Improved water and land management in the Ethiopian highlands and implications for the downstream Blue Nile[1]

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Abstract
This paper introduces and highlights some results of a multi-institutional collaborative research project under implementation. The project is entitled "Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile". In the Nile Basin, water from the Ethiopian highlands, particularly from the Blue Nile (Abay), has in the past benefited downstream people in Sudan and Egypt in different ways – agriculture, livestock, industry and electrical power. However, such free benefits are now threatened due to dramatically changing land, water and livestock management practices upstream. High population pressure, lack of alternative livelihood opportunities and the slow pace of rural development are inducing deforestation, overgrazing, land degradation and declining agricultural productivity. Poor water and land management upstream reduces both potential runoff yields and the quality of water flowing downstream. The result is a vicious cycle of poverty and food insecurity for millions living upstream and poor water quality, heavy siltation, flooding, and poor temporal water distribution for those living downstream. It is widely recognized that improved water management in the Abay Basin could significantly increase water availability for various stakeholders within the basin. Key research questions to be addressed in the project include: What are the successful interventions that help improve productivity and reverse degradation? What are the impacts downstream? What are the opportunities and constraints enhancing rural livelihoods and food security? This paper presents intermediate results related to meteorological, hydrological and physical based basin characterization, methodologies for erosion and sediment modelling and water availability and access for various production systems. Synergies and complementarities with the Nile Basin shared vision and subsidiary action projects, particularly within the Eastern Nile are also highlighted.

Key words: Blue Nile (Abay), upstream-downstream, watershed management, water allocation, degradation, sediment, modelling

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1. **Introduction**

The need for integrated water resources management to alleviate poverty and food insecurity especially in semi-arid Africa, where over 80% of rural livelihoods depend directly on land and water resources, cannot be overemphasized. Recent strides in sustainable resource management have recognized the need for a broad based, integrated approach that coordinates the activities of people dependent on a common resource-base to achieve resource-use efficiency, equity and sustainability. In the Nile Basin, water from the Ethiopian highlands, particularly from the Blue Nile (known as the Abbay in Ethiopia), has historically benefited downstream people in Sudan and Egypt in different ways: agriculture, livestock, industry and electrical power (Awulachew et al, 2008)

The sustainability of such use, the availability of the resource in terms of water quantity and quality is heavily affected and continues to be affected by dramatic changes in land, water and livestock management in the upstream catchment. High population pressure, lack of alternative livelihood opportunities and the slow pace of rural development are facilitating deforestation, overgrazing, land degradation and declining agricultural productivity. Poor water and land management by upstream uses reduces both potential runoff yields and the quality of water flowing downstream. It is widely recognized that improved water management in the Abbay catchemnt could significantly increase water availability for various stakeholders within the catchment. This would help to alleviate the impacts of natural catastrophes such as droughts and reduce conflicts among stakeholders dependent on the river.

Proposed by diverse stakeholders, a two years research project has started. This *hypothesizes* that with increased scientific knowledge of the hydrological, hydraulic, watershed, and institutional processes of the Blue Nile in Ethiopia (Abbay), constraints to up-scaling management practices and promising technologies within the catchment can be overcome, resulting in significant positive benefits for both upstream and downstream communities (i.e. win-win scenarios).

The major research questions being addressed by the project are:

1: What are the successful interventions that help improve productivity and reverse degradation?
2: What are the downstream impacts of these interventions?
3: What are the opportunities for enhancing rural livelihoods and food security?

These questions are broadly defined to prove the underlying hypothesis and all require in depth research to answer them. A substantial effort is being undertaken to identify interventions, prove concepts and evaluate their impacts. Strong partnerships have been developed with various institutions jointly undertaking the research.

This paper presents discussion of methodologies, on-going work and preliminary results, focusing on a review of literature covering meteorology, hydrology, water use, development potential and sediment transport within the basin.

