Review of Soil Erosion and Sediment Transport, and Management Status in the Blue Nile River Basin: The Case of Ethiopia

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Abstract

Soil erosion and sedimentation have a serious effect on the water abstraction structures and sustainable agriculture and that may be managed through appropriate watershed management practices. To make it, information between researchers and government or non-governmental organizations on soil erosion, sediment transport, and watershed management status at the river basin is very important. Therefore, this paper review was conducted to know the updated information about soil erosion potential, sedimentation rate, and status of watershed management practices in the Blue Nile River Basin. Approximately, 22.5% of the Blue Nile basin fell under very high to extreme areas of soil erosion potential and it needs effective watershed management implementation along the basin. The average annual soil loss and sedimentation rates of the Blue Nile river basin were 41.7 and 11.2 tons ha^{-1} $year^{-1}$, respectively. The mean annual soil loss in Blue Nile River Basin along the different stations in Ethiopia was 5395.57 ton-km^{-2} and it shows a large amount of sediment transported to the Grand Ethiopian Renaissance Dam (GERD) that will reduce dam storage capacity. Aswan high dam and Roseires reservoir received 100 and 30 million tons of sediment per year, respectively from Blue Nile River Basin in Ethiopia and the filling of GERD will raise the life span of Aswan dam from 365 years to 593 years. Around 42% of the Jemma watersheds were covered by terracing and other water management structures up to 2016 and reforestation combined with vegetative strips was the most effective for soil erosion control (87.8% reduction in the case of Jemma watershed). Therefore, cooperative watershed management practice at the basin level is very important to increase the sustainability of GERD and to protect the sedimentation of Sudan and Egypt's water storage structures.

Key Word: Blue Nile Basin, Soil Erosion, Sedimentation, Watershed Management, GERD,

1. INTRODUCTION

Ethiopia is well known for its huge water resources potential and it is considered the water tower of Africa as it is, the source of the Blue Nile and many transboundary rivers (Nigel, 2004) and many rivers with high annual flow rates. Most of the runoff leaves the country through these transboundary rivers (Awulachew *et al*., 2005).

Soil erosion and sedimentation have a series of effects on water abstraction structures (Dutta, 2016), and the sustainability of agriculture that may be managed through appropriate watershed management practices (Gebrermichael *et al*., 2005). Soil erosion by water is a major agent of land degradation in Ethiopia and more specifically in the Blue Nile River basin, and it has significant impacts on ecosystem services (Gebrehiwot *et al*., 2014), crop production (Hurni *et al*., 2015), downstream flooding (Sultan *et al*., 2018) and reservoir sedimentation, and economic costs.

In fluvial hydraulics, sedimentation is a significant parameter as it provides a possibility of being used as a capacity-predicting device in all storage zones due to which the life of a reservoir can be predicted; as there is a sole relationship between capacity and life of a reservoir (Chang, 2006). Soil erosion and solid transport in river channels often lead to reservoir siltation (Ayana *et al*., 2012)and a reduction in the amount of water available for agriculture (Coviello *et al*., 2015). The adverse impacts of increased sediment deposition can result in increased flooding, property damage, contamination of water supplies, loss of crops, social dislocation, temporary homelessness, and even loss of life (Nigel, 2004).

One-third of the Roseires Reservoir capacity which is constructed on the Blue Nile River in Sudan near the border with Ethiopia has been lost due to sedimentation and lack of insufficient watershed management in the Blue Nile River Basin in the last four decades (Omer *et al*., 2015)). Khashm el-Girba dam and Roseires dam in Sudan lost 55% and 38% design capacity in 25 and 28 years, respectively (Wolancho, 2012).

The sedimentation problem of the Aswan high dam reservoir of Egypt is coming from the Abay sub-basin in Ethiopia and the design life of the Aswan high dam reservoir is also estimated to be 265 years, which is only 50% of the reservoir's original design life due to high inflow of sediment from Blue Nile River basin (Wolancho, 2012). Ethiopia reservoirs like Angereb, Legedadi, Gilgel Gibe I, Tekeze, and others are susceptible to failure by these accelerated sedimentations. Small-scale water diversion structures irrigation in Ethiopia like Gery, Kility, Dana, and Fetam failed due to sedimentation and lack of good watershed management like terracing and soil bunds (Bitew, 2013).

Proper watershed management is the most effective method to increase the life span of hydraulic structures such as dams, weirs, and barrages and to conserve soil, water, and plants. Information flow between researchers and government or non-governmental organizations on soil erosion and sediment transport and watershed management status on the Blue Nile watershed and understanding its major drivers are essential to implement targeted management interventions. This information also minimizes the controversial idea of Sudan and Egypt on the Ethiopian Grand Renaissance Dam. This is because GERD has a positive impact on riparian countries by reducing large amounts of sediment inflow (Elnashar *et al.*, 2021). Therefore, this paper review will conduct to know the updated information about soil erosion potential, sedimentation rate, and watershed management status in the Blue Nile River Basin and the benefit of the appropriate watershed management practice adopted in the area of Ethiopian Renaissance Grand Dam sustainability and downstream countries such as Sudan and Egypt.

