Improved water and land management in the Ethiopian highlands and its impact on the downstream dependent on the Blue Nile[1]

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Abstract

This paper introduces and highlights some results of a multi-institutional collaborative research project under implementation related to "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 reaching downstream. The result is a vicious cycle of poverty and food insecurity for millions in the upstream; and poor water quality, heavy siltation, flooding, and poor temporal water distribution in the downstream threatening livelihood and economies in the downstream. It is widely recognized that improved water management in the Abay Basin will significantly increase water availability for various stakeholders within the basin. Key research questions raised 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? Focusing around these questions, intermediate results related to meteorological, hydrological and physical based basin characterization, methodologies for erosion and sediment modelling, water availability and access for various production systems are presented. Synergies and complementarities with Nile Basin shared vision and subsidiary action projects, particularly with 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 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 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 continue to be affected due to dramatic change in land, water and livestock management in the 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 in upstream uses reduces both potential runoff yields and the quality of water reaching downstream. It is widely recognized that improved water management in the Abbay catchemnt will significantly increase water availability for various stakeholders within the catchment. This will help to alleviate the impacts of natural catastrophes such as droughts and reduce conflicts among stakeholders dependent on the Nile.

Proposed by diverse stakeholders, a two years research project has started, which *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 (win-win) for both upstream and downstream communities, reducing win-lose scenarios.

The major research questions are:
1: What are the successful interventions that help improve productivity and reverse degradation?
2: What are the impacts downstream?
3: What are the opportunities and constraints enhancing rural livelihoods and food security?

These questions are broadly defined to prove the underlying hypothesis and require in depth research to respond to them and require substantial efforts in identifying interventions, proof of concepts, evaluation of impacts and strong partnerships with various bodies.

This paper therefore provides discussion of methodologies, on going work and preliminary results of the above mentioned objectives focusing on review of literature on physical based basin characterization, meteorology, hydrology, water use, development potential and sediment impact.

2. The Abbay (Blue Nile) River System Characterization

The Abbay-Blue Nile[2] Sub-basin covers an area of 311,548 km^2(Hydrosult et al 2006b). The Blue Nile 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 350m at Khartoum to over 4250m a.m.s.l. in Ethiopian highlands. Figure 1 provides the digital elevation model of the Abay-Blue Nile sub-basin and Figure 2 provides the major tributary rivers as categorized by Hyrdsult et al (2006a)

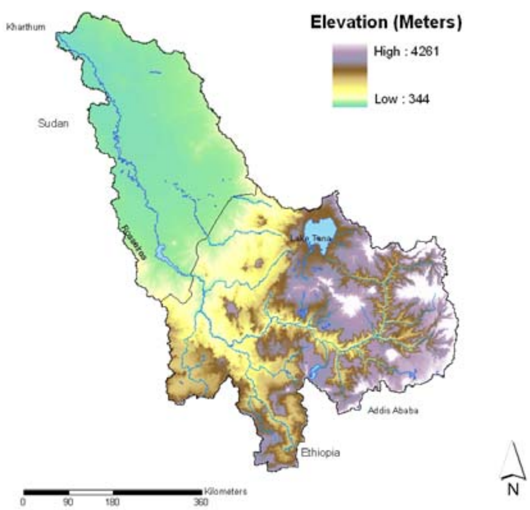

Figure 1 Map of the Blue Nile showing elevation, main tributaries and key geographic features (Source: IWMI 2007)

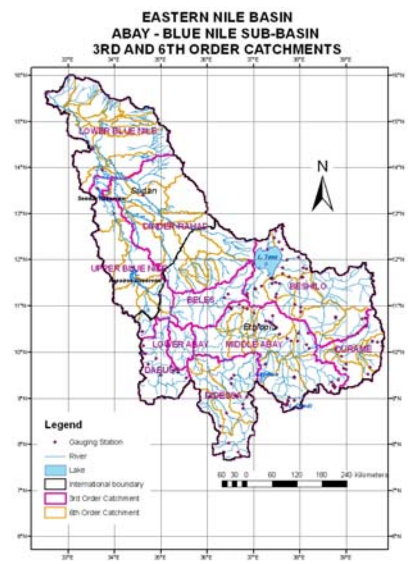

Figure 2 Abay-Blue Nile Sub-basin: 3rd and 6th Order Watersheds

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 upper basin, in particular in the loop of the Blue Nile south of Lake Tana. Rainfall

[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 the confluence to the main Nile.*

exceeds 2,000 mm in parts of the Didessa and Beles catchments. Therefore, it is apparently clear why the major sources of the main Nile flow is coming from the Blue Nile, unobstructed by large water losses like in the Sudd wetland of the white Nile.