2. Characterization of the Abbay (Blue Nile) River System

The Abbay-Blue Nile[2] Sub-basin covers an area of 311,548 km^2 (Hydrosult et al., 2006) and the river is the principal tributary of the main Nile River. It provides 62% of the flow reaching Aswan (World Bank, 2006). The river and its tributaries drain a large proportion of the central, western and south-western highlands of Ethiopia before dropping to the plains of Sudan. The confluence of the Blue Nile and the White Nile is at Khartoum. The Dinder and Rahad rise to the west of Lake Tana flow westwards across the border joining the Blue Nile below Sennar.

The basin is characterized by highly rugged topography and considerable variation of altitude ranging from about 350 masl at Khartoum to over 4250 masl. in the Ethiopian highlands (Figure 1). Figure 2 shows the major tributary rivers as categorized by Hydrosult et al (2006).

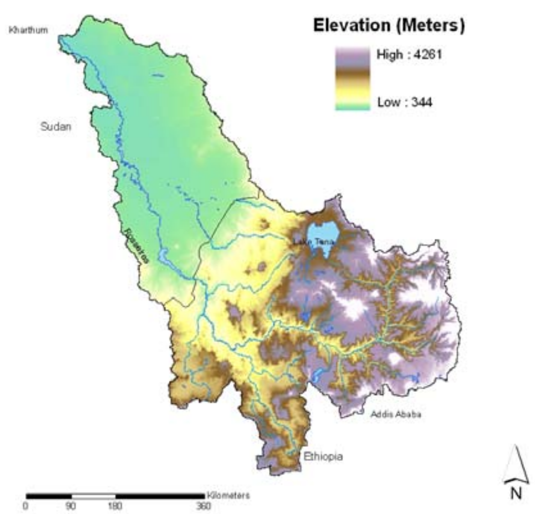

Figure 1 Map of the Blue Nile showing elevation, main tributaries and key geographic features (Source: Awulachew et al, 2008)

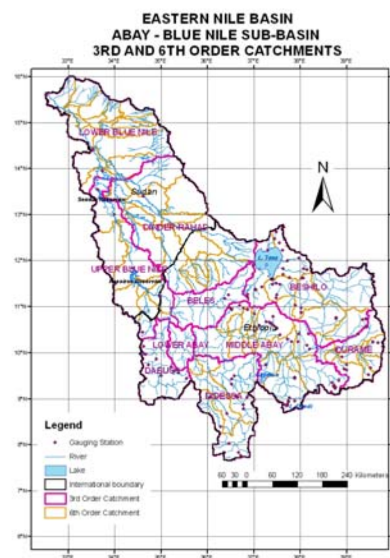

Figure 2 Abay-Blue Nile Sub-basin: 3[rd] and 6[th] Order Watersheds

Rainfall varies significantly with altitude and is considerably greater in the Ethiopian highlands than on the Plains of Sudan (Figure 3). Rainfall ranges from nearly 2,000 mm/yr in the Ethiopian Highlands to less than 200mm/yr at the junction with the White Nile. Within Sudan, the average annual rainfall over much of the basin is less than 500mm. Above Rosieres, the average annual rainfall is about 1,600 mm. It increases from about 1,000 mm near the Sudan border to between 1,400 and 1,800 mm over parts of the

[2] The Abay-Blue Nile is a sub-basin of the main Nile. The sub basin is called Abay in Ethiopia and Blue Nile in the Sudan. Generally, Blue Nile basin is widely understood to represent the Abay-Blue Nile upstream of its confluence with the White Nile.

upper basin, in particular in the loop of the Blue Nile south of Lake Tana. Rainfall exceeds 2,000 mm in parts of the Didessa and Beles catchments.

