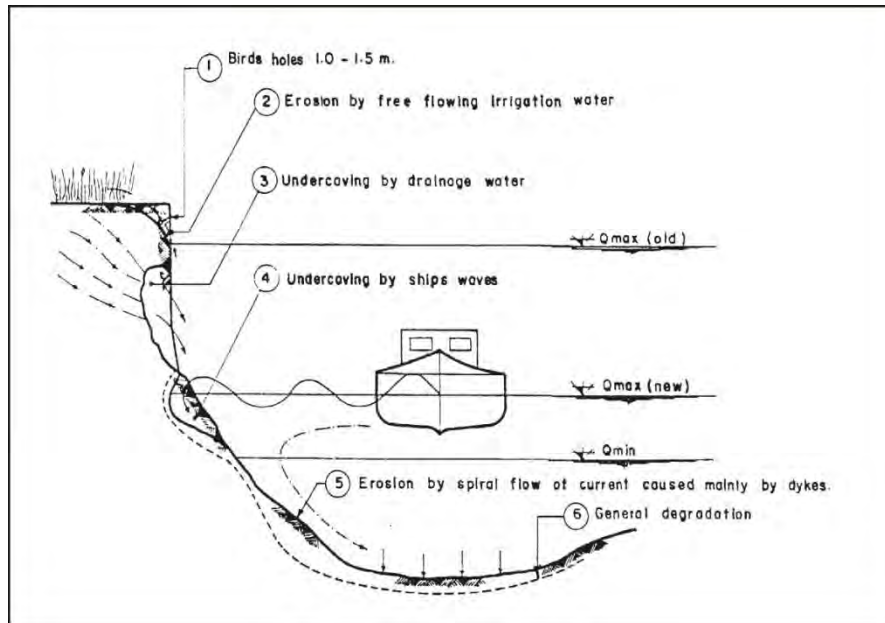
Figure 2-3: Drainage Water Caused Under Caving During HAD Construction

2.4. Bank Stability

The basic relation used in analyzing the stability of slopes, is the factor of safety defined by the formula:

$$SF = \frac{F_R}{F_D} - - - (2.1)$$
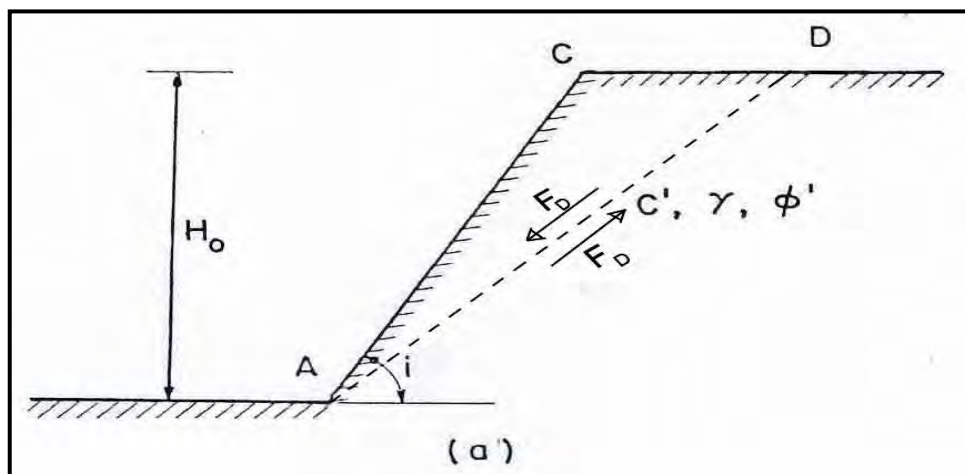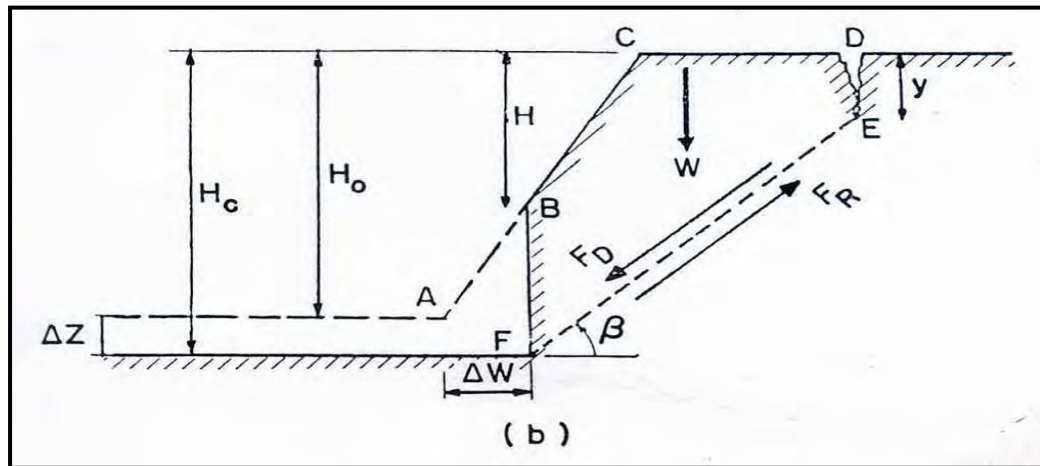
Figure 2- -4 a): River right bank at failure b) Parallel bank retreat

Where

F_D = The driving force due the weight component of the
    Sliding block.

F_R = The resisting force due to cohesion C

Φ = Angle of internal friction.

As given in Figure 2.2a,,for intensive deep tension cracks the bank geometry of Figure 2.2b should be used in the analysis which is known as parallel bank retreat. Mass wasting, sloughing and head cutting on vegetated or barren banks are some of the mechanisms of bank failure. Bank erosion process is either mass failure of the bank (block failure) or direct erosion of the bank material. Cohesive soil shrinkage is sole factor responsible for tension cracks development. This process is more pronounced at the outer bank in river bends.

2.5. Erosion Rates

Satellite images, air photos, GIS and topographic maps are essential for evaluating the erosion rate for selected river reaches. Arulanandan et al.(1980) proposed an estimate of critical shear stress τ_c at which erosion of cohesive soil starts as a function of \ Sodium Adsorption Ratio (SAR), which gives a relation of the rate of change of erosion. Osman; 1985 modified the relation to give the lateral erosion rate R for cohesive bank by the formula:

$$R = 0.0223\tau_c \; e^{-0.13\,\tau_c} \; ---(2.2)$$

It is proposed for each river reach to develop its own erosion rate relation as a function of the flow conditions, morphology, soil properties and bank geometry.

3

METHODOLOGY

3.1.   Identification of Rivers and Their Tributaries in the Nile Basin

As given in chapter (1) in the item (1.4) of the river system description all the Nile Basin Rivers and lakes are comprehensively identified. Important information and characteristics of each lake or river are given in tables. The information covers all the important aspects including yield at different gauging stations, while Figure 1.1 shows the layout of the basin.

3.2. Compilation of Data

Many studies were conducted in the River Nile investigating the problem of bank erosion in the Nile Basin Countries. These studies indicated that the most important factors influencing the processes of incision, water erosion (sheet, rills and gullies) and bank erosion are very complex due to the interaction of water and soil. This complexity has been aggravated by the intervention of human activities along the flood plains and the banks of the various rivers. The natural factors such as climate expressed in its parameters (rainfall, temperature, wind direction and speed, etc), types of soils (cohesive or non cohesive) and vegetation cover are all influencing factors on water and bank erosion. The methodology of this study included the desk study (office work), field visits, and interviews.

3.2.1. Desk Study

The office work was mainly literature review. Most of the literatures reviewed during the study focused mainly on other Nile Basin countries, especially Egypt and Sudan. Most of the studies indicated that there are many factors influencing the changes of river morphology. These factors include the followings:

- Flow velocity of the water current within the channel.
- Fluctuations of the high and low level of floods.
- The force and direction of the waves caused by wind on surface water as well the waves caused by navigation.
- Sediment transport rates (sediments types distributed vertically and horizontally associated with their chemical and physical characteristics.
- The human interferences.
- Riparian vegetation.
- Bank material, especially texture and structure properties.

3.2.2. Field Visits

Prior to the field visits, relevant materials were collected and studied. The materials used in this study are the followings:
- Sets of panchromatic aerial photographs at scale 1:20,000 from Land Survey Department, Khartoum.
- Landsat images of TM and ETM at scale 1:250,000.
- Multispectral scanner (MSS) of band 5 and 7 at scale 1:250,000 dated 1973.
- Topographic maps at scale 1:250,000 and 1:100,000.
- Other maps of climatic zones Figure 3.1 and ecological zones Figure 3.2.
- Digital camera used for documentation.

- Global positioning system (GPS) to record coordinates.
- Meteorological data were collected from various meteorological stations.

Figure 3- 1: Climatic Zones
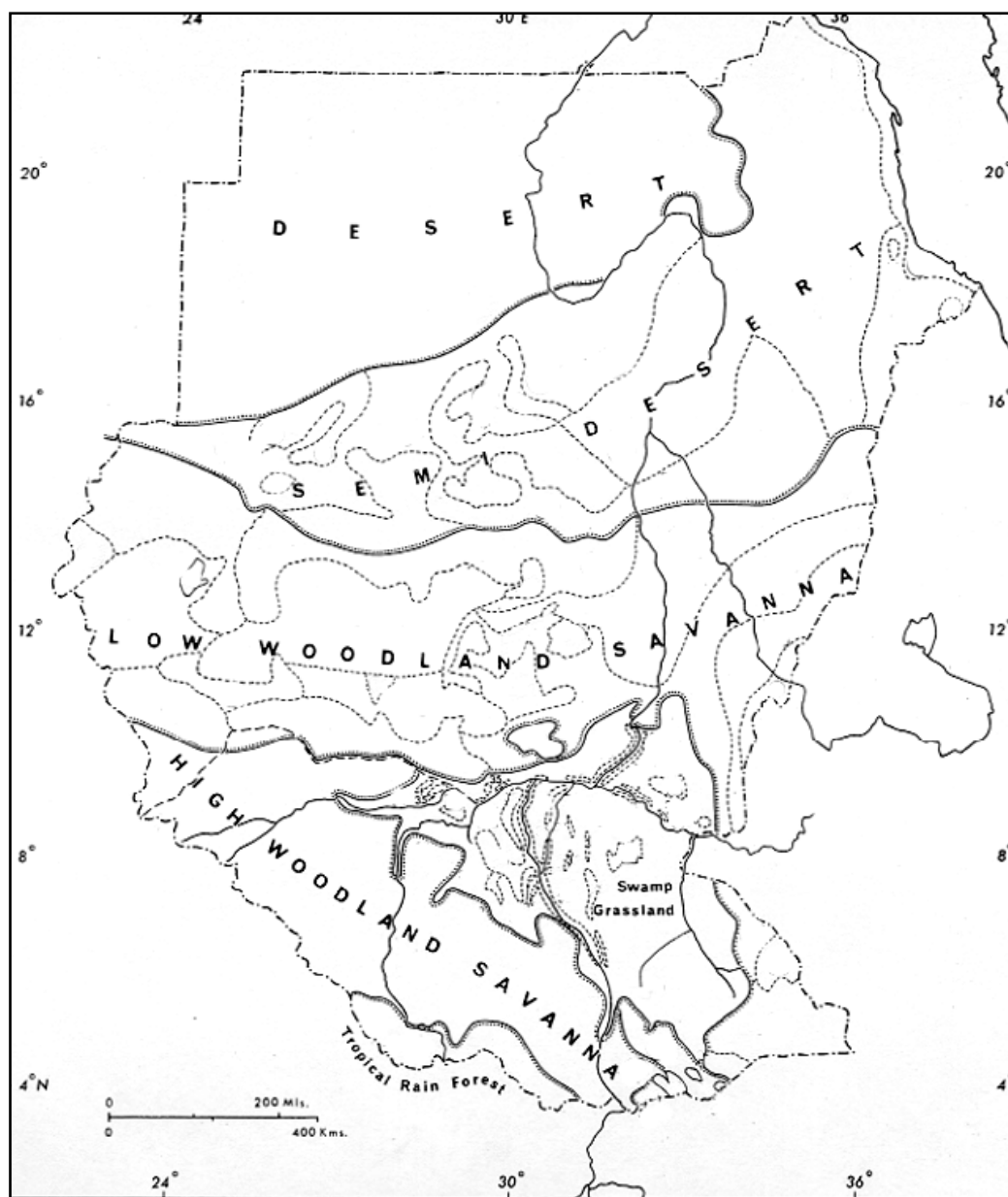
Figure 3- 2: Ecological zones

3.2.3. Interviews:

The Interviews were conducted mainly with government officials, NGOs and stakeholders discussing the impacts of water and bank erosion on socio-economic activities. The loss of arable land and migration of young people to oil production countries was also discussed.

3.3.   Case Studies Selection (Location, Problem, Scale And Tool Used)

Aerial photographs were used to map the soils related to geomorphologic units and to specify the types of the mobile dunes with the aid of GPS. The landsat images were used to show the magnitude of sand dunes along the Nile. Figure 3.3 shows both banks of the Nile are surrounded by sands and Figure 3.4 shows, gully erosion along Atbara River.

Two methods were used to recognize the criteria of the geomorphic soil units of the Nile. The element method (Buring 1960) is mainly on tones and pattern combined with physiographic method. Goosen, in 1967 used

mirror stereoscope. Visual interpretation of Landsat images (MSS) (TM) (ETM) were interpreted to identify the belts of barachan sand dunes along the Nile, Figure 3.5 as well different types of water erosion (gully) along Atbara river.

Figure 3- 3: Banks of the Nile in hyper arid zone covered by sand

Figure 3-4 : Gully Erosion Along Atbara River farming Miscellanenus land types (Kerib land) in Semi arid zone.
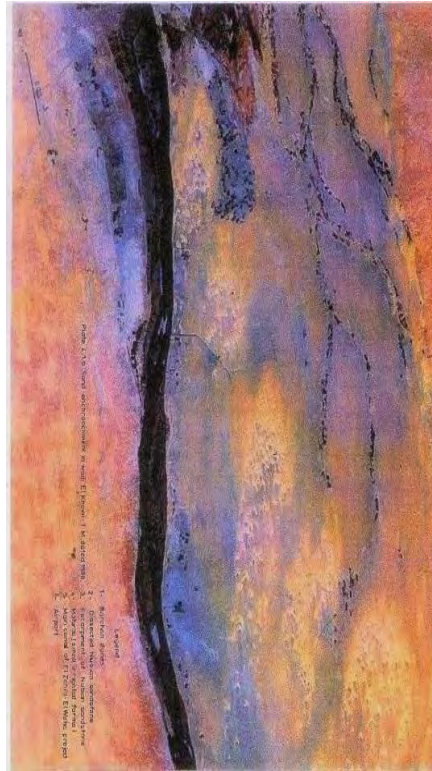
Figure 3- 5: Landsat (TM) Showing Five Colonies of Barchan Dunes of the Eastern Bank of the Nile River

The digital camera was used to document the different types of bank erosion along the Nile (Figure 3.6 and Figure 3.7). The recognition of bank erosion types will help in suggesting the protection measures.

Figure 3-6 : Bank erosion – failure as a beam type in Northern State (Karima – Dongla Reach)

Figure 3- 7: Bank erosion – Sliding failure type in Northern State (Karima – Dongla Reach)

It was observed that the Nile banks consist of cohesive layers of varying thickness resting on sandy bed. The main protection methods are rock riprap Figure 3.8 and stone pitching (revetment) are commonly used in Northern Sudan.

Figure 3- 8: Protection of pumping station at El-Gaba –Northern State by rock and cement

3.4. Working Plan

The working plan is as given in the bar chart below. The plan was extended to include the whole month of November to last week of December 2009 for completion of the report.

ACTIVITY 2009	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT
COMPLETION OF DATA	▬▬▬						
CASE STUDIES	▬▬▬▬						
RESULTS AND DISCUSSION		▬▬▬▬					
FINAL DRAFT REPORT CO			▬▬▬▬				
FINAL REPORT SA			▬▬▬▬▬▬▬▬				
FINAL REPORT NBCBN						▬▬▬	

4

BASIN SCALE STUDIES

This chapter gives assessment of erosion potential at some locations in the Nile system. The case studies are carried out at the river basin scale.

At the river basin scale, the one of the entire river basin or single sub-basins, we can recognize the entire river network or large parts of it. Typical river basin-scale issues involve soil erosion, reservoir or lake sedimentation, solid and water discharge formation. Basin-scale studies are characterized by the description of the entire river drainage network or large parts of it, such as the entire delta or specific sub-basins. Geographic Information Systems, 0D and 1D morphodynamic models, as well as 1D or 2D runon-runoff models, are the typical tools used.

4.1. Kenya Case Study

A case study of erosion phenomena by means of an integrated remote sensing approach was conducted for the Nyando River in Kenya. The objective was to initiate a preliminary study phase, on a remote sensing approach, to understand the causes of the bank soil erosion of Nyando River basin. The future goal is the development of basic guidelines or a technical manual on how to cope with erosion phenomena in the basin. The methodological approach gives particular emphasis to the use of low cost remote sensed data and the application of well known Earth Observation (EO) techniques in order to minimize the cost of land surveys. ASTER images, time series of MODIS NDVI and DEM were used to generate land use maps, provide vegetation dynamic description and identify possible erosion indicators.

One of the main challenging task of the knowledge network is to ease the information flow in hydro-technical field from the source (research) to the local end users. The Nyando Basin is considered within the huge area of interest. The main objective of the study is focused on the problems of the instability of the river bank, with particular attention on understanding the causes of the soil erosion, the degradation of the vegetation, the sedimentation and the bank erosion processes in the basin. The impact of the bank erosion of Nyando River and its tributaries is widely spread within the basin causing a great set back for the socio-economic development in the catchment area. Within this general context the present preliminary research suggests the application of low cost remote sensing techniques which investigate the land use pattern (e.g. vegetation types, farmland, water quality, etc.) and their temporal dynamics in the Nyando Basin area. The proposed approach has a number of benefits particularly interesting for African environments because:

- The used database is extremely low cost.
- The work integrates different sources of data and exploits the wealth of information of previous studies.
- The use of satellite imagery can offer a manageable overview of the territory at a glance, which is particularly effective in the typical complex and mixed African pattern.

4.1.1. General Description of the Area

The Nyando Basin covers an area of about 4.484 Km2. It lies between latitudes 0° 7' 0" N and 0° 25' 0" S and is bounded by longitudes 34° 34' 0" E and 35° 43' 0" E of the Equator. The Nyando catchment is represented in Figure 4.1.