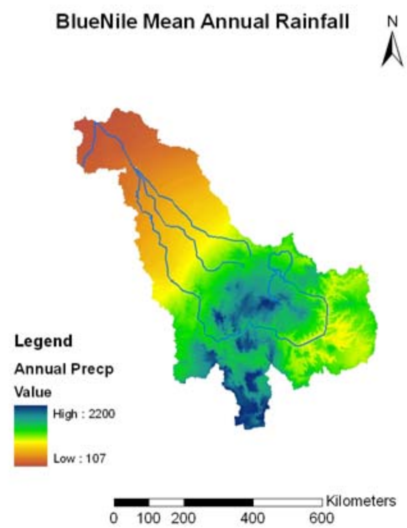

Figure 3: Abay – Blue Nile: Mean Annual Rainfall (mm/yr)

The Basin temperature varies between the highest variation of 44°C to 21^{o}C in Sudan for May and Ethiopia for February respectively and the lowest temperature ranges 14°C in Sudan for January and less than 3°C in Ethiopia. The temperature and rainfall values imply the resulting evapotranspiration and water requirements for agricultural production and losses of water in water management systems

Observing the flow records and according to Hydrosult (2006b), there are considerable seasonal variations in flow. The monthly low flow of the Blue Nile is 302 million m^3/month in February and the peak flow is 13,151 million m^3/month in August.

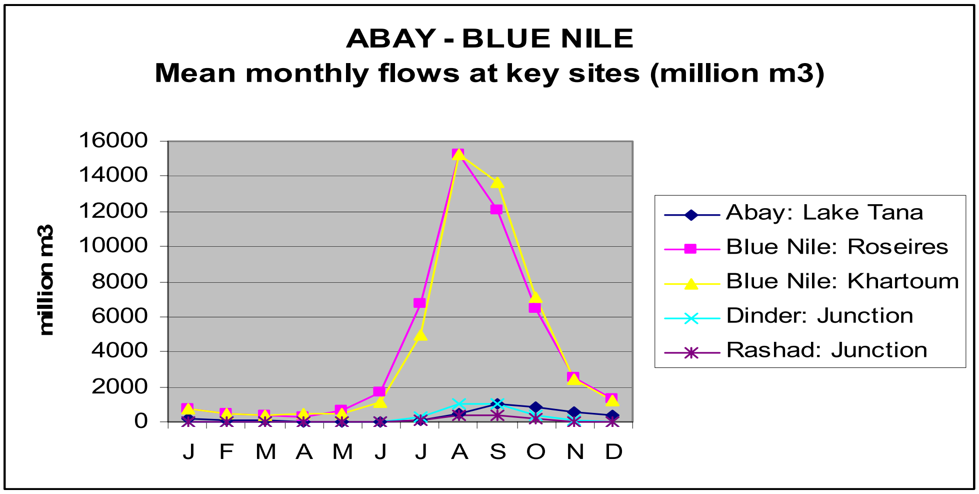

Figure 4. Abbay - Blue Nile Sub-basin: Mean monthly discharge at key sites (million M^3)

Similarly, there are considerable variations in annual discharge. The annual discharge for the Blue Nile for long time series of 1920–1960 appears to have oscillation around the mean. From 1960 to 1984 there have been a general decrease in discharge until 1985. Thereafter discharges have gradually increased (Ahmed, A, 2006, Hydrosult et al, 2006).

3. Runoff Mechanisms and Water Availability

3.1 Modeling runoff

The Abbay-Blue Nile and Nile hydrology studied by many using models. Awualchew et als (2008) documents 13 various models for Abbay-Blue Nile and 22 other models for Nile hydrology related to rainfall-runoff. None of these models are widely adopted in the basin or and attempt to review them has been made, and development of such models is continuing. 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 minimally 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 is developed by Tesfahun, D, et al (2006) employing a hyperbolic sine function to assure that the soil storage reservoir has to be filled up after the dry season before runoff is being produced in significant quantities.