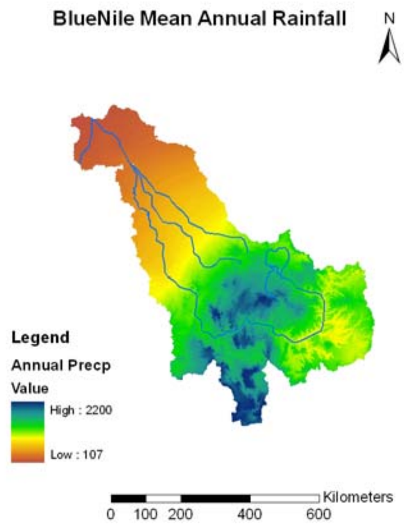

Figure 3: Mean annual rainfall across the Abay – Blue Nile catchment (mm/yr)

The highest basin temperature varies from 44°C to 21°C in Sudan in May and Ethiopia in February respectively. By comparison, the lowest basin temperature varies from 14°C in Sudan in January to less than 3°C in Ethiopia. These temperature and rainfall values indicate high evapotranspiration in places in the basin, highlighting both the need for irrigation and the potential for high losses of water in water management systems.

There are considerable seasonal variations in river flow. The mean monthly low flow of the Blue Nile at Khartoum is 302 million m^3/month in February and the peak flow is 13,151 million m^3/month in August.

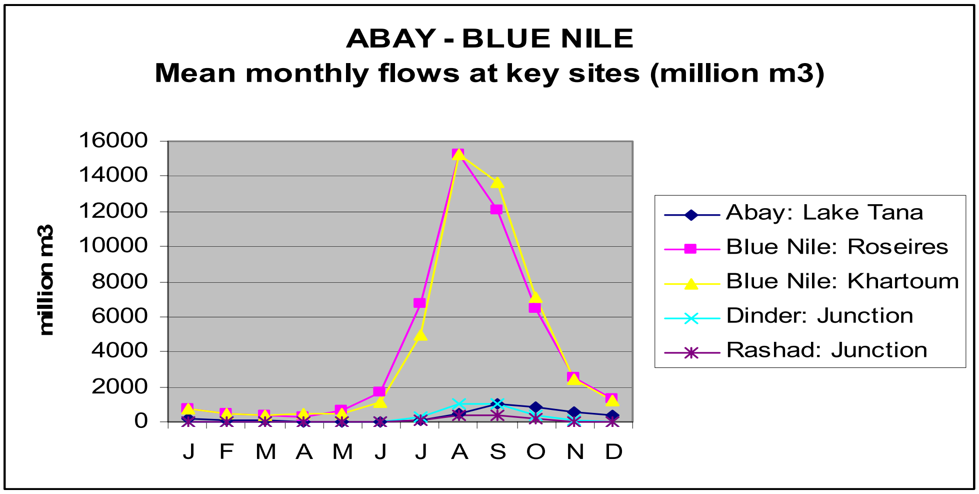

Figure 4. Mean monthly discharge (million M^3) at key sites in the Abbay - Blue Nile Sub-basin:

Similarly, there are considerable variations in annual discharge. The annual discharge for the Blue Nile oscillated around the mean between 1920 and 1960. From 1960 to 1984 there was a general decrease in discharge. Thereafter annual discharge has gradually increased (Ahmed, A, 2006, Hydrosult et al, 2006).

3. Runoff Mechanisms and Water Availability

3.1 Modeling runoff

Many models have been used to study the hydrology of the Abbay-Blue Nile. Awualchew et al. (2008) identifies 13 rainfall-runoff models that have been used (c.f 22 other models for the hydrology of the whole Nile). None of these models are widely adopted in the basin and development of similar models continues. The question to be answered remains; what simulation model or models should be used for simulating the hydrology for the Abay/Blue Nile basin? Since the direct runoff is dependent mainly on the total rainfall and only slightly influenced by the intensity of the rainfall, the obvious choice for modeling the Nile hydrology are the water balance type models. Water balance models are also appropriate because they require minimal input data (e.g., precipitation (P) and potential evapotranspiration (PET) data that are generally available). An interesting approach to simulate this phenomenon was developed by Tesfahun, D, et al (2006) employing a hyperbolic sine function to assure that the soil storage reservoir has to be filled, after the dry season, before runoff is produced in significant quantities.