The Nyando River is 142 km long; it has a discharge ranging from a minimum of 2 m^3/s to the extreme flood of 850 m^3/s and has a high silt load. The Nyando and its upper tributaries rise in the Tinderet forest in the North-East of the Mau Summit-Londiani District in the East and the Western Mau Forest and Kericho in the South. The catchment area of the river system is in Kericho and Nandi Districts, which lie above 2000 m above the sea level and occurs in a high rainfall zone with mean annual rainfall of between 1800mm to 2000mm. The rivers in the basin have steep defined courses in their upper reaches, but on reaching the flat low-lying areas near the Lake Victoria they meander and periodically overflow their banks before terminating into Miruka swamp neighboring the Lake Victoria. The Nyando River has one main tributary river, the Ainomotua and three smaller tributary streams (the Cheronget, the Kabletach and the Asawo), the contribution of which is very small. The river finally flows into the Miruka Swamp as well.
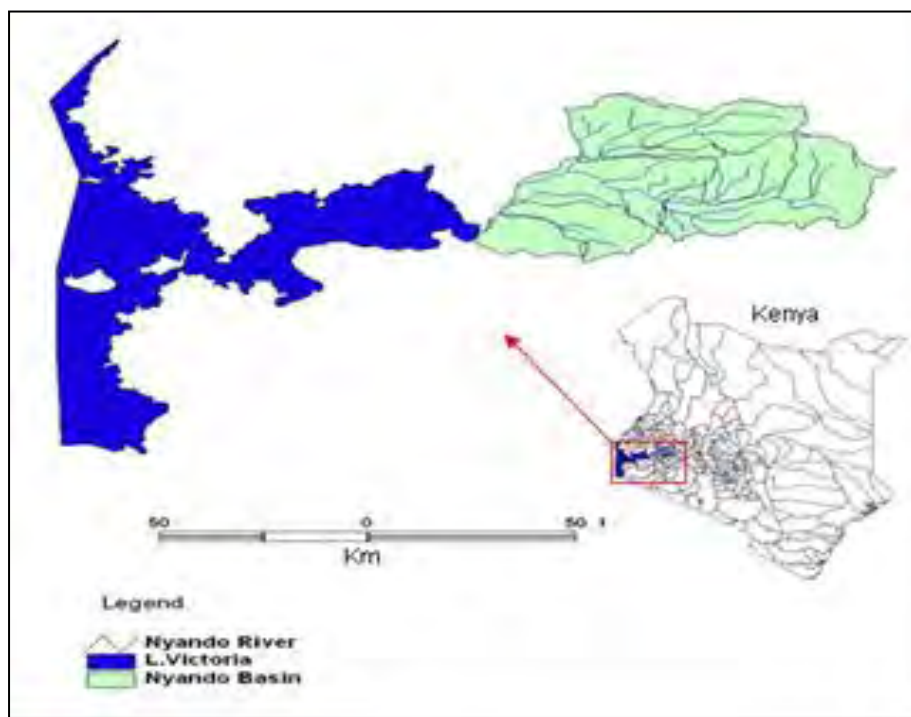
Figure 4- 1: Location of Nyando River Basin in Kenya

The vegetation of the upper catchment is mainly forest (Tinderet forest), while the middle catchment can be classified as scattered trees and grass, which has greatly been modified by clearance, cultivation and burning due to human settlement.

The low plain experiences a mean annual rainfall of 1,260 mm most of it falling between March and May and a smaller peak between September and November. Extreme droughts occur in January and February. The mean annual maximum temperature ranges from 25° to 30° centigrade while the minimum is between 9° to 18° centigrade. The soils are recent alluvial medium to heavy clays of poor drainage, weak structure and are therefore well suited for rice production.

4.1.2. Data Base

The chosen database for this preliminary study had to face some cost constrains and only low cost imagery or free products could be afforded. Despite the low cost materials, high quality data for the purpose of this project could be retrieved. The database was composed of the images/products listed in Table 4.1.

Table 4- 1: Used database

No.	Sensor	Product	Resolution	Date
2	Tera -ASTER	AST14OTH – L3 (Radiance at the Sensor Orthorect.)	15, 30, and 90m	12 Dec. 2003 and23 Dec. 2007
23	Tera - MODIS	MOD13Q1 (MODIS/Terra Vegetation Indices)	250 m	every 16 days from Jan. to Dec. 2007
1	SIR-C/X-SAR	DEM SRTM (from EPIDEMIO project)	50 m	14 Jun. 2005 (production date)
1	SIR-C/X-SAR	vectorial layer (from FAO GeoNetwork)	N/A	27 Nov. 2006 (production date)

Two adjacent ASTER images were needed to cover the whole area of Nyando basin. They had to be mosaced seamlessly as no contemporary acquisitions for the two frames were available in ASTER archive. In order to minimize the difference in vegetation stage, the two scenes were both chosen in the same month (December, dry season), when the vegetation is likely to be in a similar stage, even though from different years (2003 and 2007).

The ASTER bands at 15 m (green, red, NIR) resolution were visually interpreted to identify the main land use/ land cover types of Nyando basin. The use of the DEM allowed the creation of 3D - representations of ASTER optical images which were particularly effective in the visual interpretation of the satellite data in Figure 4.2.
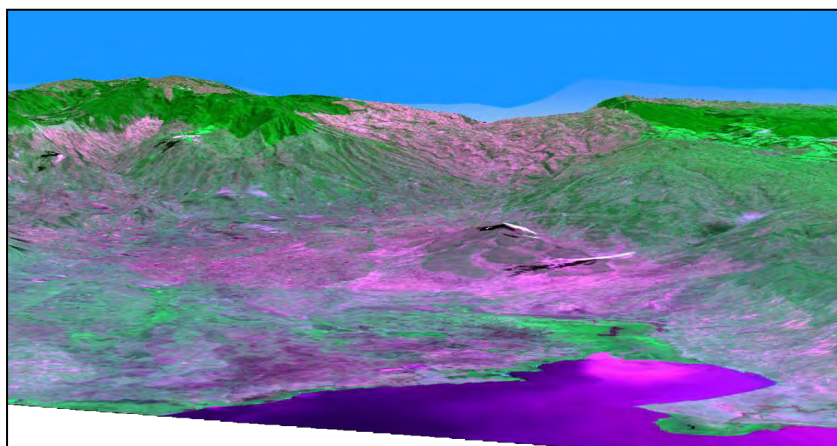
Figure 4-2 : Nyando catchment ASTER image DEM Data

Particular attention was given to the vegetated areas. Some sample areas of different vegetation types were identified and contoured with reasonable approximation in shape and boundaries. Identified land use/cover classes included, rangeland, farmland, tree savannah, forest, water off-shore, water close to Nyando estuary, swamps, and urban areas. Rangeland in the Nyando area can be described as the typical natural vegetation, native grasses, grass-like plants and shrubs. Some savannah type trees (Acacia spp.) are present as well.

The high resolution areas, which had been identified on ASTER images (15 m resolution), were then used as an input in a classification process of MODIS-NDVI dataset, which is at lower resolution (250 m).Therefore, even when approximate, the areas at higher resolution could well fit into the lower resolution data base. The MODIS Normalized Difference Vegetation Index (NDVI) are robust spectral measures of the amount of vegetation present on the ground (NDVI=(red-IR)/(red+IR)). They involve transformations of the red (620-670 nm) and near-infrared (841-876 nm) bands designed to enhance the "vegetation signal" and allow for precise inter-comparisons of spatial and temporal variations in terrestrial photosynthetic activity (Heute et al. 1999). The 16-day product is the result of a composition of cloud free pixels collected over 16 subsequent

daily images. They are merged to create a single almost cloud-free image map with minimal atmospheric and sun-surface-sensor angular effects (Holben, 1986).NDVI curves for each land cover class were calculated from 23 subsequent 16-day NDVI products all along 2007 and compared. A classification process was then run for all above mentioned classes except urban areas, which were too small for the low resolution dataset. The classification process (Maximum Likelihood algorithm with NDVI application) on such multi-temporal dataset considered each one of the 23 NDVI composite images as if it was a spectral band. This approach discriminates among vegetation types on the basis of their temporal variations. In fact, some of the cover types are relatively constant throughout the year (e.g. forest, off shore water) whereas other vegetation types are more sensitive to the rainy/dry season variations (e.g. rangeland). Therefore, the NDVI temporal variations among classes are considered in this context more determinant for their identification than their spectral difference.

A post classification process was then carried out. The aim of this operation was to select areas on the classified maps, which were particularly vulnerable to floods and, at the same time, to characterize them in terms of vegetation cover (particular attention was given to farmland). To this end the areas bordering the main rivers and the large area of the Nyando estuary were considered. The first ones were selected three regions consisting of Nyando, Ainomotua and Cheronget Rivers. They were contoured all along the waterways and approximately 1 km across. The latter (hereafter called "10 m area") was contoured with the DEM for 10 m in height from 1134 m (Lake Victoria shore) up to 1144 m and included also the Miruka Swamp. These four regions were considered as potentially vulnerable to flood and/or erosion phenomena. Statistics on the classified map were thus calculated for them. The results reported the distribution of the land use/cover classes for each region. In addition, the small urban area of Kisumu, which was left out during the classification process because of the small size, was eventually overlaid on the classified map. Some basic to ponymy was then added.

In the following paragraphs the dynamic behaviors of the some of the considered cover types are described in terms of NDVI variations throughout the year 2007. The multi-temporal NDVI behaviour of the sampled rangeland pixels in 2007 is represented in Figure 4.3 and compared with the contemporary rainfall data in Nyanza Region (source: FAO/GIEWS, 2009). The rangeland NDVIs show the typical natural trend of the spontaneous vegetation, as the curve follows the rainfall trend after a short delay. Whereas the farmland curve is rather more constant in the time as effect of the irrigation and/or farming practices, which tend to maintain a vegetated land cover also in the dry season. However, the farmland curve may be the result of the average behavior of many crops that can be differently scheduled along the year. The forest NDVI values, as expected, are also relatively constant throughout the year and always higher than the other cover types, Figure 4.3.
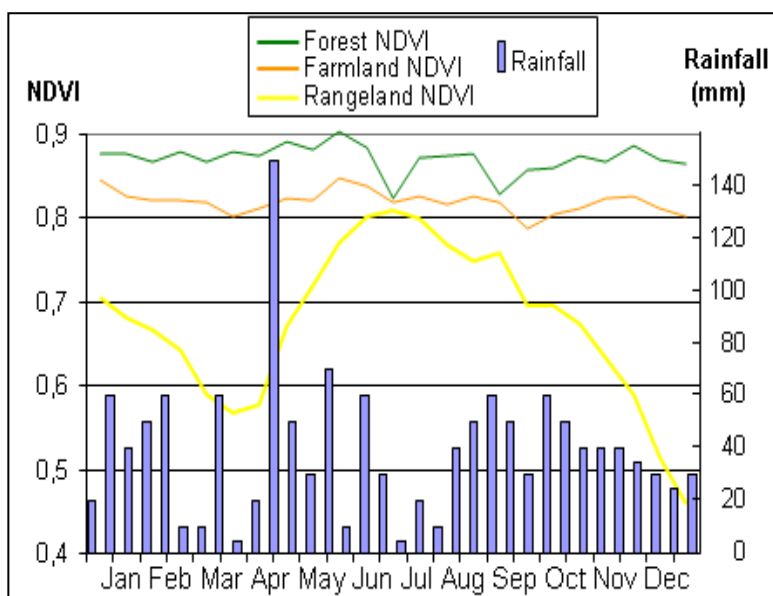

Figure 4-3: NDVI multi-temporal behavior of rangeland, farmland and forest in 2007 compared with rainfal

4.1.3. Off Shore Water and Nyando Estuary Water (Lake Victoria)

The temporal behavior of the two sampled water types is represented in Figure 4.4. Both of them have remarkably lower NDVI values as compared with the previously described classes. However, the water of Lake Victoria, especially in the vicinities of Nyando estuary, shows noticeable variations quite in agreement with the recorded rainfall and, consequently, with the seasonal vegetation variations of rangeland. The increase in NDVI values of the water can be explained with an increase of sediment and organic matter transport from the Nyando stream, which in turn can be due to the soil erosion during the rainfall. If the NDVI variations in the lake are from the effect of the soil erosion it can be assumed that the NDVI measurements of the water in the Lake Victoria can be considered as a good index of soil erosion. In particular, the water close to the Nyando estuary is more affected by soil transport into the lake than the water off shore. This explains why the NDVI measure of the water flowing into the lake from the estuary is always higher along the year thus suggesting that it can be more sensitive to the phenomenon.

Rainfall recordings of the same period are also reported. Figure 4.5 shows the final map resulting from the classification and post-classification process on the multitemporal MODIS NDVI image. The accuracy of the results was checked against the ASTER image only for the classes with low temporal variation like water and forest, while farmland and rangeland, being subject to seasonal change, could not be compared with the single acquisition of ASTER image. The main dominant classes in the classified image are the farmed areas (43% of the total) and the rangeland (37%) in the lower portion of the basin, while forest areas (8%) are mainly constrained in the upper part of the basin, above 1400 m asl. Two water types were also identified in the lake: off-shore water (the large majority) and the water close to the estuary (only about 20 Km2), of which the specific NDVI dynamic behavior was already described.
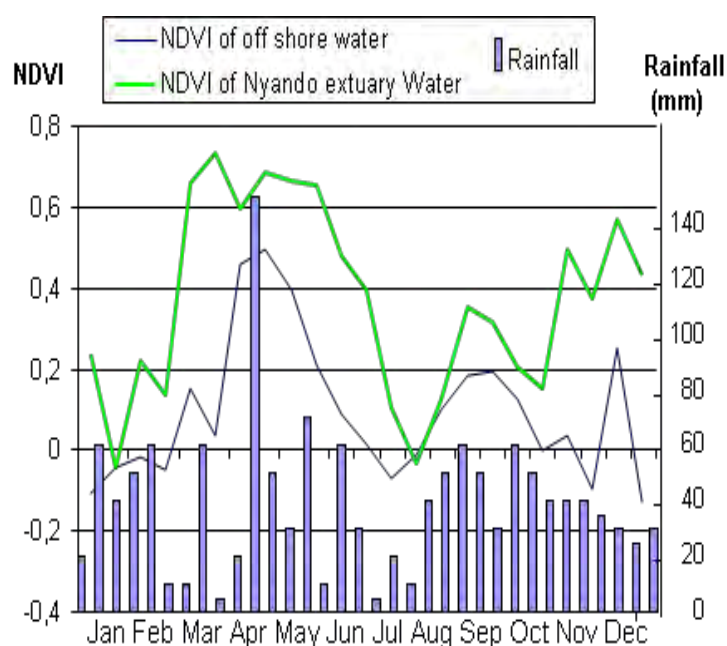
Figure 4- 4: NDVI Multi-temporal behavior of the off Shore water and water from Nyando Estuary in 2007 in the Lake Victoria.

Figure 4.6 shows the area extensions of the land cover classes in the four areas considered potentially vulnerable to flooding. The "10 m area" has the maximum farmland extension thus being the most exposed region to fertile soil erosion. It can be concluded that the available low cost EO database, the classification algorithm and the NDVI indexes can find their applicative utility in the investigation of the erosion phenomena in the Nyando basin. Two conclusive remarks can be drawn from these preliminary results:

- The NDVI variations in the water along the year 2007 are well in agreement with the rainfall. This is probably due to the soil transport of the waterways into the lake. Therefore, it can be assumed that the

water NDVI of Lake Victoria, especially close to Nyando estuary, can be considered a good indicator of the erosion phenomena of the basin.

- The area next to the Lake Victoria shore and including Miruka swamp ("10 m area") is more intensively cultivated than the riparian areas in the basin. Therefore, given the presence of farming activities and crops, the occurrence of floods and erosion phenomena in that area is expected to cause heavier human impact than in other vulnerable areas. This suggests that the need of water management works is more urgent in the "10 m area" than elsewhere.