Ultimately there is a need for additional model development because water balance models only give the discharge at the base of the watershed 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. Moreover, it is unlikely that the lumped basin scale models (e.g., SWAT, EPIC, WEPP etc) predict the runoff distribution correctly, because they are based on the Soil Conservation Service Curve Number, which uses soil type and vegetation characteristics to determine the runoff and not topography as should be the case in the Ethiopian highlands. Distributed saturation excess models such as TOPMODEL (Beven et al. 1984) , the Soil Moisture Distribution and Routing (SMDR) model (Johnson et al. 2003, Gérard Merchant et al, 2006; Hively et al. 2006; Easton et al. 2007), the Variable Source Loading Function (VSLF) (Schneiderman et al. 2007) model could all, potentially, be applied to the Ethiopian portion of the Blue Nile and yield satisfactory results, but all have extensive data needs, and thus may be infeasible. Recently Easton et al. (2008) re-conceptualized the SWAT model to model correctly predict the distribution of saturation excess runoff, thus there is the potential to incorporate SWAT as well. Currently, we feel that using several models in combination may result in the best outcome. Our understanding of the hydrology can be furthered using a combination of model predictions using VSLF and a modified version of SWAT which incorporates the changes made by Easton et al. (2008) as well as modifications currently being implemented that include correctly the behavior of the watershed as it becomes wetter as the rainfall season progresses and produces more runoff.

3.2 From Hydrology to Existing water use

Ethiopia currently utilizes very little of the Blue Nile water because of various reasons such as its inaccessibility, major centers of population lie outside of the basin, inadequate resources for investment, lack of capacity, 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 Fincha station.

In addition to the above, however, recent development in Ethiopia through Tana-Beles intra basin transfer enables generation of 460MW power production and potential of development of irrigation of about 40,000ha in the Beles Basin. Furthermore, additional small dam projects around Lake Tana expected to improve the profile of development of irrigation access of water in the basin.

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 irrigation scheme 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.

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 (e.g. Lahmeyer, 1962; USBR, 1964; JICA, 1977; EVDSA, 1980; HALCROW, 1982; WAPCOS, 1990; BCEOM, 1998). 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.

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

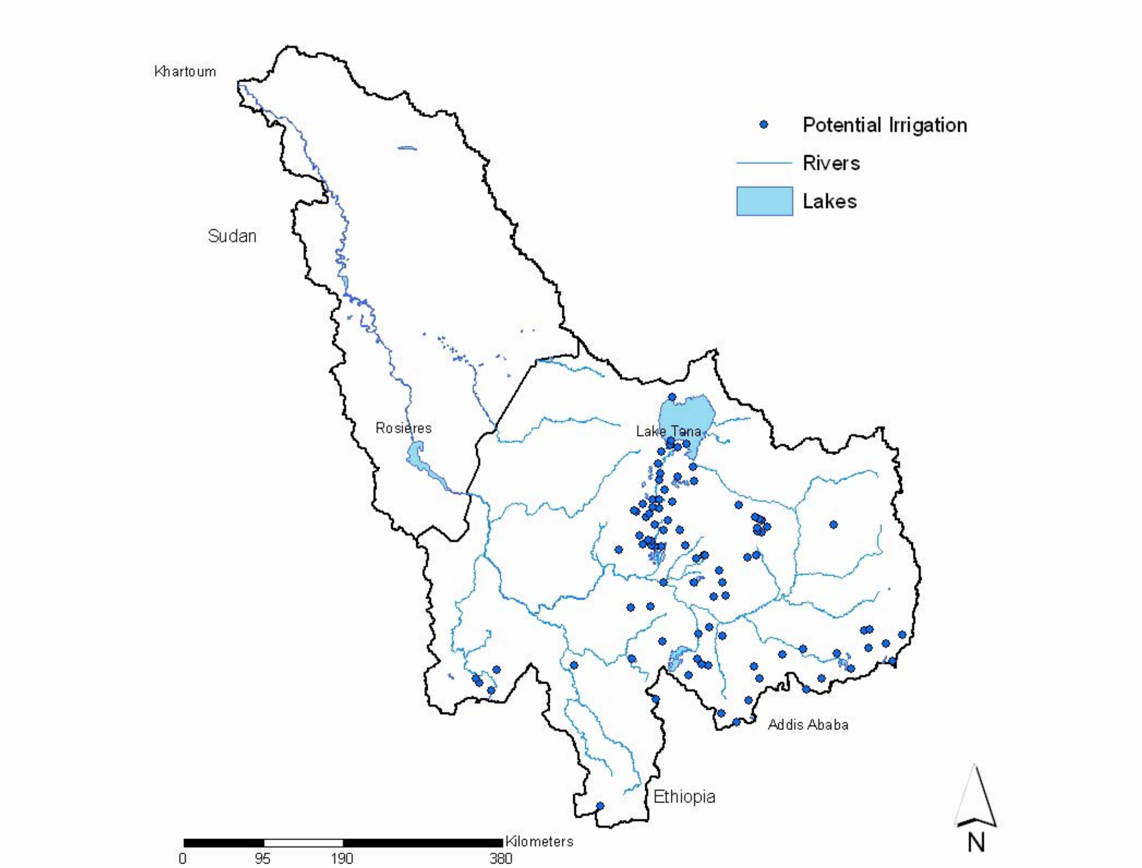

Figure 5.2: *Map showing* potential *sites for future "modern" irrigation schemes in the Ethiopian Blue Nile*