Ultimately there is a need for additional model development because water balance models only provide the discharge at the watershed outlet and do not give the spatial distribution of runoff within the basin. The runoff distribution is especially important for prediction of erosion and sedimentation. Although many semi-distributed models claim to predict the spatial distribution of runoff, very few have been validated. Currently, we feel that using several models in combination may result in the best outcome. Our understanding of the hydrology can be enhanced by using a combination of model predictions. We are using both the simple parameter SWAT model based on the generalized curve number method and a modified version of SWAT which incorporates

modifications reflecting actual behavior of climate and the watershed runoff generating processes. At this stage, in addition to reviewing the various existing models, we have employed SWAT, taking the Gumera watershed as a sub-basin for modeling. Within this we have generated flow at the outlet in combination with sediment modeling and analyses of the impact of different land and water management interventions (see also section 4 below). Accordingly, the modelling and performance evaluation of unmodified SWAT provides (calibration, validation) resulted in Nash – Suttcliffe simulation efficiency (ENS) of (0.76, 0.72) , correlation coefficient (R^2) of (0.87, 082), and mean deviation of (3.29 %, -5.4%) showing a good agreement between measured and simulated monthly flows. See Tenaw, M. (2008) for further information.

3.2 From Hydrology to Existing water use

Ethiopia currently utilizes very little of the Blue Nile water for a range reasons, including its inaccessibility, the fact that major centers of population lie outside of the basin and there are inadequate resources for investment etc. To date only two relatively minor hydraulic structures have been constructed in the Ethiopian Blue Nile catchment. These two dams (i.e., Chara Chara weir and Finchaa) were built primarily to provide hydropower. The combined capacity of the power stations they serve is 218 MW represents approximately 30% of the total currently installed power capacity of the country (i.e. 731 MW) (World Bank, 2006).

There is very little irrigation in the Ethiopian Blue Nile catchment. The total irrigated area is currently estimated to be little above than 10,000 ha, but since this does not include the small-scale traditional schemes it is certainly an underestimate of the real total. Currently, the only major irrigation scheme in the Ethiopian part of the catchment is the Finchaa sugar cane plantation (8,145 ha), which utilizes water after it has passed through the hydropower plant at the Finchaa dam.

In contrast to Ethiopia, Sudan utilizes significant volumes of Blue Nile water for irrigation and also for hydropower production. Two dams (i.e., Sennar and Roseries) have been constructed on the main river approximately 350 km and 620 km south-east of Khartoum. These provide hydropower (primarily for Khartoum) as well as water for the huge Gezira and Rahad irrigation schemes. The installed power capacity at the two dams is 295 MW which represents 25% of the countries total capacity (i.e., 1200 MW from both thermal and hydro power stations). The existing irrigation scheme exceeds 1.3 million hectares, see Table 1. More than 50% of the operation and maintenance cost of the Gezira irrigation scheme in Sudan goes for de-silting of the irrigation canals. Furthermore, both the Roseires and Sennar reservoirs have lost significant storage capacity due to siltation, with most sediment flowing in from the Ethiopian highlands

Scheme	**Command Area (ha)**	**Crops**
Gezira and Managel	882,000	Cotton and mixed crops
Rahad	148,000	Mixed crops
El Souky	29,800	Mixed crops
Public Pumps	73,500	Mixed crops
Private Pumps	58,800	Mixed crops
Al Gnaid	34,900	Sugar

Sugar North West Sennar	14,700	Mixed crops
Abu Naama	12,600	Mixed crops
Al Sait, Waha	50,400	Mixed crops
TOTAL	1,305,000	

Table 1: Existing Irrigation Schemes in the Sudan (Source: Ahmed, 2006)

3.3 Future development potential

The Nile riparian countries have agreed to collaborate in the development of the Nile water resources to achieve sustainable socio-economic development. There is significant potential for additional exploitation and both Ethiopia and Sudan plan to further develop the water resources of the river.