Further results and details of this work with a more extended NDVI dataset and with higher resolution imagery are expected.
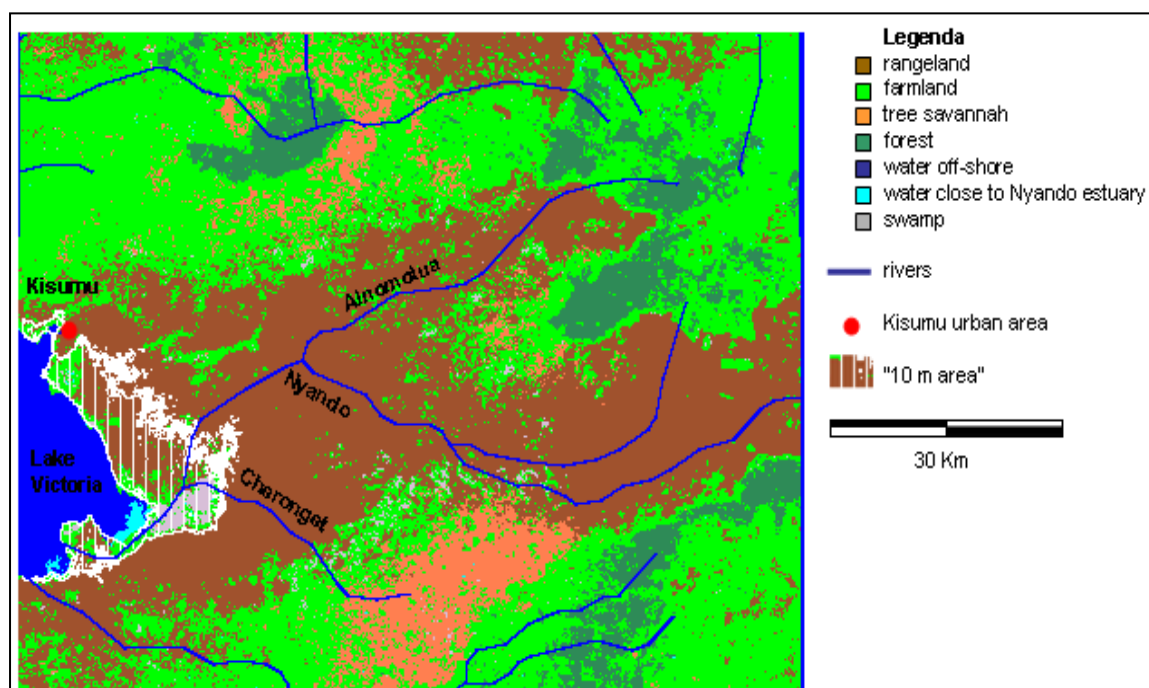
Figure 4- 5: Classified map of Nyando Region
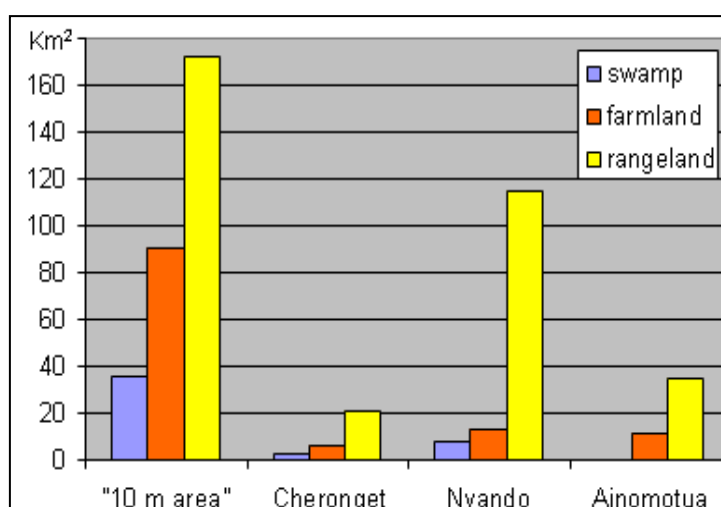
Figure 4- 6: Extension of land cover types in the four areas considered potentially vulnerable to flooding

4.2. Ethiopia Case Study

Previous studies and field observations confirmed the fact that soil erosion is a serious problem in the Amhara and the other regions within the Nile Basin parts of Ethiopia. It was confirmed by the Eco-Systems, that in-depth analysis and field reviews were done considering the different stages of the problem. In fact, there has been a long standing recognition of the seriousness of the problem, which explains the need for a number of earlier studies that have been conducted on issues of soil erosion and relevant mitigation measures. It has been understood, however, that those studies are scattered and need to be consolidated. Moreover, efforts to arrest the problems of soil erosion are being exerted by the Government, NGOs and the communities. While these efforts are producing successful results, their replication and scaling-up to different parts of the country is still limited. This study is supposed to fill the gaps in data and consolidate the different information available into a comprehensive report. It will provide inputs into what type of pilot mitigation efforts/activities including Transboundary nature to help in arresting the deteriorating situation relating to soil erosion and develop best practices and models for replication within the country and beyond. The information and data would reflect the extent and impact of the issue with the view of using that information as inputs to guide in the Nile Transboundary as well as possible joint work with the Sudan. The conducted study was based on primary research/study, resulting in outputs more practical and realistic applications to the forthcoming planning and implementation processes for erosion-mitigation interventions.

Studies of the master plans of Baro-Akobo, Abbay and Tekeze River Basins carried out by the Ethiopian Ministry of Water Resources have enriched this study. Much of the basic information needed, including maps have been used from the three river basin studies. Field visits give a closer insight to the soil erosion problem with localities more susceptible to soil erosion. The area of Baro-Akobo, Abbay, Tekeze and Mereb River basins is shown in Figure 4.7. Their estimated area is 360,803 km^2, which is about 34% of Ethiopia, with annual runoff about 72.13 BCM/yr .
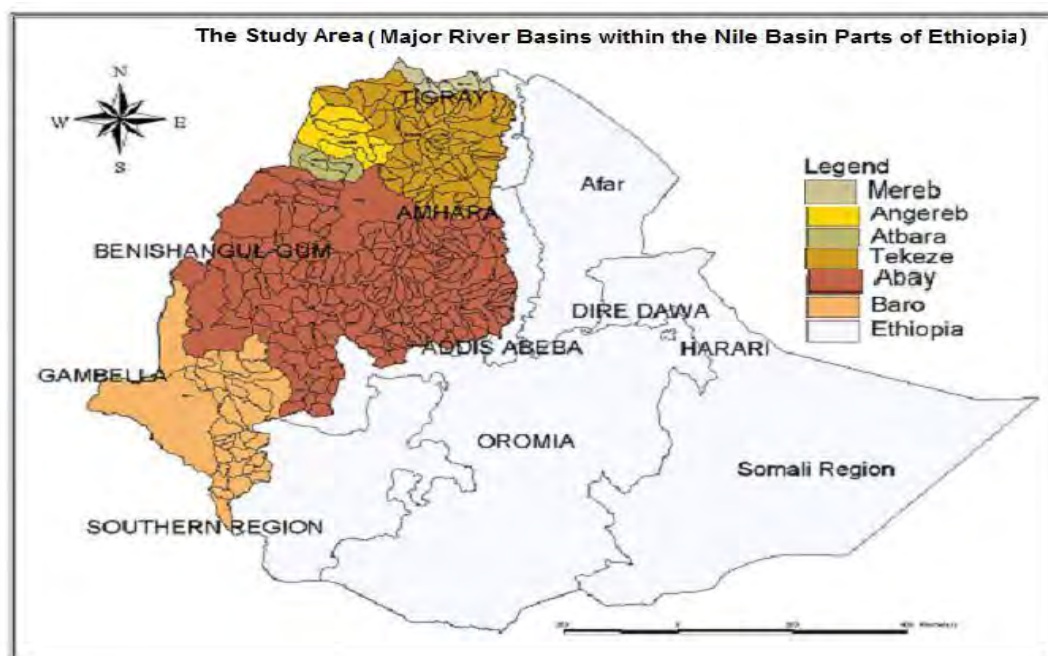
Figure 4- 7: The Nile Basin in Ethiopia

The deteriorating natural resources within the Nile Basin parts in Ethiopia, involves upstream degradation, causing significant transboundary impacts. The two tributaries, the Abbay (Blue Nile) and the Tekeze (Atbara) Rivers, contribute about 86% of the annual supply of water to the Nile, with an estimated catchment area of 332,000 km^2. Observations evidence, revealed that land and soil degradation in the Ethiopian highlands reached very high serious erosion rates. The magnified erosional degradation, resulted in economic impact, associated with productivity loss of 10% estimated as 10 to 3,000 Million Ethiopian Birr (400 million dollar).The topography of the Nile Basin part within Ethiopia is a relief of high mountains and plateaux, with meandering streams. Figure 4.8 prepared from the data of the three river Nile Basin parts of Ethiopia with agro ecological studies. These topographic features, coupled with the climatic characteristics of the highlands, have direct implications on the soil erosion process.
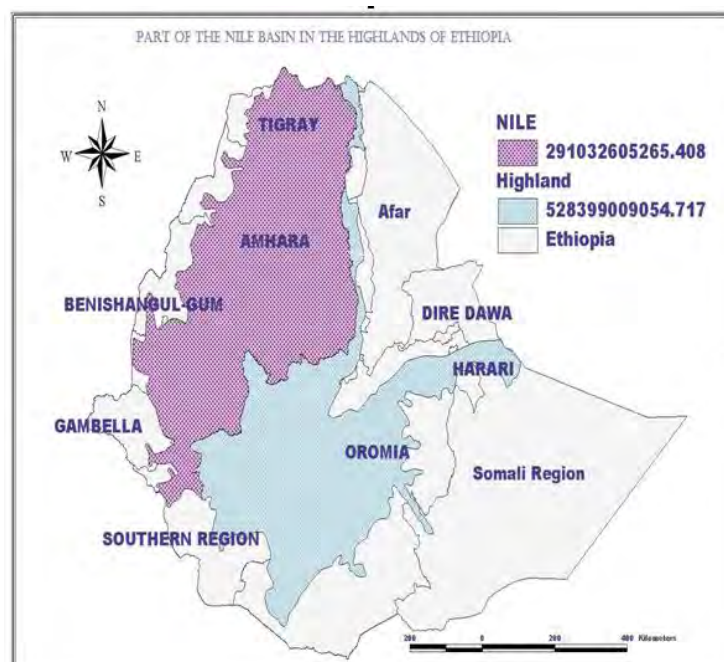
Figure 4- 8: Altitude ranges in the study area

Climate has a direct impact on erosion and its variation during the year is strongly influenced by precipitation and wind speed. In January most of the country of Ethiopia is under the influence of the northeast trade winds, resulting in an extensive dry, season for most of the country, while Northward in the period March to June movement of moisture laden monsoonal air masses progressively from in the Southwest, while by July, most of the country is under the influence of this southwest monsoon, which correspondingly brings about the onset of the main rainy season (Krempt) over much of the Ethiopian land mass. The climate in Ethiopia ranges from hot and nearly desert-like climate to temperate on the high plateau and even cold on the mountain peaks. Table 4.2 and Figure 4.9 illustrate rainfall pattern regimes in the Nile Basin parts in Ethiopia designated as A, B,D, and E.
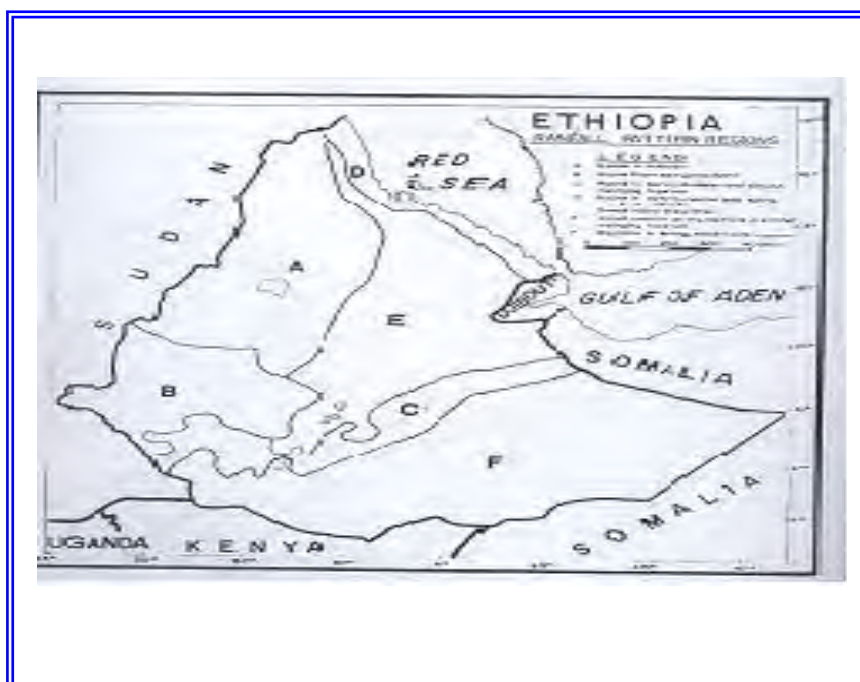
Figure 4- 9: Rainfall regimes of Ethiopia (Source: FAO, 1984)

Table 4- 2: Rainfall Pattern Regimes of Ethiopia (Source: FAO, 1984)

Code	Summary description
A	One comparatively short rainy season in summer
B	One comparatively long rainy season dry season in winter. Some stations with year round growing period
C	One comparatively long rainy season with rainfall peaks in spring and autumn separated by a season with less but still considerable rainfall
D	Long rainy season in winter and small rainfall peak in summer
E	Main rains in summer preceded by a small rainfall peak in spring or by prolonged period of moderate rainfall
F	Two short rainy seasons. Main rains in spring, small rains in autumn

Note: Spring, summer, autumn and winter refer to seasons of the year according to common usage in the temperate northern hemisphere.

Floods with high variability of climate and river flows, from higher altitudes with higher precipitations, associated with deforestation of the uplands , inappropriate land use and watershed management, enhances higher rates of runoff and soil erosion. As the case is in many parts of Ethiopia, high rainfall concentration and intensive cultivation of steep slopes result in excessive runoff and erosion in most parts of the Nile basin within Ethiopia.

Sedimentation problems are inescapably closely related to soil erosion problems. Severe consequences of the high sediment loads of those rivers flowing into Lake Tana have been reported.. Sedimentation in the Baro-Akobo river basin, seems less serious as compared to the other two river basins forming the Nile Basin parts in Ethiopia. The relatively extensive wetlands in the basin also trap much of the sediment and the flatter terrain is somewhat less susceptible to soil erosion, which implies less sediment load. Bank soil erosion in the area is entirely caused by flowing water. It starts as sheet, erosion and developed to rill and gully erosion. Traditional conservation practices existed Conservation measures were practiced through the soil conservation programmers in the different parts of the country. Currently, the Ethiopian Government has generally put a strategy that soil conservation, activities including protection against bank erosion should be implemented following in the watersheds.

4.3. Case Study of Rwanda

Rwanda lies in the Nile basin catchment area and the erosion process covers most of the country area. The country being mountainous erosion exists on the side slopes of the agricultural arable land. Erosion adjacent to the Nile bank is not as serious as in other localities in the basin. This land erosion is carried by water into the basin as sediment. Therefore, it is worth consideration because it has an equal adverse effect on the Nile catchment area as that of the banks erosion. Rwanda agriculture arable land affected by this type of erosion is 26.338 km^2. This area is estimated at around 60% of the total country surface. Erosion is also affected by the high population density, which is 425 Hab/km^2 on average, with the cropping in hill slopes. It is generally accepted that for slopes between 2% to 5% farming practices are enough, up to 25%, anti erosion measures (hedges, trenches) become necessary. Above 25% heavy works like terracing are recommended and the conservation of cultivated lands becomes more difficult on slopes above 35%. Beyond 65% any cultivation should be avoided. Unfortunately in Rwanda, only 23.4% of the country's lands are less or not prone to erosion, 37.5% require protection before their use, and 39.1% are highly prone to erosion. The classification of soils according to their slopes is as shown in Table 4.3, and classification of areas according to risk of erosion is shown in Table 4.4.

Table 4-3 : Classification of soils according to their slopes

Slope class	0-2	2-6	6-13	13-25	25-55	>55
% of soils	7.14	7.74	27.12	19.70	30.04	8.27

Table 4- 4: Classification of areas according to the risk of erosion

Risk class	Very high	High	Average	Low	Very low
Surface (ha)	357.529	436.563	763.005	340.376	136.625
% of soils	17.6	21.5	37.5	16.7	6.7

The two tables show that slope factor clearly justifies the intensity of erosion which spreads over the country. Erosion control measures are not sufficient to contribute to the intensification of agricultural production. Systematic approach, of making a better typology of landholding and get their utmost management is important. Water resources in Rwanda are abundant; irrigation has been and is still less addressed in agricultural sector. Surface irrigation is the method well known in Rwanda. The area is undermined by the hilly landscape-changing climate, irregular and aggressive overpopulation, in addition to the high pressure exerted on soils, which led to excessive erosion. Soil losses are substantial and are estimated as about 500 tons/ha. Heavy rains and the cultivated hills slopes cause degradation. The deterioration is thus caused by water erosion, coupled with inadequate conservation measures, associated with rapid degradation. Insufficient soil conservation is the main challenge for a sustainable development in Rwanda with the adverse effects on the Nile basin catchment area. This adverse effect should be studied in details to cast more light on the erosion process in the Nile basin banks part of Rwanda.

Critical analysis of causes of failures of erosion control projects and search for reliable and innovative issues which could contribute to a better success of erosion control programmes are to be introduced in the area.

4.4. Case Study of the Sudan

Soil erosion is recognized as the top environmental threats that are facing Sudan with complexity of consequences and impacts not only at the national level but also at the transboundary level, which warrants thorough investigations. General data and information on soil erosion are available but scattered and insufficient. The goal of this study is to perform rapid survey assessment and identify the extent and magnitude of erosion.

The main objective of the study is to conduct rapid field survey and assessment of soil erosion threats, associated with desk review to collect available data and information. The specific objectives include:

 ❖ Compilation and analysis of data and information to identify the magnitude and extend of the problem.
 ❖ Formulation of mitigation interventions for the hotspots to arrest deteriorating situations.
 ❖ Examine successful previous promising mitigation initiatives/activities being undertaken at the local and transboundary levels to be scaled up and identified.

Rapid field survey and assessment in the form of general basic field data and sampling pertaining to soil erosion were developed. Information included both primary and secondary data. The approach taken to conduct this survey included, collection and review of secondary data, aerial photographs and land sat images; direct field observations and assessment of visual indicators (landscape, soils, vegetation cover, degradation, river bank, wind and water erosion, water resources and agricultural activities). Key-informants were group discussion with farmers, interviews of households, interviews and group discussions with CBOs, NGOs and official meetings with government staff.

The rapid field survey study included erosion hazard in the area, agriculture lands threatened by the sand movements, methods of protection against wind erosion. It also depicted reasons for not using proper tree shelterbelt for protection, causes of river bank erosion, methods for controlling river bank erosion. 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 Dinder Rivers. During the field survey, a total of 30 random villages were selected, regarding various aspects of erosion threats. 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.

4.4.1. River Bank Erosion

The mechanism of erosion starts with the well known rill erosion, and then developed to gully erosion. Gully erosion is an advanced stage of rill erosion, 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 Atbara River from south of New Halfa Town into Ethiopian highlands and Blue Nile from Elmaseed Town, 50 Km south of Khartoum Town to Ethiopian border. Kerib land was also observed with less variable intensity along ElRahad and ElDindir Rivers.

In these areas the topography has steep gradients and deeply incised in the substratum. The natural vegetation cover has been removed for agriculture 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.

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 bottoms of the gully floors are sometimes cultivated by 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 as shown in Figure 4.10.

The loss of arable land was 13.4 km^2/year in the period 1985 to 1987, 9.8 km^2/year in the period 1987 to 1990 as shown in Table 4.5 cited from Hassan M. Fadul et al. (1999). The land covered by the gullies during 1987 along Atbara River was estimated as 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.

At the lower Atbara where rainfall is not sufficient for rain-fed agriculture, has profound effect on reducing runoff. 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).

Figure 4- 10: Cultivated gully floors in the Blue Nile area (UmRamad)

Table 4- 5: 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

River bank erosion is a natural phenomenon governed by many factors of climate, hydrology, soil characteristics and human practices. Because of these factors, river 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 may be modification of channel characteristics such as position and morphology. Once the river deviates at any point from its course, the unbalanced erosive force increases with local deviation producing meandering pattern which may lead to serious changes within the influenced reach such as deviation from the main flow path, creating sand bars associated with appearance or disappearance of islands.