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 apparently 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 heightnenning 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	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 (see below)	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 Karadobi project for which the pre-feasibility study was conducted last year (Norconsult, 2006).

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. 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

Soil erosion is a major watershed problem in Abbay-Blue Nile Basin. Generally the sediment transport phenomenon is a function of many process and parameters. It is well known that, in any watershed the extent of erosion degradation and sediment yield are related to a complex interaction between topography, geology, climate, soil, vegetation, land use and man-made developments. Erosion in the land surface takes place in the form of sheet erosion, rill and inter rill erosion and gulley erosion. Eroded/sediment particles that are taken further in to the river are called delivered sediment or sediment yield from a given watershed. The delivered sediment travels with the flow as suspended material as far as the hydraulic conditions permit the transportation of such material. The other component of the sediment transport comes from the bed and bank material and travel with the flow as suspended or bed load. The transported particles move further downstream depending on the prevailing hydraulic conditions related to slope of the river, velocity, discharge, cross sections, etc which are describing the stream power.

Erosion in the Ethiopian Highlands is characterized by the detachment and entrainment of solid particles from the land surface/Ethiopian plateau or from the bed and banks of streams as the water flows down. The highland is characterized by steep slope, intense rainfall, poor vegetation cover, poor land cultivation practice, hardly and soil protection measures, resulting in significant erosion and sediment transportation phenomenon. The problems are compounded by intrinsic factors, not only related to physical and hydraulic problem related to high stream power due to the nature of the river and its tributaries, but also various social, institutional, political, etc problems. 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 compared with the available water discharge data. Some measurements of suspended sediment load are available, and a measurement of bed load is nearly not made. As such detail study and modeling of sediment therefore is very difficult.

However, previous direct and indirect studies made at various locations such as bathymetric survey at Roseires and Senar reservoirs in Sudan and bathymetric surveys made at Lake Tana provide useful information on sediment impacts. Study through the long term impact of sediment in the Senar dam for 56 years (1925-1981), Ahmed et al (2006), shows the sediment deposition has never exceeded deposition or loss of volume of over ½% (4.6 Million m^3) per year. The following period (1981-1986) the sedimentation increased drastically with a rate of 80 million m^3 per year (9½%) i.e. a reduction of 400 million m^3 (43%) in only 5 years. The Sennar dam in 61 years lost 71% of its original reservoir capacity (660 million m^3). The drastically increased sedimentation is attributed to enhanced incoming sediment partly and poor dam operation rules during the latest years.

Roseires dam, which was constructed in 1964 on the Blue Nile, is the biggest reservoir in Sudan with 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. This may be attributed to increased sediment incoming, poor reservoir operation, changing policies in reservoir and irrigation management etc.

Comparison of bathymetric surveys of Perangeli in 1987 and Kaba in 2006, revels that the annual sediment deposition rate of Lake Tana appears 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 14m) of Lake Tana is significant, particularly it is a concern interms of deposition of sediment at the mouth of the rivers.

As further undertaking of the research related to this paper it is anticipated to tackle this particular problem by considering various levels of understanding the erosion, sediment transport and sedimentation phenomenon at various level with varying methodologies. Research catchment level detail modeling of erosion modeling, sub watersheds level sediment yield, tributary sub-basins level sediment discharge relationships and large lakes and reservoir level based sedimentation studies are some of the envisaged undertakings.

5. Conclusions

This paper provides certain overview based on literature review and preliminary analysis on Abbay-Blue Nile characterization, hydrology, modeling, sediment and water use and potential of the basin. This is essentially a preliminary work as part of a two and half years project on "Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile" also known as Upstream-Downstream in the Nile. The project in addition to applying and testing various models and approaches to generate improved knowledge of the basin, it has strong emphasis in analysizing situation of the existing condition and impacts of future interventions with respect to watershed management, water allocation and policy & institutions. It is anticipated that it also contributes significantly and establish good synergies with existing NBI and ENTRO projects.

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