In Ethiopia possible irrigation projects have been investigated over a number of years. Currently envisaged irrigation projects will cover a total of more than 174,000 ha, which represents 21% of the 815,581 ha of potential irrigation[3] estimated in the basin (BCEOM, 1998) (Figure 5). Major irrigation schemes that are currently being planned and/or implemented are described in Table 2.

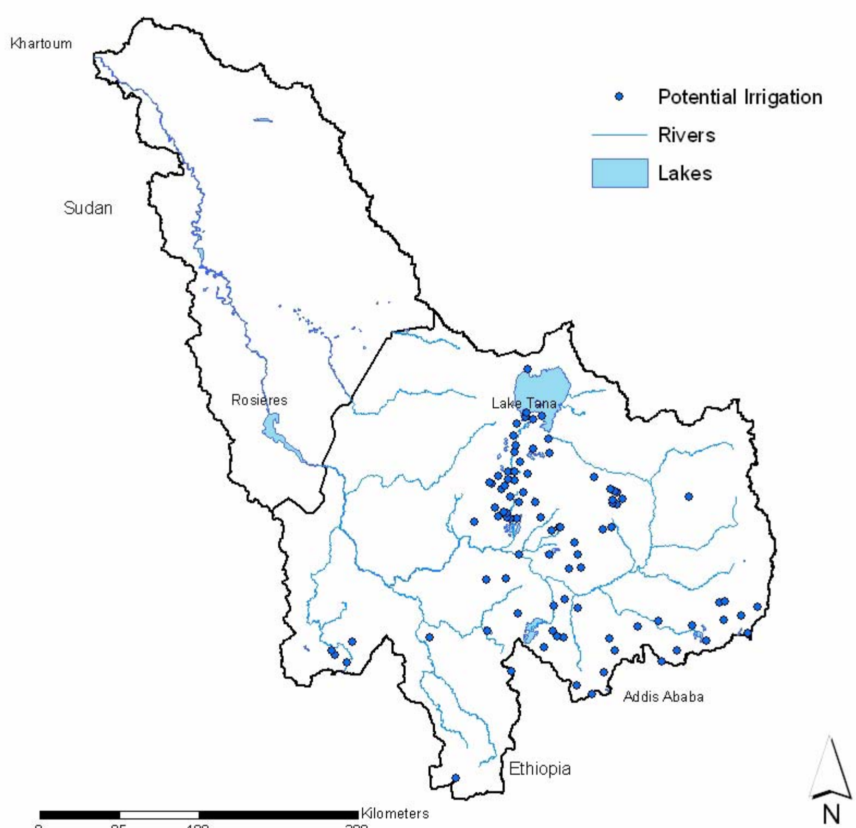

Figure 5: *Map showing potential sites for future "modern" irrigation schemes in the Ethiopian Blue Nile*

[3] *This comprises 45,856 ha of small scale, 130,395 ha of medium scale and 639,330 ha of large scale schemes*

An analysis of water resources required to support the Ethiopian irrigation development, proposed in the Abay River Master Plan (BCEOM, 1998), indicates that approximately 5,750 Mm^3 would be needed to irrigate between 370,000 and 440,000 ha. This represents approximately 12% of the mean annual flow into Sudan (see above). More recently it has been estimated that the water required for the 220,416 ha of highest priority irrigation would be between 2,200 Mm^3 and 3,830 Mm^3 (Endale, 2006). The near future undertakings are shown in Table 2.

Sudan is also planning to increase the area irrigated in the Blue Nile basin. Additional new projects and extension of existing schemes are anticipated to add an additional 889,340 ha by 2025 (Table 2). The major planned intervention is the heightening of the Roseires dam by about 10m. Unless irrigation efficiencies are significantly better than those currently achieved in the Gezira and other schemes, this will require approximately 9,300 Mm^3 more water than is abstracted at present.