The Nile River and its tributaries within the Sudan are passing through alluvial plains along most of their reaches, which easily respond 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).It 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, 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 undermines and loosens the bank soil, and distorting the river equilibrium. Dumping of the materials forms a sort of isolated groins causing deflection of flows with change in bed level and water slope. A direct result is contraction of the width of the river with redistribution of its flow which increases the dimension of the channel through bank erosion in the opposite direction.

A big change in the magnitude of river bank erosion in the southern Blue Nile area is explained by changing the crop pattern of orchards. Initially the orchards were planted mainly in good soil with binding characteristics occupying 80 % of cultivated land and the remaining 20 % for banana trees. With the increase in the prices of banana, the growers tried to increase their economic returns removed the citruses trees down to ratio of only 30 % and replaced them by banana (70 %). Figure 4.11 depicts the increased rate of bank erosion influenced by this new cropping pattern.

Figure 4-11: 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. Velocity variation is in the order of 0.6 m/s to 3 m/s. This is due variation of flow caused by the heavy rainfall in the catchments area of Ethiopian highlands, Equatorial plateau, especially the Blue Nile, which accounts for some 60 % of the Nile total discharge with only about 10 % originating from Lake Tana. The large flows are responsible for bank erosion and sediment transport. The rapid drawdown of the Nile as a result of dam operation or seasonal drought is believed to accelerate bank slides problem. In attempts to restore its equilibrium either aggradations or degradation, or both usually occur. These are related to meandering pattern as an ultimate result of bank erosion along many reaches in the Nile. 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, as shown in Figure 4.12. It is also depicted and documented along Atbara River and Blue Nile. At Atbara River the hot points are downstream of Khasm ElGrib dam. The Blue Nile is exhibiting active bank erosion at different locations. The most serious suffering areas are downstream of Roseires Dam, Singa to AlSuki,

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 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 4.6. 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 is presented in Table 4.7.

The total land loss ranged from 13 to 52 % with an annual loss estimated 0.1 – 1.0 feddan, (feddan = 0.42 ha). It is normal to have both erosion and recession occurring simultaneously near each other. When river increases its width 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. The recession forces 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.

Table 4- 6: Loss of lands and date palm trees due river bank erosion (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

Table 4- 7: Threatened land by river bank erosion in Lower Atbara and main Nile

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

The real threats and adverse impact for the bank erosion were 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 Figure 4.13. 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.

Figure 4- 12: River bank erosion along the Main Nile River (Barber area)

Figure 4- 13: River bank erosion at Forestry Department Rest House at AlSuki

5

REACH SCALE STUDIES

If we zoom in the river system, we can recognize different river reaches, each one characterized by its plan form style and sinuosity. The river reach is a large part of the river that can reasonably be considered as "uniform". It is characterized by one value of the water discharge, although changing with time, and one longitudinal bed slope, also changing with time, but much more slowly. Depending on the reach characteristics, the typical temporal variations range from hours to days for the discharge; from years to several tens of years, for the longitudinal bed slope. A river reach in morphodynamic equilibrium is characterized by a longitudinal bed slope that can be considered as constant at its typical temporal scale. Reach-scale issues mainly deal with the assessment of the impact of human interventions, such as river training and rehabilitation, and with the natural river evolution on the long term. Morphodynamic studies regard bed aggradation and degradation, river incision, changes in sinuosity and plan form style. The typical tools are 0D, reach-averaged morphodynamic models, describing the equilibrium state, as well as 1D, cross-sectionally-averaged models.

This chapter describes and discusses three case studies: the Singa case study, a HEC-RAS-based study, and the Khartoum Bank Protection case study.

5.1. Singa Case Study

With main objective to study and understand the Blue Nile River bank erosion down stream Roseires Dam and find means to mitigate the problem, Salih (2008) studied bank erosion along the Blue Nile River downstream of the Roseires Dam. He found that the erosion phenomenon was clearly observed at Singa city. The bank erosion in that locality caused severe problems to the local people. In particular; it caused damage to buildings and farmlands. Observations indicated that bank erosion has been increasing in the last decade.

The bank erosion of the Blue Nile River reach downstream of the Roseires Dam is mainly due to sandy layers underlining cohesive banks at the outer bend. This resulted in undermined bank toe, leading to bank caving. Rapid variation of the water depth between high and low flows contributes significantly to bank erosion. Waves generated by the Singa ferry contribute to bank erosion especially when the water level is low. The waves attacking the bank toe slope and erode these layers giving an over hanging blocks that soon fail.

The study revealed that groundwater is an important factor affecting the bank stability in the study area. Furthermore, the study also revealed that bank erosion is enhanced by the bed degradation phenomenon that was observed downstream Roseires Dam. The degradation was due to increase of flow discharge in the last three decades, as well as due to the natural meandering of the river. In the period from July to September, the river rises rapidly carrying considerable amounts of sediment, followed by rapid diminishing in the dry season. The river is meandering with average width of approximately 450m, and a slope of about 12×10^{-3}. The average rainfall is estimated as 600 mm/year, while the mean annual evaporation at Ed"damazin is $2000 m.m^3 / year (5.45 m.m^3 / day)$, increasing to about $2190 m.m^3 / year (6.0 m.m^3 / day)$ at Sinnar.

This corresponds to average temperatures of 28.3 and 28.8 °C at the two locations, respectively. Land use pattern is changing rapidly due to urbanization and agricultural activities in the area, causing an increase in annual sediment entering the river from the upstream catchment"s area to 140 millions tons. The land use changes together with increased rainfall in the upper parts, increased the flow of the Blue Nile River. Figures 5.1a and 5.1b show the discharge of the Blue Nile White Nile and Main Nile at different stations along its longitudinal profile, during the period 2000 to 2008.
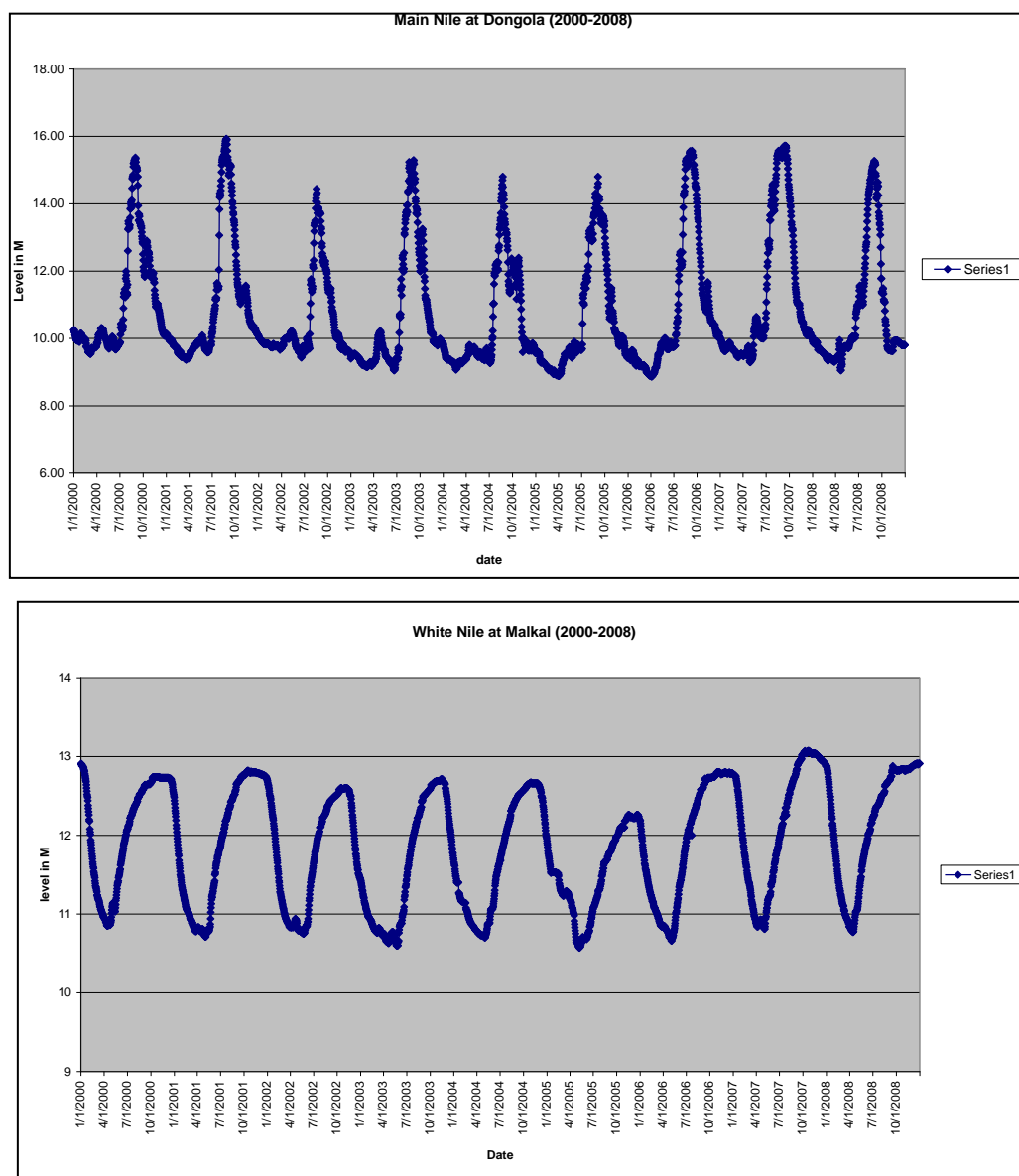
Figure 5-1a: Discharge of the Blue Nile, White Nile and Main Nile at Different Stations
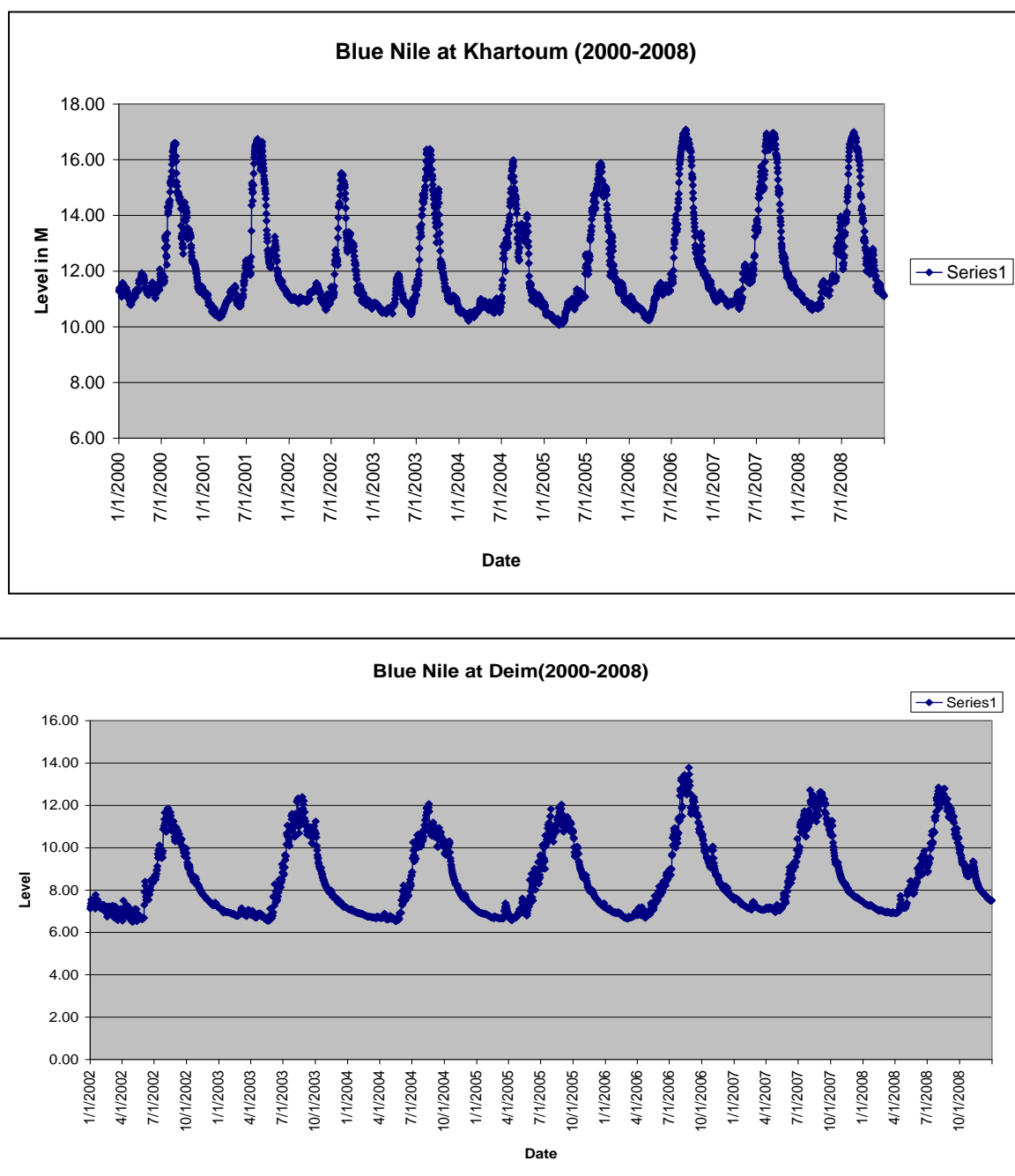
Figure 5-1b Discharge of the Blue Nile, White Nile and Main Nile At Different Stations

The study reach of the Blue Nile Rivers lies between the two dams of Sinnar and Roseries. The latter was implemented in 1966 to increase irrigated agriculture and power generation in Northern Sudan. Sinnar Dam which was constructed in 1925 regulates the Blue Nile flow into the Gezira scheme and downstream to the main Nile. Singa, the capital city of Sinnar State about eighty kilometers upstream Sinnar Dam, suffered severe bank erosion due to its location on the concave bank (left) of the Blue Nile River. The suffering reach lies between Singa City Bridge and the pumping site of Al Ramash Agricultural Pump Scheme Figure 5.2.

Water abstraction upstream of Singa city, within the reach between, Roseires Dam and Sinnar Dam for irrigation supply Abu Naʽama Kenaf Scheme (30,000 Feddan), Rahad Scheme which is supplied from the Meina pumping station (300,000 Feddan), Blue Nile Agricultural Pump Schemes with 262000 feddans.

Appropriate mitigation measures to bank erosion, were conducted through analysis and quantification of the morphological trends of the Blue Nile River in the study area. These trends included planimetric and bed level changes.
To predict long-term, large-scale morphological changes downstream of the Roseires Dam Salih used three mathematical models, namely: Miandras, Delft 3D and Sobek-Re. Miandras which is a one-line package for the simulation of the long-term effects of bank erosion and accretion, was used to study the planimetric changes of the reach under study. Channel migration was observed through the movement of the river centerline. Results obtained from Miandras Model reproduced the migration trend as derived from the field measurements and from aerial photograph 1999 together with low-resolution satellite image from 1984.Delft 3D and Sobek Re mathematical models were used in the long-term bed level changes prediction.

The study result showed that the sediment deficit water released from the Roseires Dam caused bed degradation. The degradation of channel bed coupled with the cohesive nature of the bank and its steepness caused loss of stability of the channel bank associated with bank erosion.
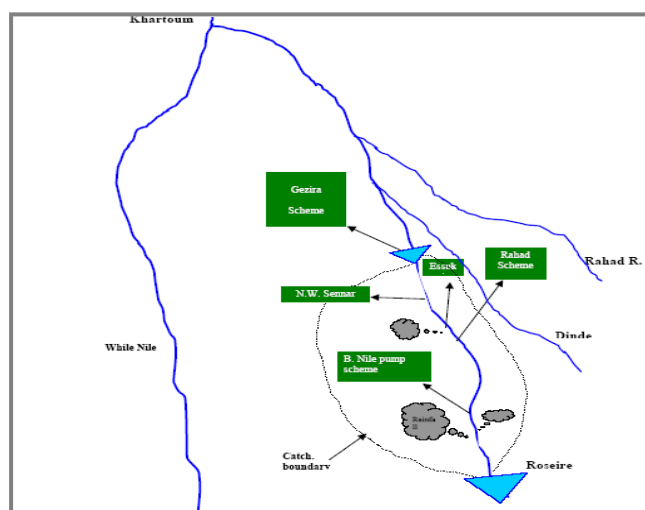
Figure 5-2: Reach affected by erosion

Integration of the three models results allowed the detection of the long-term morphological trends influencing bank erosion in the area. Mitigation measures, using groins with riprap, were identified and studied using the model Delft 3D. It was revealed that bed degradation increases in the area due to width reduction when using groins. Due to the changes in slope height, soil type and cultural resources, etc, it was anticipated that the most suitable bank protection work in the study reach was a combination of riprap and bioengineering (the use of plants).

It can be concluded that bank erosion is not just influenced by flow parameters, geological properties, groundwater, waves that are generated by the Singa ferry but also by bed degradation. It can also be concluded that the most promising bank protection work in Singa reach appear to be a combination of riprap and bioengineering. The good agreement between Miandras results and Delft 3D shows that channel

deformations in this river can be predicted using Miandras. It is revealed that heightening of the Roseries Dam causes extra trapping of sediment in the reservoir and flow reduction downstream.

It is recommended to carry out regular survey to monitor the cross-sectional changes and the bed level changes in the reach between Rosaries and Sinnar. It is also recommended to use GIS and remote sensing to study the riverbank erosion and erosion rate in relation to the morphology of the Blue Nile. Application of similar modelling in combination with physical experiments to study river bank erosion in other river reaches as downstream of Merowe dam is also recommended.

5.2 Study of Nile Bed Erosion Using Hec-Ras

This study provides a quantitative assessment of the potential morphological changes and evaluated the erosion potential along the Blue Nile River in Sudan. The extent of the study area is from downstream Roseries reservoir to Khartoum, for a total length of 635 kilometers. HEC-RAS Model is utilized to configure the hydrodynamic model of the flow for sediment analysis and evaluate the transport capacity of the river system.

5.2.1. Configuring Hec-Ras Sediment Analysis Model for The Blue Nile River Basin

Initially, a total of 87 surveyed cross-sections for the Blue Nile River from Roseires to Khartoum were collected from the Ministry of Irrigation and Water Resources (MOIWR Khartoum – Sudan). Study considered 87 covering a reach of about 525 km. In addition to the Geometric data, time series flow records for Eldeim Station and Sediment load measurements for Eldeim and Sennar station were collected for the flood season of Year 1998. The rating curve at Khartoum station was used as downstream boundary conditions.

5.2.2. Model Results

The Water surface elevation at peak time and during rising and falling limbs are superimposed on the channel cross-section as shown in Figure 5.3a. The velocity and shear stress hydrographs are shown in Figure 5.3b and 5.3c. The cumulative mass bed change with time for the cross-section is given in Figure 5.3d.
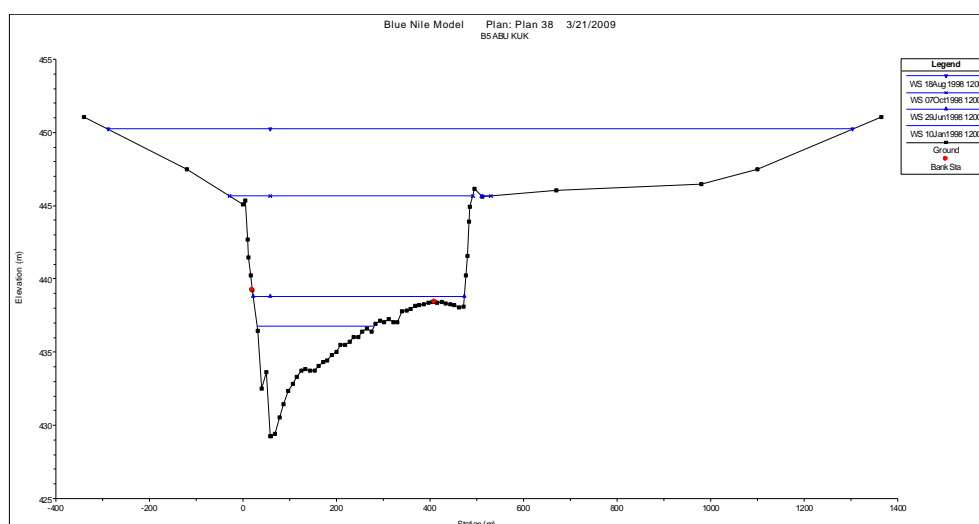

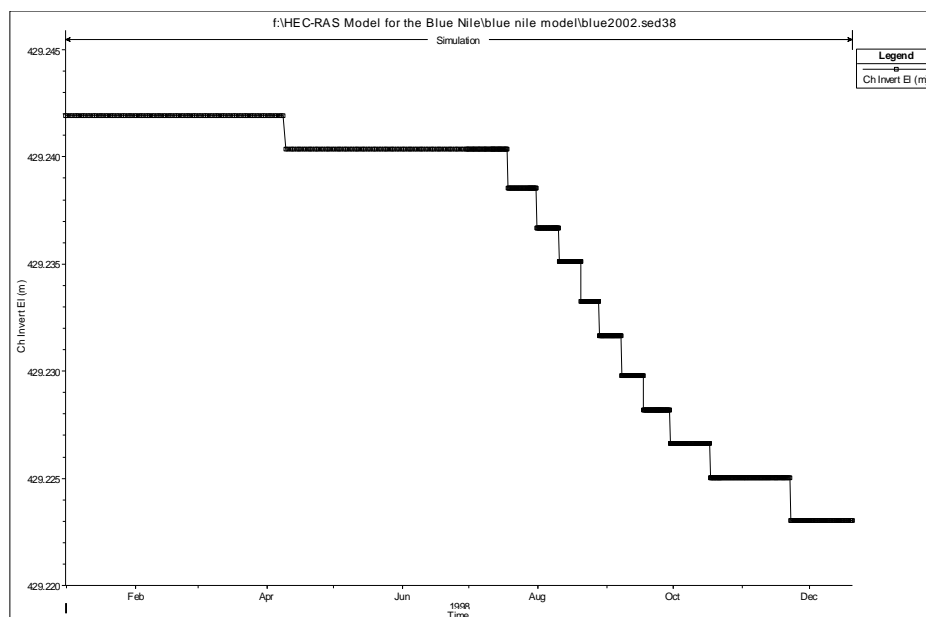**Figure 5-3a:** Cross-Section with water surface elevations at different times in 1998
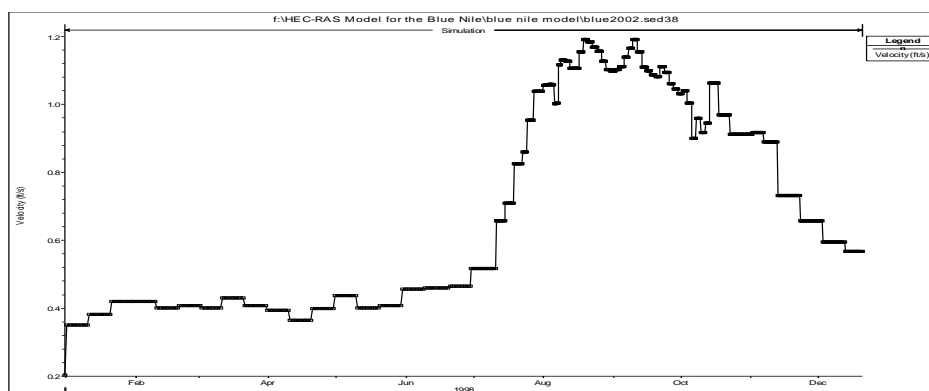
Figure 5-3b: Changes in channel invert with time

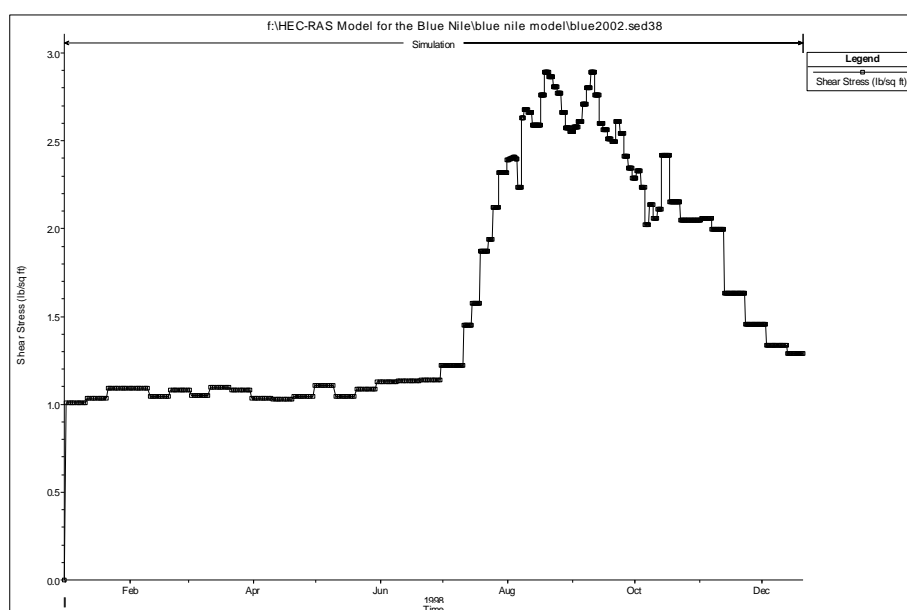**Figure 5-3c:** Velocity variation with time

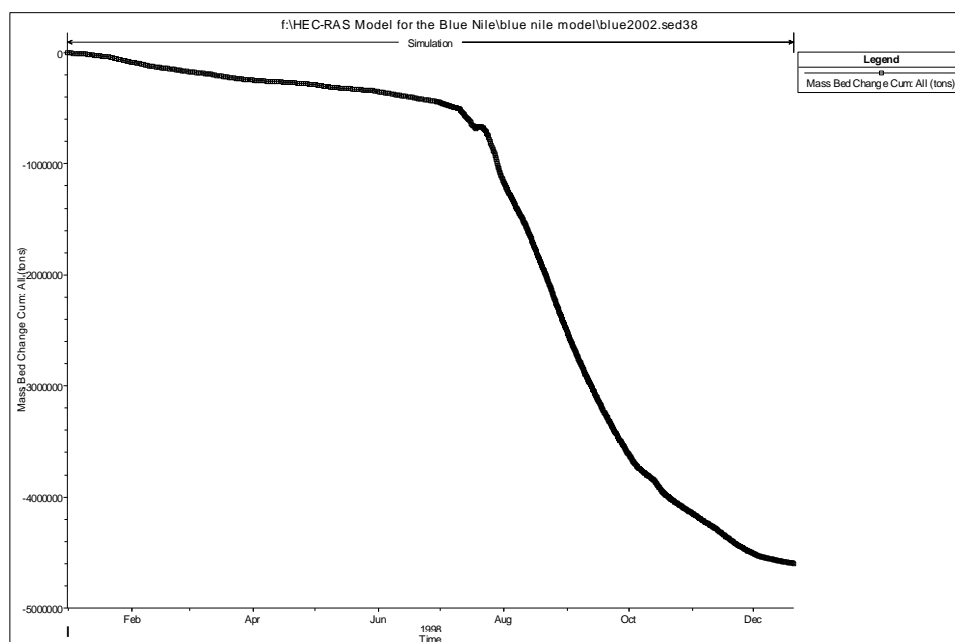**Figure 5-3d:** Shear stress variation with time

Figure 5-3e: Cumulative Mass Bed

Main results:

- The cross-section of the Blue Nile River at Abu-Kuk River Station No. 83 is degrading.
- The total conveyance capacity of the section is about 0.88 million cubic meter per second.
- The net annual change in bed elevation is about 21.2 mm.
- The maximum shear stress experienced at the bed during peak time is about 5.66 N/m^2.
- The total loss in sediment mass bed is about 4.7 million tons.
- There is severe erosion and severe channel degradation rate.
- The resulting velocity during peak time which is function of channel slope is found to be in the range of 4 m/s which are considered erosive velocities.

5.3. Nile Bank Protection at Khartoum

Severe bank erosion was reported within the Nile system since 1930‟s in the most downstream reaches in Northern Sudan. In the Sudan the Nile River is known to have an average channel width ranging from 400 m to 500 m, increasing to 600 m up to 1000 m during flood seasons. Its velocity ranging from 3.5 m/sec in the flood season to less than 0.7m/sec in the low flow season. The water level gauge height fluctuates between 8 m to 10 m during the low and high flows. In the Sudan the Nile River carries about 176×10^6 tons of sediment per year which is equivalent to about $470 \times 10^6 - m^3$ per year(Four hundred and seventy millions cubic meters of sediment every year approaching about half million cubic meter annually taking specific gravity as 2.7).

The Nile flowing from the high elevations have had erosion from steep reaches in the upstream reaches. However the phenomenon of sediment and erosion being the two faces of one coin may occur upstream as well as downstream. In the vicinity of Khartoum reports and studies indicated that noticeable bank erosion has occurred.

Obviously the large and rapid drop of the water levels and the high velocities are the main reasons for bank erosion of the Nile near Khartoum. Erosion development is clearly depicted in the cross sections prepared by the Ministry of Irrigation shown in.

In Figure 5.4, cross section 38 is the most upstream one, and the three cross sections are near Tuti Island. Figures 5.5-5.9 show eroded banks and protected banks in the Blue Nile, While Nile, and the Main Nile adjacent to Khartoum. The determination of the rate of erosion of the Nile river banks is difficult due to the lack of information.

However the phenomenon can be depicted by GIS producing maps for determining erosion rate of banks and lateral shifts of natural channels. Such information is available at Tuti Island. Figure 5.10 represents a map of Tuti Island showing some bathometric levels at the confluence of the Blue Nile and the White Nile, produced by GIS technique.
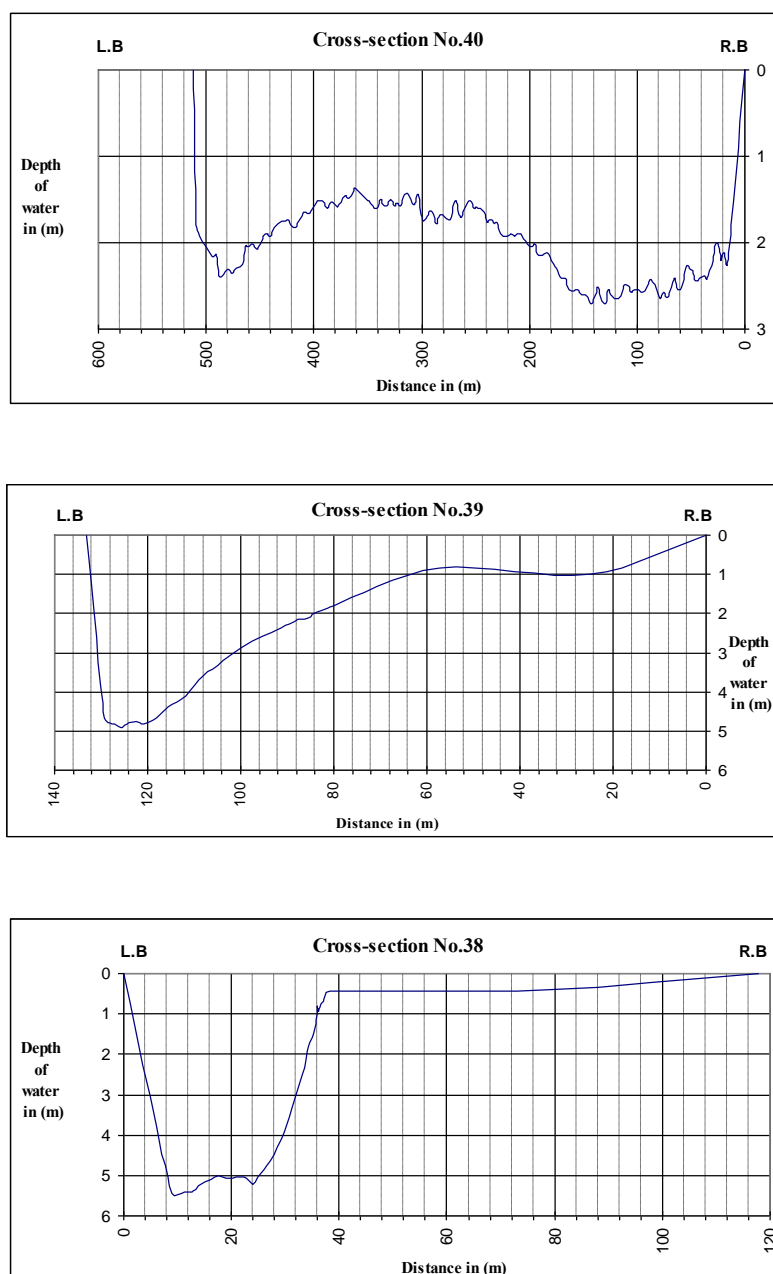

Figure 5-4: Cross sections showing erosion development near Khartoum

Figure 5-5: Blue Nile eroded bank

Figure 5-6: Blue Nile protected bank

Figure 5-7: White Nile eroded bank

Figure 5-8: White Nile protected bank

Figure 5-9: Main Nile eroded and protected banks

5.3.1. River Training and Tuti Island Protection

Ibrahim developed a plan for prioritized investment for community's protection living adjacent to the Nile River in Blue Nile, Singa, Khartoum and Nile States. He made the designs of flood control measures. Eight villages were approved by the NBI to be protected two in each of the four States. The villages being affected by the rivers flood all require embankments surrounding them. Tuti Island is one of the studied areas. The embankments of each village depend on the boundary length around each village. Part of the embankments are to protect the village from flash floods caused by rain storms .The rain storms cause inundation to the village in lengths surrounding the village but not adjacent to the river. The approach leading to mitigation of villages problems revealed that different types of protection measures require building of embankments.
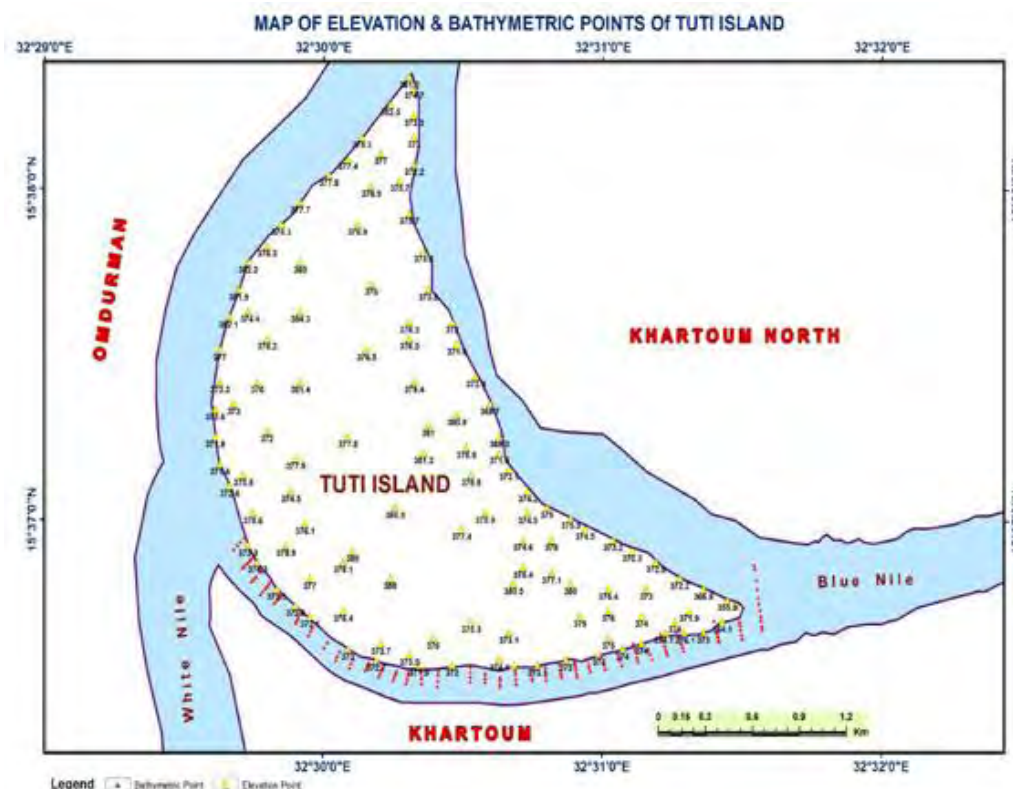
Figure 5- 10: Bathymetric levels in near Tuti Island

The embankments are of three types or classes:
- ❖ The guide banks adjacent to rivers. These are earth banks covered with dry stone pitching, they are known as dry pitching revetment .In recent development they are preferably build of gabion cages filled with stones. Figure 5.11 shows an embankment cross section of a typical transverse bank construction.
- ❖ Transverse banks perpendicular or at an angle with the river bank. These are similar to the previous class but are wider and stronger. There are known as spurs or groins. Figure 5.12 shows an embankment cross section of a typical guide bank construction.
- ❖ Earth banks surrounding the village far away from the river. These are made of compacted hard clay without stone pitching. Figure 5.13 shows an embankment cross section of a typical earth bank construction.
- ❖ The method adopted in the design of these protection banks is based on practical experience on one hand and experimental findings on the other.