Table 2: *Major planned irrigation development in the Blue Nile basin*

Name	**Catchment**	**Command Area (ha)**	**Description**	**Possible completion date**
		Ethiopia		
Angar-Nekemt Irrigation Project	Angar	26,000	Two dams to be built on the upper reaches of the river	Unknown
Didessa Irrigation project	Didessa	55,000	Three dams to be built on the Didessa River and the Dabana and Negeso tributaries	Unknown
Koga Irrigation and watershed management project	Koga	7,200	Dam currently being constructed on the Koga river, which flows into Lake Tana	2008
Lake Tana Irrigation projects	Lake Tana	50,000	In addition to the Koga scheme, four dams to be constructed on the major inflowing rivers to Lake Tana as part of the Lake Tana development project	Unknown
Extension of Finchaa sugar cane scheme	Finchaa	12,000+	Extension of existing scheme from the west bank to the east bank of the Finchaa river, using flow regulated by the existing Finchaa reservoir.	Unknown
Beles	Beles	140,000(?)	Using water diverted from the Tana catchment, after it has been used for hydropower production	2009 (?)
	TOTAL	264,200		
		Sudan		
Rahad	Rahad	19,740+	Extension of existing scheme	2025
El Souky		6,300+	Extension of existing scheme	2025
Public Pumps		39,900+	Extension of existing scheme	2025
Private Pumps		4,200+	Extension of existing scheme	2025
Sugar North West Sennar		4,200+	Extension of existing scheme	2025
Abu Naama		2,100+	Extension of existing scheme	2025
Al Sait, Waha		50,410+	Extension of existing scheme	2025
Kenana II and II		420,100		2025
Rahad II	Rahad	210,000		2025
South Dinder	Dinder	132,000		2025
	TOTAL	889,340		

+ additional areas (i.e. to be added to existing schemes)

Source: various

In the Ethiopian Blue Nile more than 120 potential hydropower sites have been identified (WAPCOS, 1990). Of these 26 were investigated in detail during the preparation of the Abay River Basin Master Plan (BCEOM, 1998). The major hydropower projects currently being contemplated in Ethiopia have a combined installed capacity of between 3,634 MW and 7,629 M. The exact figure depends on the final design of the dams and the consequent head that is produced at each. The four largest schemes being considered are dams on the main stem of the Blue Nile River. Of these schemes the furthest advanced is the Tana-Beles intra-basin transfer which will have an installed capacity of 460 MW. As part of this development a number of irrigation dams are also planned on the tributaries flowing into Lake Tana.

In addition to the schemes discussed, it is anticipated that power generation will be added to several of the proposed irrigation projects where dams are being built. It is estimated that this could provide an additional 216 MW of capacity (BCEOM, 1998). The possible total annual energy produced by all the hydropower schemes being considered is in the range 16,000 – 33,000 GWh/yr. This represents 20-40% of the technical potential in the Ethiopian Blue Nile (i.e. 72,000 GWh/yr) estimated by the Ministry of Water Resources. Currently it is anticipated that much of the electricity generated by these power stations could be exported to Sudan and possibly Egypt.

4. Erosion, Sediment and Sedimentation Problems

According to Hydrosult et al (2006b), the Ethiopian plateau is the main source of the sediment in the Blue Nile system. Some erosion occurs within Sudan, mainly on and around the rock hills (*Jebels*), which have become devoid of vegetative cover. Most of this is deposited on the footslope of the hills and does not enter the drainage system. Some water induced soil movement also occurs on the flat clay plains, but given the poorly developed surface drainage system little of this sediment reaches the main rivers. However, those streams which do reach the river during the rainy season carry heavy sediment loads.

The problems of erosion are compounded by intrinsic factors, not only related to the physical and hydraulic properties of the river but also various social, institutional, political issues. Erosion and sediment problems are strongly related to land use policy, natural resources management, level of development of the socio-economy, degradation/deforestation of the tributary watershed, cultivation practices, conservation measures, etc.

Information concerning the sediment load of the Nile is nearly non existent. Some measurements of suspended sediment load are available, but there are almost no measurements of bed load. As a consequence detailed evaluation and modeling of sediment transport in the basin is very difficult.