Figure 5-11: Transverse banks (Spurs or Groins)
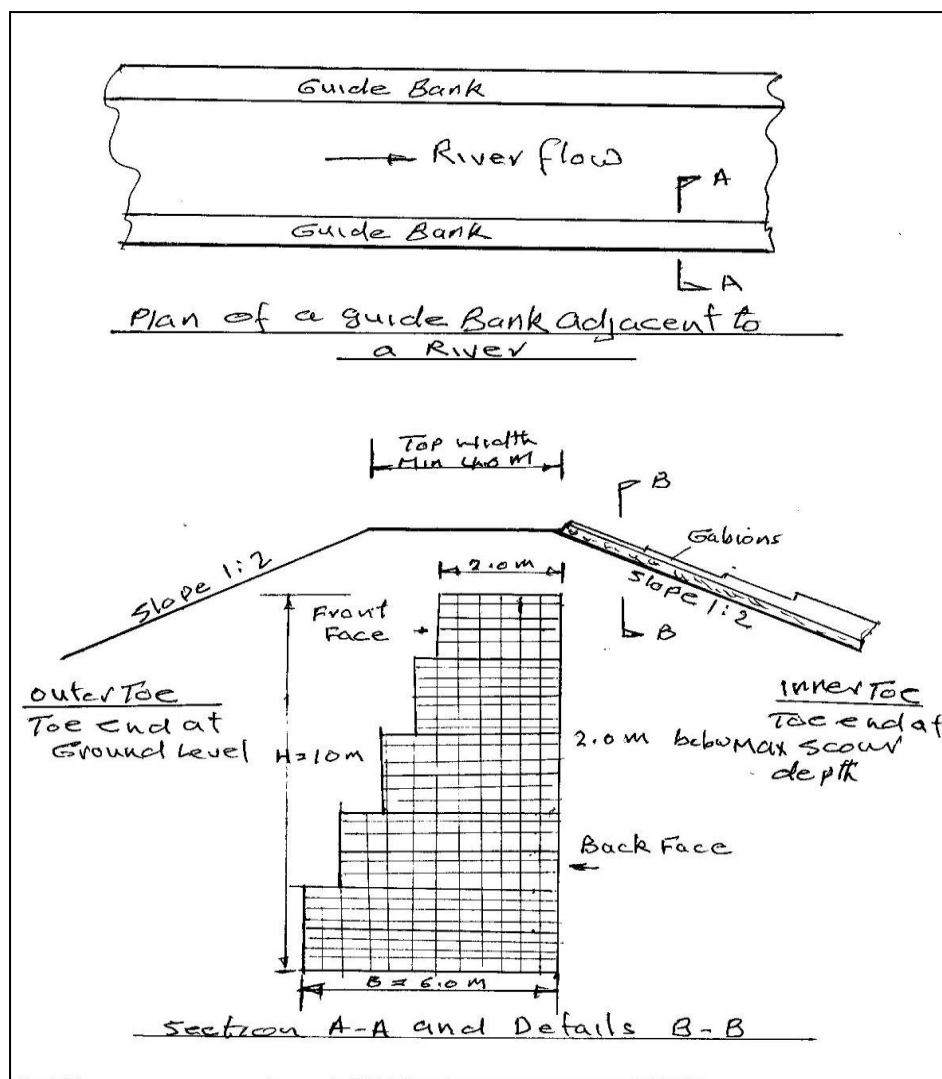
Figure 5-12: Guide banks adjacent to rivers
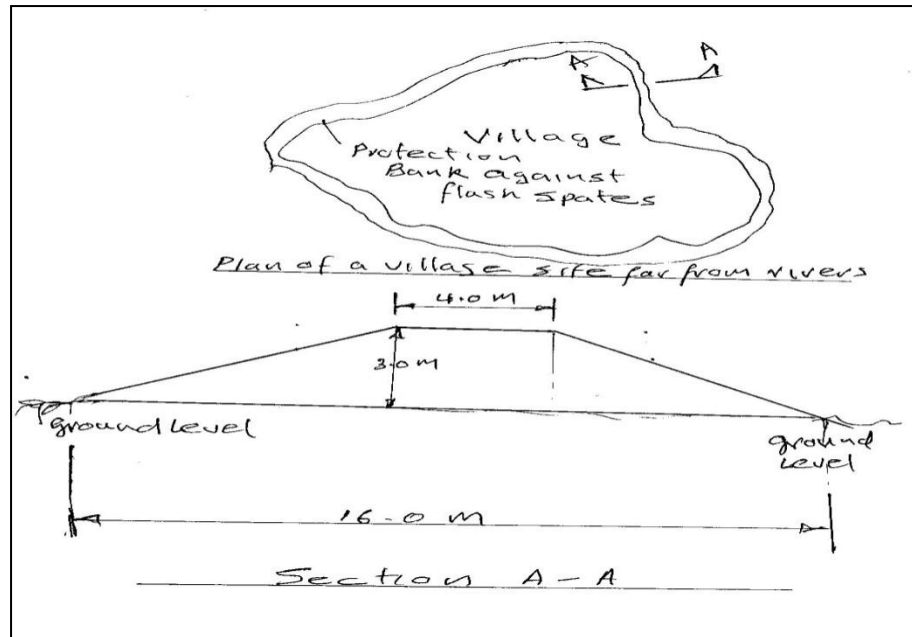
Figure 5-13: Earth banks

The method adopted in the design of these protection banks is based on Kassala River Training Department (Unit) practical experience on one hand and experimental findings on the other carried out by Ibrahim. The design of groins is based on the empirical equations relating the length of the groin to its eddy length and width and the expected scour depth. The equations are of the forms:

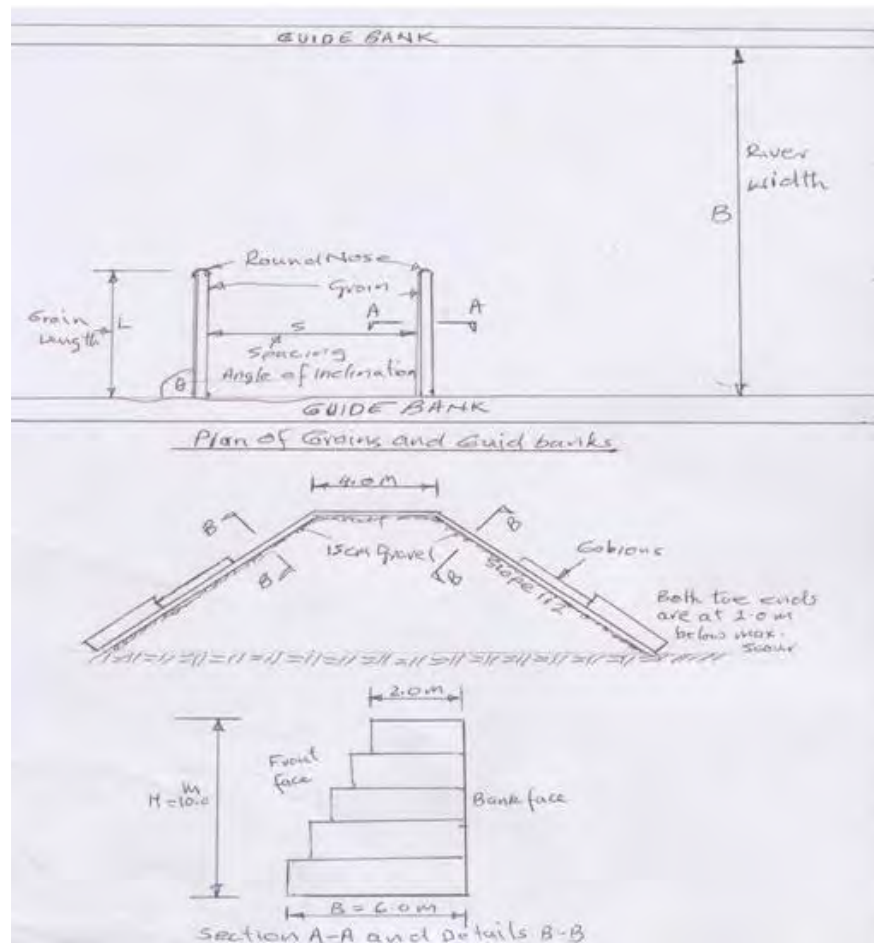$$\frac{d_s}{D} = 4.821 \left(\frac{E_L}{b} \right)^{-0.094} \left(\frac{E_W}{B} \right)^{0.289} F_r^{0.455} \left(\theta = \frac{\pi}{2} \right) --------------(5.1)$$

$$\frac{d_s}{D} = 2.639 \left(\frac{E_L}{b} \right)^{-0.092} \left(\frac{E_W}{B} \right)^{0.248} \left(\frac{\tau}{\gamma_{sub} d_{50}} \right)^{0.106} \left(\theta = \frac{\pi}{2} \right) --------------(5.2)$$

$$\frac{E_L}{b} = 0.089 \left(\frac{b}{B} \right)^{-1.995} F_r^{-0.899} \left(\theta = \frac{\pi}{2} \right) --------------(5.3)$$

$$\frac{E_W}{B} = 0.736 \left(\frac{b}{B} \right)^{0.604} F_r^{-0.135} \left(\theta = \frac{\pi}{2} \right) --------------(5.4)$$

Where: D = Depth of flow, d_s = Scour depth, b = Length of groin, E_L =Eddy length generated, E_W =Eddy width generated, B =Width of channel, F_r = Froude number of approaching flow, θ = Angle of inclination of the groin with the bank, τ =Tractive shear stress, d_{50} =Diameter of sediment particle, and, γ_{sub} =Submerged weight of sediment particle.

Table 5.1 shows the lengths of the embankments of each class for Tuti village. Table 5.2 gives the bill of quantities of each type or class for Tuti city.

Table 5-1: Lengths of each embankment class for Tuti Village

Village Name	Embankment Type Class		
	Guide banks	Transverse banks	Earth banks
	Meters	Meters	Meters
KHARTOUM STATE Tuti Island Community	5000	5000	5000

Table 5-2: Bill of quantities of Tuti Island for each of the three classes embankments

The guide banks adjacent to rivers					
Item	Unit	Quantity	Description	RateSG	AmountSG
1.	M^3	150000	Earth fill compacted in layers sprayed with water	30	4500000
2.	M^3	4500	Gravel Backing 15 cm thick under gabions	30	135000
3.	No.	50000	Gabions	400	20000000
4.	M^3	200000	Stone to fill gabions	35	70000000
Transverse banks spurs or groins.					
Item	Unit	Quantity	Description	RateSG	AmountSG
1.	M^3	150000	Earth fill compacted in layers sprayed with water	30	4500000
2.	M^3	9000	Gravel Backing 15 cm thick under gabions	30	270000
3.	No.	100000	Gabions	400	40000000
4.	M^3	400000	Stone to fill gabions	35	14000000
Earth banks					
Item	Unit	Quantity	Description	RateSG	AmountSG
1.	M^3	150000	Imported Cohessive soil compacted in layer sprayed with water	40	6000000
Total Tuti Island Amount					159405000

The layout of Tuti City of Figure 5.10 contains some spot heights and elevations adjacent to rivers or water channels in the vicinity of Tuti City. Figure 5.14) shows a typical picture of gabion protection works. Figure 5.15 shows a typical groin cabion construction. Figure 5.16, shows a typical bank failure when there are undesired activities in the area, which include digging the bank slope, building houses or water channels on the top or side slope of the bank.

The work should be extended over a number of years. Priority should be the protection of the weakest points in the village and be considered as the short term solution.

Figure 5-14: Typical guide bank gabion walls

Figure 5-15: Typical gabion groynes in construction

Figure 5-16: Guide bank failure

The remaining unprotected parts of river banks in the vicinity of Tuti City can be phased to be implemented in future as a long term solution. The distinction between the short term and long term solutions should preferably be decided upon on site.

The proposed mitigation measures shown in this study will hopefully protect Tuti City against catastrophic floods and will train the Blue Nile River. The training will definitely be manifested on the Blue Nile in the eastern part of the Island, which is suffering bank failure and collapse loosing valuable land. It is also expected to have a positive response on the Main Nile by washing away islands which were observed recently to build in the middle of the Main Nile to the North of Shambat Bridge obstructing navigation.

6

CROSS-SECTION AND DEPTH SCALE STUDIES

Section-scale studies focus on the main river channel. Point bars, central and multiple bars are the characteristic geomorphological features at this spatial scale. Typical engineering issues are river navigation and the design of hydraulic works, such as groynes and bridges. Typical tools are 2D, depth-averaged, models formulated for curved flow, which often have to include bank retreat and advance. Modelling often regards bar formation, bar migration, channel widening or narrowing as a natural development or as an effect of human interventions. This chapter includes assessment of river bank erosion at a section scale. It describes two studies: a study on bank erosion in Egypt, a rapid assessment of bridge site river section stability (northern Sudan case study).

If the observation point moves from a point above the river to a point inside the river channel, we end up looking at the vertical contour of the river cross-section from a point located either upstream or downstream. In this case, we can recognize the river banks and the water depth with its variations in space, due to the presence of local deposits and scours. Typical issues requiring depth-scale morphodynamic studies are the assessment of scour around bridge piers, bank erosion, bank accretion, dune formation. Typical tools are either 3D or 2D and 1D vertical morphodynamic models, often focusing on local bed level changes or on vertical variations, of, for instance, salinity, suspended solid concentration, soil characteristics (stratification) and bank slope.

One case study is carried out at the depth scale, it is the Bridge pier scour (River Nile in Sudan).

6.1. Egypt Case Study Bank Erosion

6.1.1. Description of the Study Area

The case study of Salam village in Egypt is located at about 371.6 km downstream of Aswan Dam was conducted. The village extends along 1.2 km reach of the main River Nile on the outer curve. Figure 6.1 shows the location of the study area.

Figure 6-1: Satellite Image of Salam Village Location

The geometric and topographic characteristics of Salam village consist of 4m wide road which separates the village from the western Nile River bank. The bank side slopes are 1:1 up to bank height of 3 m. There is 4m berm at bank height of 3m, followed by another berm of 1.5 m wide. This is followed by a side slope of 1:1 to 1m below the minimum water level. The bank was protected by stone pitching, which survived for a period of more than 15 years. Some holes with failure in some places appeared in the bank as shown in Figure 6.2.

Figure 6-2: General view of bank toe protection

The purpose of the study is to investigate the causes of the bank failure with a view to develop a sustainable solution to the problem of bank erosion and partial bank failure.

6.1.2. The Hydrographic Survey

Hydrographic survey consists of survey to 1.2 km reach fronting the Salaam village in addition to an extension of 1.6 km upstream and downstream of the village, making a total surveyed reach of 2.8 km. The contour map generated from the field survey is shown in Figure 6.3.

It is clear from the contour map that the width of the river at that part is very narrow. This means that the current velocity is highest at that part of the river. There exist three big scour holes of about of 1200 m long and 100 m wide near the western bank in vicinity of the village. The bed levels on two of the scour holes ranges from 42m to 35m above mean sea level (m.s.l) and on the third scour hole the bed level range from 42 to 25m above (m.s.l).There exist two groins along the western bank of the river reach. The first groyne with a length of 25 m is located at River Section No 8 and the second groyne having a length of 10 m at River Section No. 12. The water levels at that area range from 43 m to 47 m above mean sea level during minimum and maximum discharge, respectively. The measured velocities at sections 1 and 2 are shown in Figure 6.1. The locations of sections 1 and 2 are shown in Figure 6.3.

6.1.3. Numerical Model

The Delft-2D horizontal depth average flow computation program developed by Delft Hydraulics (1993), the Netherlands, was employed to model the surveyed reach at Salam village.
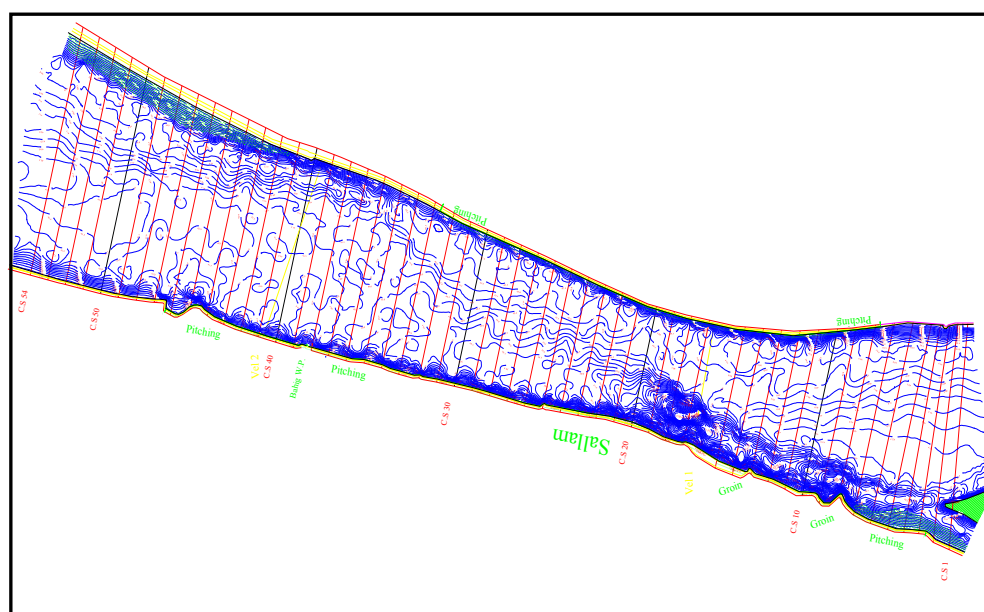
Figure 6-3: Contour map of surveyed area in 2008

The total length of the simulated reach is about 2.80 km. It includes the area of the river which has the bank failure. In addition to that area, enough distance upstream and downstream this area was included for the boundary conditions. A curvilinear grid was designed with fine grid size which ranges from 5 m to 18 m. The depth profile was created based on the hydrographic survey data. The recent bathymetric survey was superimposed. The initial conditions were set by giving suitable values to the water levels, as well as the velocity components in both the longitudinal and lateral directions. Convenient hydraulic parameters were chosen upstream and downstream the modeled reach based on the field measurements to set the boundary conditions. The discharge was used as an upstream boundary and the water level as a downstream boundary.

The hydraulic roughness coefficient was defined at each grid point. Chezy coefficient was varied in the range of (40 to 70 m$^{1/2}$/s). The hydraulic eddy viscosity was also defined as uniform value. The suitable time step and the total simulation time were defined in such away to achieve steady state conditions.

To verify the model results corresponding surveyed flow variables were compared with model output. The water surface slope was adjusted in the model by changing the Roughness Coefficient until a similar slope to the prototype was obtained. The measured velocity profiles at sections 1 and 2 were compared with those resulting from the numerical model. According to this comparison, change in roughness coefficient at some grids occurred and good agreement between the measured and resulting velocities at sections 1 and 2 was achieved as shown in Figure 6.4.

In order to decrease the velocity beside the western bank different scenarios were simulated separately on the program as follows:
   a.   Case 1: Existing condition (Doing nothing).
   b.   Case 2: Extending the second groin to a length of 60 m in addition to filling the lower part of scour hole to level of 40.0 m above mean sea level.
   c.   Case 3: Filling the lower part of scour hole to a level of 40.0 m above mean sea level.
   d.   Case 4: Dredging the bed and deepening the channel in areas closer to the scour hole until level of 40.0m above mean sea level is achieved.

The results of each run which is shown in terms of velocity variations at 4 cross sections and comparison with existing condition are shown in Figure 6.6. the location of the 4 cross-sections is shown in Figure 6.5.

1-Analysing the velocity profiles at cross sections A, B, C, D and E shows that the velocity at the western side of the river do not decreased than the existing situation. This means that above suggested alternatives for the solution are not convenient in this case.

2- Comparing the contour map resulting of 2008 shown in Figure (6.5) with that one resulting in 2003 shown in the appendix. The followings were found:
   a) The three scour hole existed before 2003.
   b) The centre of the holes did not move until 2008.
   c) The scour depth almost did not change except for the third scour hole
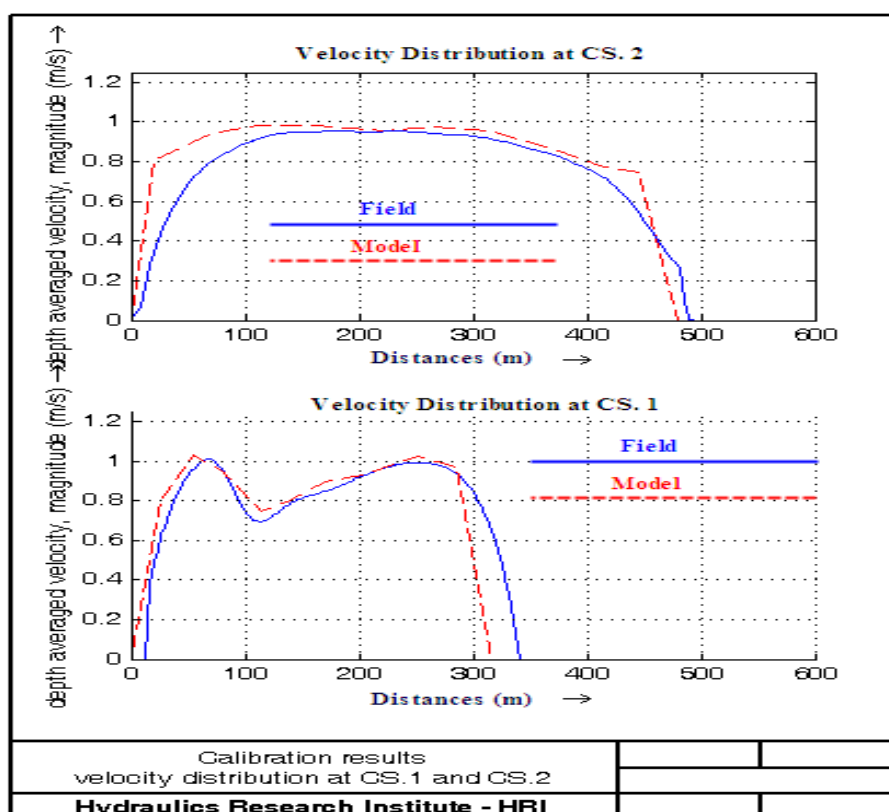
Figure 6-4: Measured and simulated velocity at Sections 1 and 2

From the above analysis it is concluded that:-

1-The place located at the outer curve and the width of the river is very narrow at that part, so the momentum of the water movement is high. The proposed suggestions did not decrease the velocity at the western part of the river at the outer curve.
2- The scour holes are stable
3-The maintenance of the bank protection at that location where it was established 15 years ago

Figure 6-5: Location of the cross sections used in velocity profiles comparison

Figure 6-6a: Depth-averaged velocity for different scenarios

Figure 6-6b: Depth-averaged velocity for different scenarios

Figure 6-6c: Depth-averaged velocity for different Scenarios

6.2. Geomorphic Assessment Across The Main River Nile at Aldaba (North Sudan)

Aldaba Bridge is proposed to connect Aldaba City on the western Main Nile to Karima City of North Sudan. The proposed bridge site is about 50 km downstream of Merowe 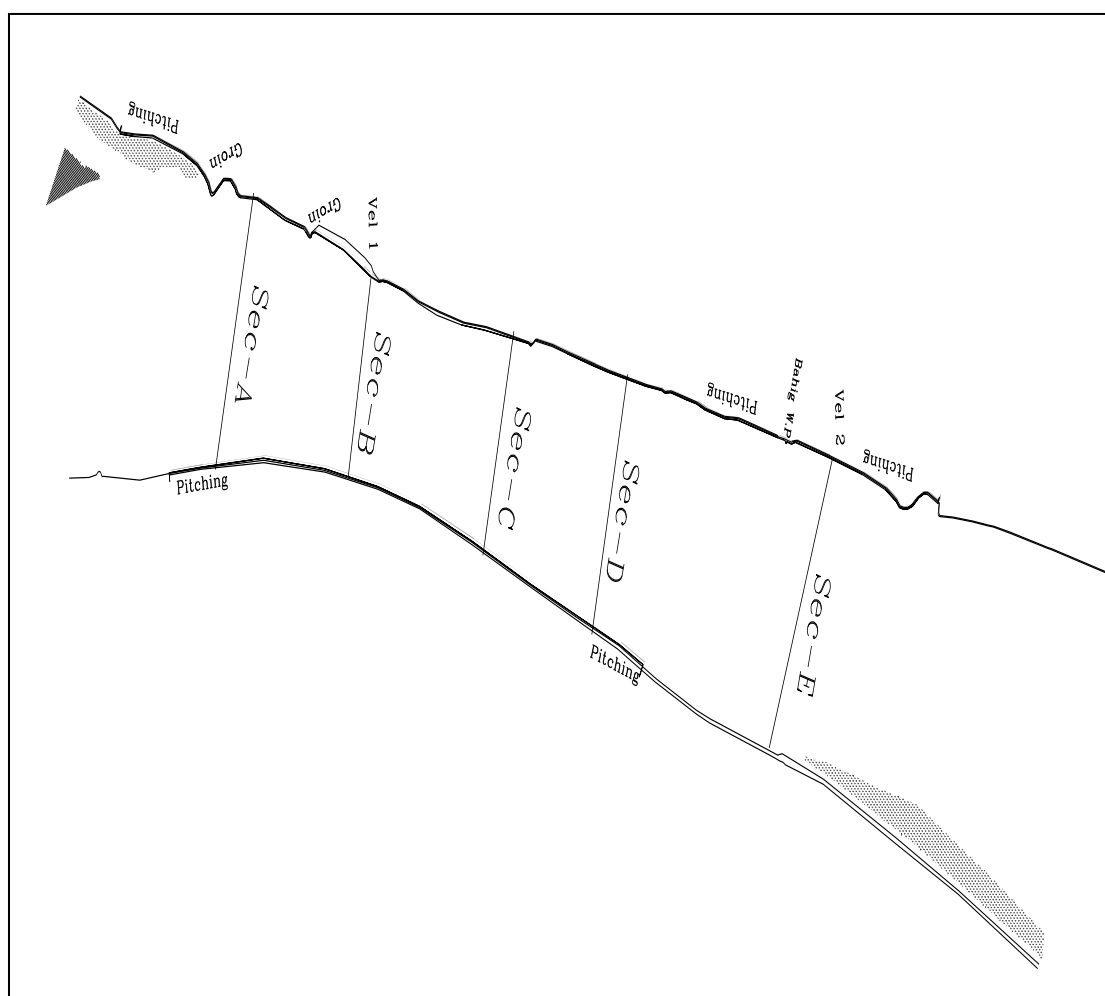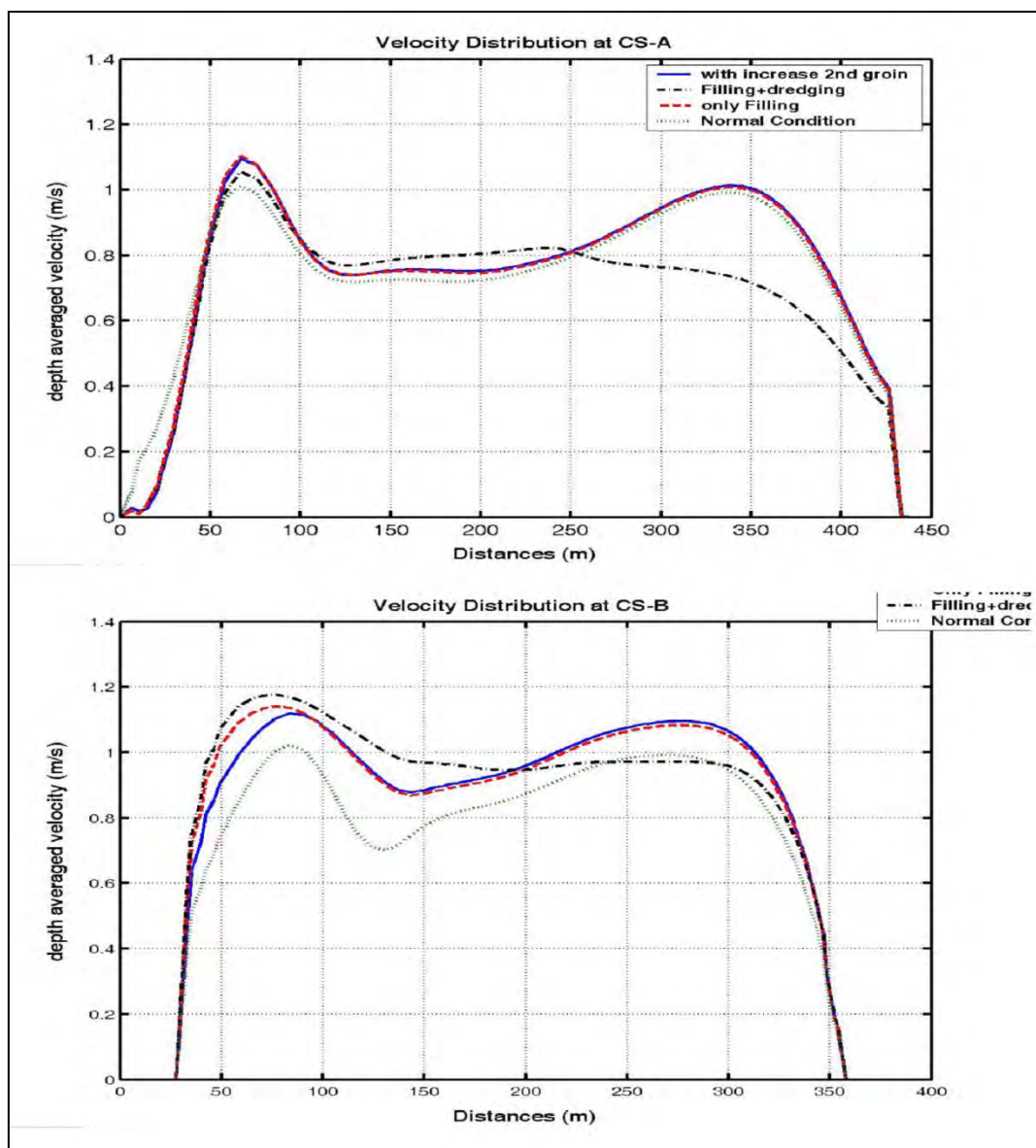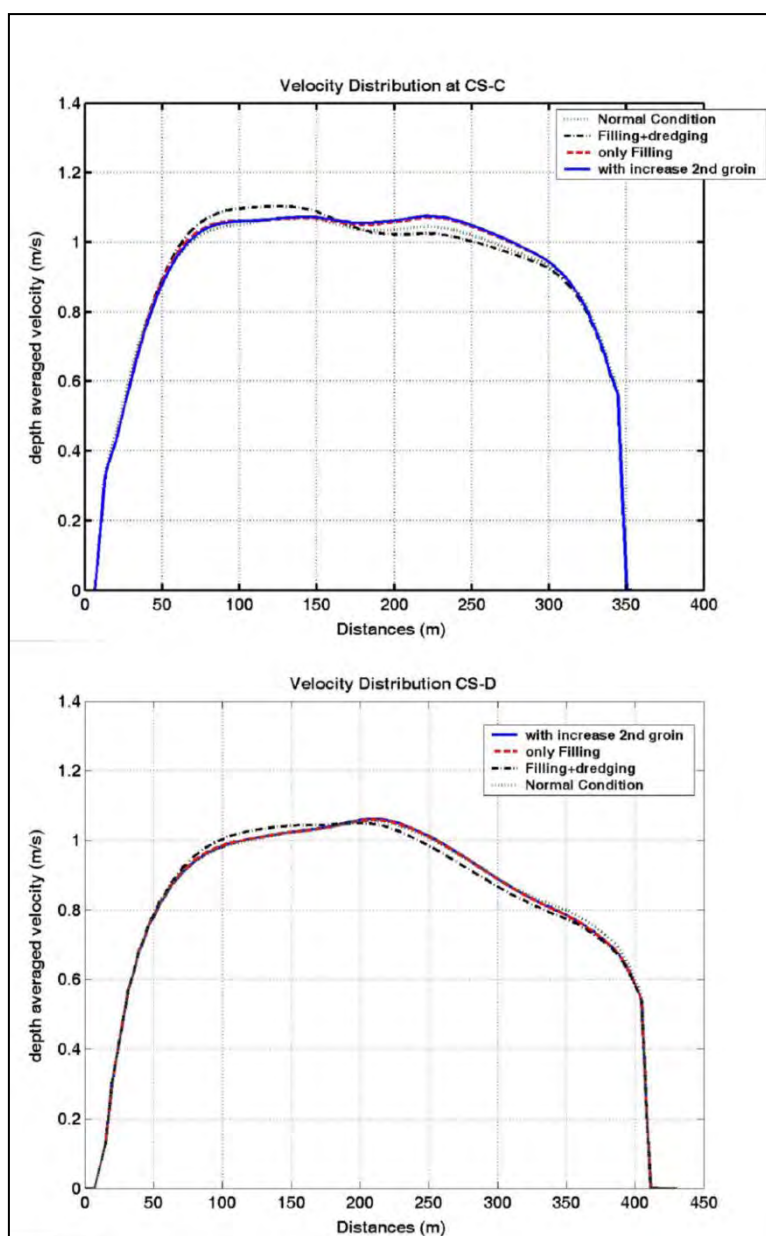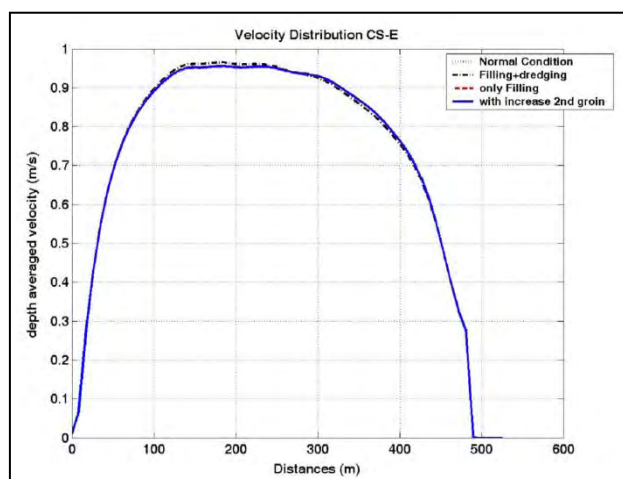Dam. The extent of the study area is about 7.4 km and covers an existing island just upstream of the proposed bridge site. Figure 6.7 shows the overall map of the study area and the approximate location of the bridge crossing.
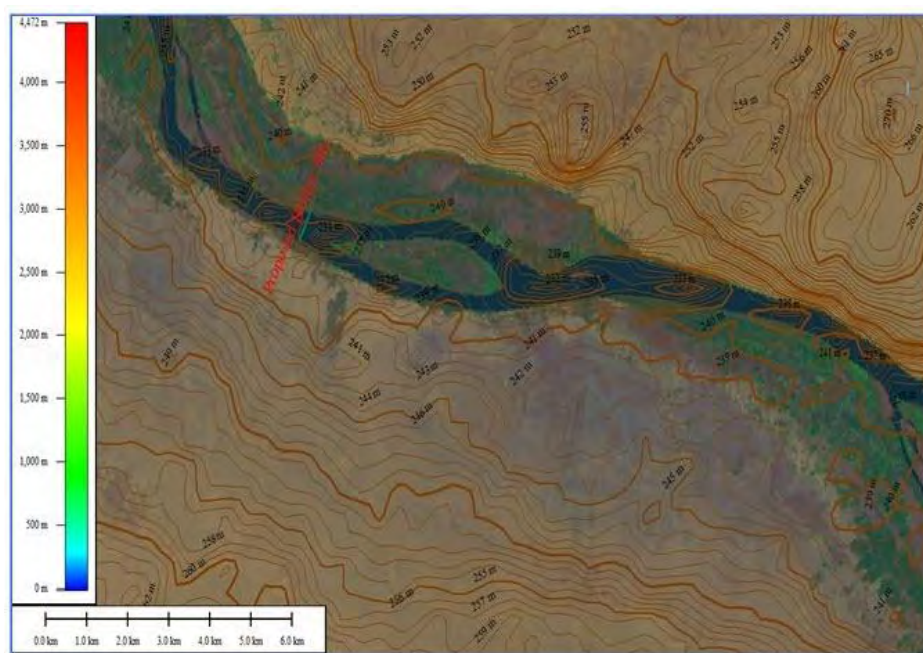

Figure 6-7: Site map

The average channel width along the reach under consideration is about 330 m, and the flow depth varies from 6m to about 14 m. The river valley has a plain terrain with the eastern portion severely stricken by sand encroachment and desertification. The river Nile around the study area is typically alluvial and the channel characteristics depend upon the relative resistance of bed and bank material to erosion in the different cross-sections along the channel. The height of the bank ranges from 5 to 10 meters with steeper bank slope on the eastern side and relatively flatter slope on the western bank. The type of vegetation on the bank varies from woody vegetation to bare soil. Figures 6.8-6.13 show pictures of the river banks along the subject reach.