However, previous direct and indirect studies have been made at various locations. These include bathymetric surveys at Roseires and Senar reservoirs in Sudan as well as at Lake Tana in Ethiopia. These provide useful information on sediment impacts. A study of the long term impact of sediment in the Senar dam over 56 years (1925-1981), shows the

sediment deposition never caused the loss of volume to exceed ½% (i.e. 4.6 Million m^3) per year (Ahmed et al., 2006). However, in the following period (1981-1986) sedimentation increased dramatically to a rate of 80 million m^3 per year (9½%) i.e. a reduction of 400 million m^3 (43%) in only 5 years. Overall, the Sennar dam lost 71% of its original reservoir capacity (660 million m^3) in 61 years. The drastically increased rate of sedimentation between 1981 and 1986 is partly attributed to enhanced incoming sediment due to increased upstream erosion and partly to poor dam operation.

Roseires dam, which was constructed in 1964 on the Blue Nile, is the biggest reservoir in Sudan with an initial capacity of 3.3 Billion m^3. Roseires dam is located about 200 km upstream Sennar dam. In the first 15 (1976-1985) years the drop in the capacity was 650 millions m^3 with a rate of 43 Mm^3 per year. A drastic increase in the sedimentation rate occurred in the period (1985-1992) with a rate of 60 Mm^3 per year and a reduction of 427 Mm^3. As with the Sennar dam, this change can be attributed to increased inflowing sediment, poor reservoir operation as a result of changing policies in reservoir and irrigation management etc.

Comparison of bathymetric surveys of Perangeli in 1987 and Kaba in 2006, reveals that the annual sediment deposition rate of Lake Tana is 3.5 mm/year. This implies there is significant sediment deposition (loss up to 10.5 Million m^3 per year). Unless drastic erosion and sedimentation measures are undertaken, the impact on the shallow lake (maximum depth 14m) will be significant. Of particular concern is the deposition of sediment at the mouth of the rivers.

As further undertaking of the research being conducted in this study is to investigate the erosion, sediment transport and sedimentation phenomenon at various scales with a number of different methodologies. Research will be conducted at catchment level (i.e. detailed modeling of erosion processes, sub watersheds, tributary sub-basins (i.e. empirical estimates of sediment yield) and large lakes and reservoirs. The latter will be based primarily on bathymetric and sedimentation studies.

Results of the modeling in the Gumera watershed provide useful knowledge. In addition to the runoff simulation result discussed in section 3.1 above, we have investigated the erosion and sediment yield, impact of interventions using vegetative filter strips using unmodified SWAT modelling environment. We have used both primary and secondary physical, hydrological and sediment data measured in the catchment and at the outlet of the watershed. Accordingly, sediment simulation result (calibration, validation) shows ENS of (0.85, 0.79), R^2 of (0.74, 0.62), and mean deviation of (-14.2%, -16.9%) showing a good agreement between measured and simulated monthly sediment. This is particularly, useful to understand and estimate the overall sediment yield of the entire Blue Nile basin, particularly given the problem of data unavailability of sediment yield in watersheds. The results of the vegetative filter strip for non tolerable erosion rate at base scenario exceeding 11 ton/ha shows that, an average annual sediment yields were reduced by 52 % to 62 % for a 5m buffer strip and 74.19% to 74.35% for a 10m strip (Tenaw, 2008). The significance of the study is that it is possible to identify critical erosion risk area, understand the sediment and runoff generated from various sub-watersheds,

evaluate impact of interventions of watershed management and thereby proper degradation reversal measures be adopted.

5. Conclusions

This paper provides an overview of water and land management issues in the Abbay-Blue Nile. Preliminary results of a research project on "Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile" have been presented. The project in addition to applying and testing various models and approaches to generate improved knowledge of the basin, has a strong emphasis in analayzing situation of the existing condition and impacts of future interventions with respect to watershed management, water allocation and policy and institutions. It is anticipated that it will also contribute significantly and establish good synergies with existing NBI and ENTRO projects.

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