Khartoum Unit Consultancy Corporation carried out bathymetric survey, soil survey; with gradation test as well as hydraulic analysis to evaluate scour depth at the bridge site. A contour map was generated as shown in Figure 6.14, using a software. The soil survey was conducted by analyzing samples taken from locations shown in Figure 6.15. Soil samples taken from the bed and banks revealed that the textures are silty clay material dominates the banks with clay of 30 %, while the bed material ranged from sand to gravel. For the stream stability assessment test they applied HEC-20,on bed and banks. Field observations indicated that location (2),is more stable than location (1) of Figure 6.6. However the analysis indicated that both locations suffer intensive scour requiring bank protection. Accordingly they suggested a location about half to one kilometer downstream location (1), where investigations indicated that the river has stable bank suitable for the bridge construction.

Figure 6-8: Eastern bank D/S of proposed bridge

Figure 6-9: Western Bank D/S of the Proposed Bridge

Figure 6-10: Erosion of the eastern bank upstream of the bridge site

Figure 6-11: Erosion of the western bank upstream of bridge site

Figure 6-12: Sand encroachment on eastern bank

Figure 6-13: Brick making activities along the western bank
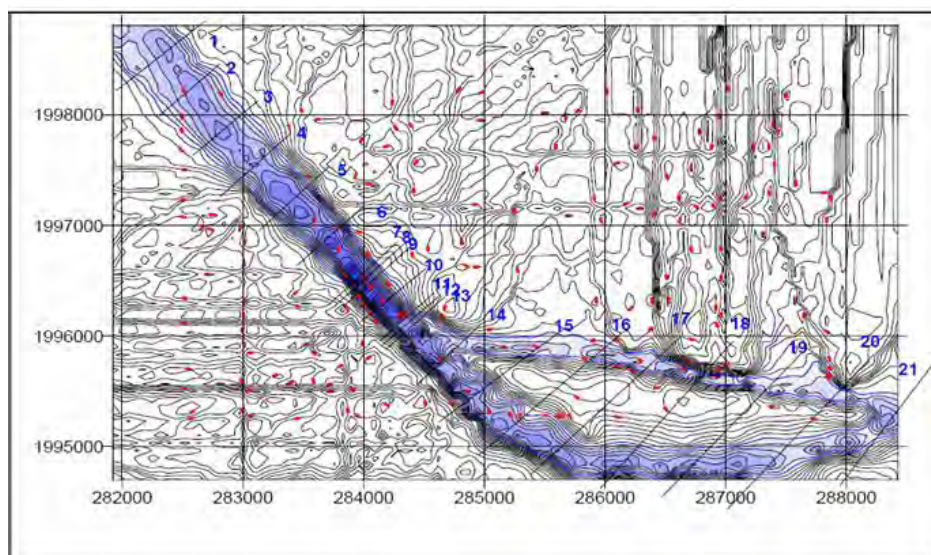
Figure 6-14: Generated contour map for the study area
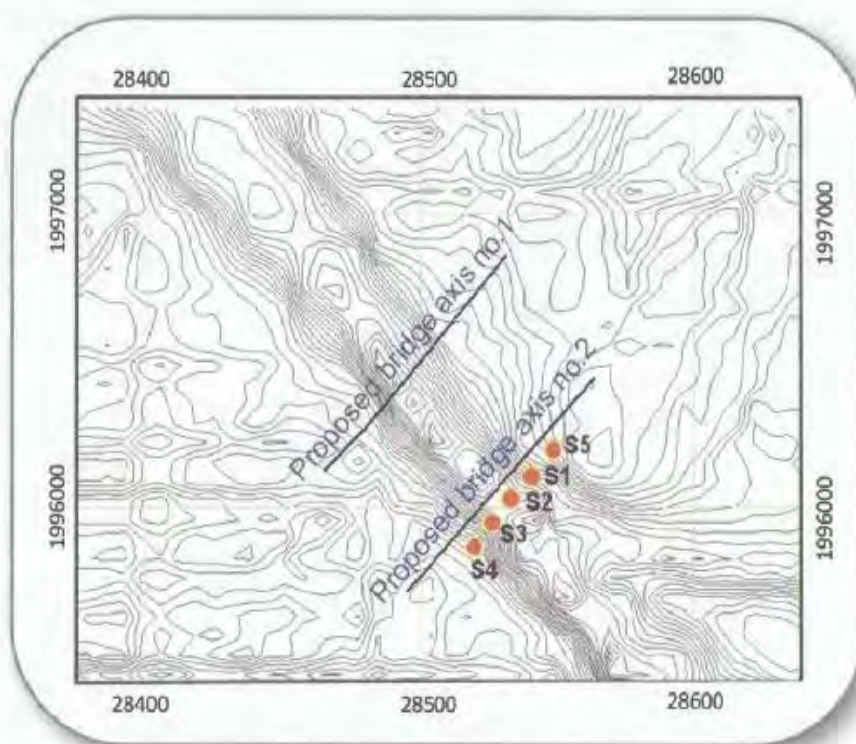
Figure 6-15: Location of soil sampling

6.3. Bridge Pier Scour (River Nile in Sudan)

In the last 10 years 11 bridges have been constructed and/or under construction across the Nile. More bridges are planned in the coming few years. Estimating local scour depth for bridge abutments and piers are very important for safety of the structure and optimization of the substructure cost. In this regards Akode conducted a study of bridge pier scour.

6.3.1. Local Scour

Local scour is observed to occur when the flow direction is obstructed by a body or abruptly changed. These results in high flow accelerations at the boundaries of the obstructed body and generation of horizontal and vertical strong vortices that lead to material removal and generation of scour hole around the structure. Figure 6.16 shows local scour concept.
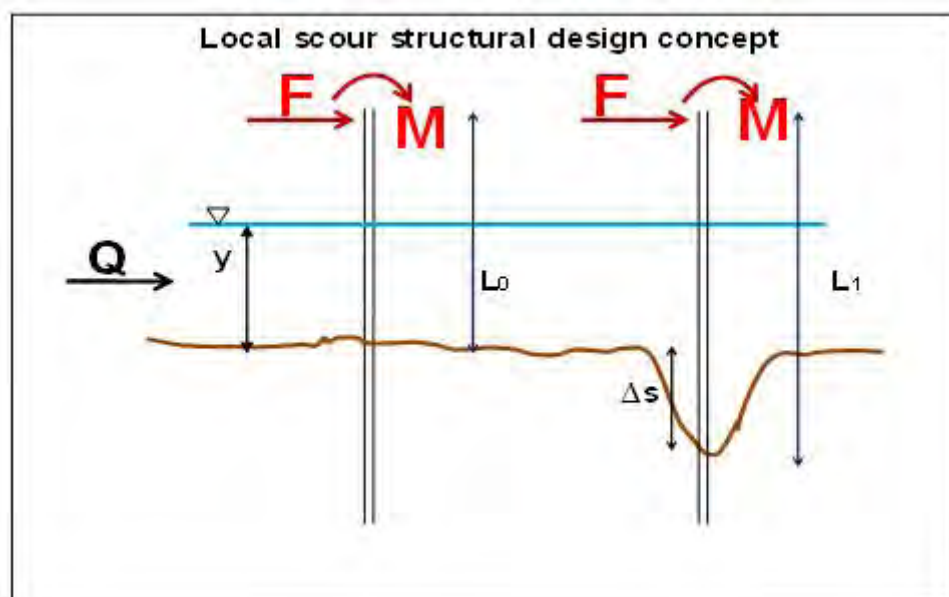
Figure 6-16: Local scour concept

6.3.2. Scour Conditions

In the case of clear water scour the flow of sediment into the scour hole is zero. In the case of live bed scour there is inflow of sediment into the scour hole. If the sediment amount entering the scour hole is greater than the rate of material removal then the scour depth is decreasing with time. Else it will increase with time. For the Nile the case is the live bed scour, as depicted in Figure 6.17.

Figure 6-17: Live bed scour in the Nile River

6.3.3. Local Scour Estimates

For angle of attack ≤ 0.Use equations with correction factor K2= 1.0.For such case practical ranges are Scour depth Δs = 2.4 times the pier width a, for Fr < 0.8.Scour depth Δs = 3.0 times the pier width a, for Fr > 0.8.If angle of attack > 5 degrees use equations with correction factor K2 > 1.0.

All existing relations are empirical ones based on laboratory studies. For simple piers cases where Δs is the local scour depth and a is the width of the pier and C is a factor usually depends on the geometry of the pier and Froude number (C= 2.4 - 3.0).

$$\frac{\Delta s}{y} = C\left(\frac{a}{y}\right)^{\alpha} Fr^{\beta} - - - - - - - - - - - - - -(6.1)$$

Modified CSU equtation is given as

$$\frac{\Delta s}{y} = 2K_1 K_2 K_3 K_4 \left(\frac{a}{y}\right)^{0.65} Fr^{0.43} - - - - - - -(6.2)$$

Where: K_1 = shape correction factor, K_2= angle of attack correction factor, K_3 = bed shape (form) correction factor, and K_4 = armoring correction factor.

Table 6.1 shows the values of the factors related to angle and shape, and Table 6.2 shows the values of bed form types.

Table 6-1: Values of factors related to angle and shape

Shape Of Pier	K_1	Values Of K_2			
Square Nose	1.1	Angle	$\frac{L}{a} = 4$	$\frac{L}{a} = 8$	$\frac{L}{a} = 12$
Round Nose	1.0	0	1.0	1.0	1.0
Circular Cylinder	1.0	15	1.5	2.0	2.5
Group Cylinder	1.0	30	2.0	2.75	3.5
Sharp Nose	0.9	45	2.3	3.3	4.3
		90	2.5	3.9	5.0

Table 6-2: Values of K3 for different bed form types

Bed Condition	Dune Height	K_3
Clear Water Scour	N/A	1.1
Plane Bed And Anti Dunes Flow	N/A	1.1
Small Dunes	$3 > H \geq 0.6$	1.1
Medium Dunes	$9 > H \geq 3$	1.2 to 1.1
Large Dunes	$H \geq 9$	1.3

For complex piers foundations, there is much complication, and laboratory studies are still going on. Currently the method demonstrated by HEC-18 is used in the analysis and local scour depth calculations. The idea is to calculate the scour depth corresponding to pier stem Δs1 and the pile cap Δs2 and the piles group Δs3 assuming equivalent full pier depth.

The total scour

$$\Delta sT = \Delta s1 + \Delta s2 + \Delta s3 \text{----------}(6.3)$$

For the pier stem scour component

$$\frac{\Delta s_1}{y_1} = k_{hpier}[2K_1K_2K_3K_4\left(\frac{a*}{y_1}\right)^{0.65} Fr^{0.43}] - (6.4)$$

$$a* = see\ HEC - 18\ chapter\ 6$$

For the pile cap scour component

$$\frac{\Delta s_2}{y_2} = 2K_1K_2K_3K_4K_W\left(\frac{b*}{y_2}\right)^{0.65} Fr^{0.43} - - - - - -(6.5)$$

$$K_W = Correction\ factor\ for\ wide\ piers\ in\ shallow\ flow.$$

$$b* = see\ HEC - 18\ chapter\ 6$$

For pile group scour component

$$\frac{\Delta s_3}{y_3} = k_{hpile} \left[2K_1 K_3 K_4 \left(\frac{s*}{y_3} \right)^{0.65} Fr^{0.43} \right] - - - - - (6.6)$$

$$s* = see \; HEC - 18 \; Chapter \; 6$$

For the local scour total depth

The total local scour depth ΔsT is the sum of the three scour components.

ΔsT = Δs1 + Δs2 + Δs3 --------(6.7)

Akode indicated that the values of the general scour and contraction scour if any are to be added to the total local scour depth. Observed scour values for some bridges in Sudan are as shown in Table 6.3.

Table 6-3: Scour values for some bridges in Sudan

No.	Bridge	Pier Type	Sour Δs m	Designed Scour Depth m
1	New Atbara bridge	Multi. columns	2.0	-
2	Khartoum North (military)	2 shafts above & 1 below	2.7	-
3	Khartoum North (steel bridge)	2 continuous braced shafts	2.54	-
4	Mek Nimir bridge	Complex pier	3.0	10 (per. cont.)
5	Dongola bridge	Multi. columns	1.9	5.5
6	El Damer bridge	Multi. columns	-	4.8m
7	Matama bridge	Complex pier	-	12m
8	Karima-Merowe bridge	Complex pier	5.8***	12m
9	Halfaya bridge	Complex pier	-	7m

7

LESSONS LEARNED, CONCLUSIONS AND RECOMMENDATIONS

This chapter gives the recommendations and conclusions revealed in the form of lessons learned from the studies and practical experiences gained through discussions and field visits as well as meetings conversations and discussions concerning the whole report.

7.1. Conclusions

The main conclusions are outlined below.

It can be assumed that the water NDVI of Lake Victoria, especially close to Nyando estuary, can be considered a good indicator of the erosion phenomena of the basin. Further results and details of this work with a more extended NDVI dataset and with higher resolution imagery are expected.

The occurrence of floods and erosion phenomena is expected to cause severe human impact. River bank erosion is a natural complex phenomenon governed by inter-related factors in the Nile River Basin. Erosion occurs in a variety of types mainly influenced by climate, hydrology, soils, operation and maintenance of hydraulic structures across the rivers and human irrational practices of land uses.

Areas experiencing serious riverbank erosion are the Main Nile, Atbara River and Blue Nile. The White Nile banks are relatively stable with little or no erosion. Gully erosion degradation is usually extended as a strip bordering streams and cultivated or grazed land in semiarid or dry sub-humid zones. Upper Atbara River reaches and localized reaches along the Blue Nile represent the most intensively degraded land by gully erosion, forming the main sediment sources.

The human interference in the vicinity of the river in soil excavation for brick making and tree cutting are responsible for undermining the river equilibrium, which force the river to behave differently producing bank erosion to regain balance.

Increased rates of bank erosion in the southern Blue Nile are influenced by changing the cropping pattern that replaces big deep-rooted fruit trees by shallow rooted banana trees.
Accumulation of sediment material, blockage of inlet channel and damaging of pumping sets and buildings manifested River bank erosion into loss of valuable fertile agricultural lands through river widening, irrigation water shortage through water recession.
The state of soil erosion in the study area in Ethiopia has reached alarming levels and is increasing under the combined pressures of increasing population and the land's loss of vegetation cover.

Soil erosion in Ethiopia may be regarded as the single most important problem in the study area as it undermines current, future agricultural production, agro-industrial development, long term use of the water resources dependent on reservoirs and dams within the study and transboundary areas.
The biophysical processes and causes responsible to the prevailing severe soil erosion in the Nile Basin Parts of Ethiopia and the Equatorial basin have high intensity rainfall, erodible soils, steep and long slopes of the high lands, poor vegetation cover due to inappropriate land management practices that rendered 80% of annual soil losses by erosion.

The choice of techniques for soil and water management measures is associated with the objectives, which are water management, fertility restoration, and maintenance or improvement of vegetation cover.

Finally, it can be concluded that the upper reaches of the Eastern and Equatorial basins are deeply incising associated with severe gully erosion. While the lower reaches in Sudan and Egypt, the River Nile is of meandering nature causing pronounced bank erosion, due to flat topography and dry climate.

7.2. Recommendations

The main recommendations are outlined below.
- Erosion control should be considered as one of the parameters of agricultural intensification but not a means itself.
- Proposals for future research should deal with the behavior of the main rivers in details.
- Future mitigation and protection should include tributaries.
- Dissemination of the results is to be through the publication in the net and NBCBN Website.
- Water management policies are urgently needed.

Finally, it is important:
- To promote cooperation on transboundary environmental issues.
- To limit the excavation of soil for brick making.
- To minimize the human interferences in the route of river flow, its flood plains, and river banks to decrease water erosion.
- To encourage the use of remote sensing and GIS because it proved to be a successful tool in evaluating the rates and types of erosion with minimum cost.
- To mitigate sand encroachment and fix barchan dunes along the Nile in the downstream countries viz Sudan and Egypt.

8

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Full Profiles of Research Group Members are available on: The Nile Basin Knowledge Map
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NILE RIVER BANK EROSION AND PROTECTION

Along the Nile River and its tributaries, erosion represents a serious problem. The impact of this problem is widely spread within the Nile basin countries causing a great set back for their socio-economic development. Soil erosion mainly occurs in the upper catchments, whereas bank erosion, which can be extended to gully formation and excavation, occurs along the upper river network.

Erosion is a natural phenomenon governed by many factors, including climate, hydrology, soil characteristics and human practices. River bank erosion, in particular, is affected by the excavation of soil for brick making, and building materials, cutting of trees, cropping pattern management and dumping of solid materials, mostly close to urban centers. Valuable irrigable lands are lost because of riverbank erosion along the Blue Nile and the main Nile River. The total irrigable land loss in Sudan was estimated to range from 13 to 52 % (unpublished data from the Forest National Corporation, FNC). The major factor currently affecting the magnitude of riverbank erosion in the Blue Nile area has been identified in the change of the cropping pattern. The large flows cause floods, bank overflow and surface drainage difficulties during the rainy season, which cause bank erosion. The rapid drawdown of the Nile as a result of dam operation or seasonal drought and sand encroachment enhance bank failure. Thus, changes in the river hydrodynamics can significantly influence the changes that may take place within the Nile course. Soil erosion occurring in the upper catchment is mainly caused by deforestation practices. The results are local losses of arable land, deep gully formation and a large increase of sediment input to the river system, leading to sedimentation problems more downstream.

Research projects on water erosion were carried out in different countries with the aim of increasing the knowledge on the entity and characteristics of the erosive phenomena along the Nile River system and evaluating the consequences. Given the large number of works dealing with soil erosion in the upper catchment, it has been decided to include all the results of these works in this report so that the erosion problem could be fully represented. The works have been classified by their spatial scale.

Knowledge Networks for the Nile Basin

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