2. Blue Nile River basin

2.1 Location

The Blue Nile Basin and its main tributaries drain an estimated area of 324,000 km^2, about 250,000 km^2 on the Ethiopian Plateau (Figure 1). The Blue Nile Basin stretches between 35^0 00’ 00” E and 40^0 0’ 00” E longitude, and 8^0 00’ 000” N and 12^0 0’ 00” N latitude. The main head of the Blue Nile (Abbay) River is Lake Tana, which is the greatest freshwater lake in the country and it is situated in the north part of the basin (Shobary *et al*., 2021).

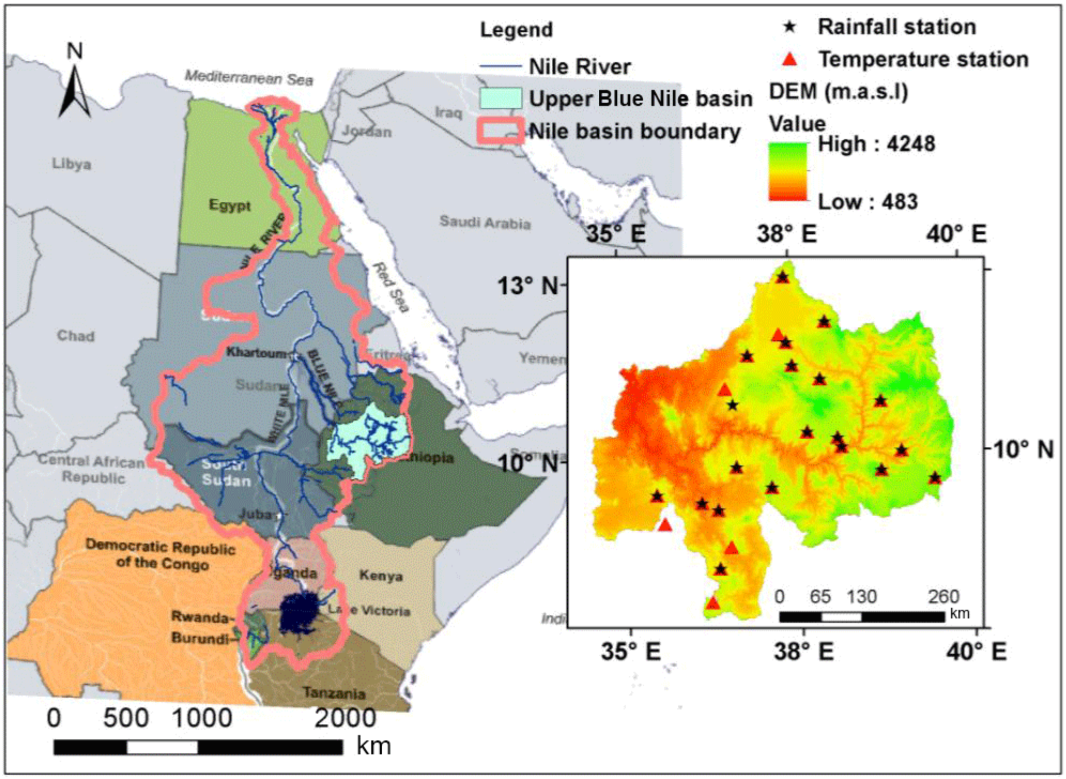

Figure 1: Location of upper Blue River Basin (Chang, 2006)

2.2 Climate

A large amount of rainfall is concentrated in the Ethiopian highlands ranging from 1500 to 2200 mm with peaks in August; on the other hand, the rainfall in the lowlands is less than 1500 mm. The climate of the basin differs from one region to another. The western part possesses the highest temperature, with maximum and minimum ranges of 28^0C-38^0C and 15^0C-20^0C, respectively. In the eastern and central parts of the basin's part, a lower temperature is monitored and the maximum temperature ranges from 12^0C to 20^0C, while the minimum ranges from -1^0C to 8^0C. In the lowlands, high temperature and high potential evapotranspiration is ranging between 1800 mm and 2232 mm per year. The lower potential evapotranspiration is observed between 1200 and 1800 mm per year in the eastern and southern parts of the basin. In the highlands, there is the lowest temperature, it has the least potential evapotranspiration below 1200 mm per year (Yilma and Awulachew, 2009).

3. Soil Erosion, Sediment Transport, and Watershed Management

3.1 Soil Erosion Potential

3.1.1 Erosion Potential on Upper Blue Nile River Basin

The soil erosion potential of the watershed in the upper Blue Nile River basin varied with its management system. Abay/upper Blue Nile River Basin has around 14 sub-basins (Figure 2) and the erosion potentials of the basin varied from low to very severe soil erosion severity. The soil erosion potential of each basin depended on soil type, topography, and land use/land cover change of the basin (Organic *et al*., 2015).

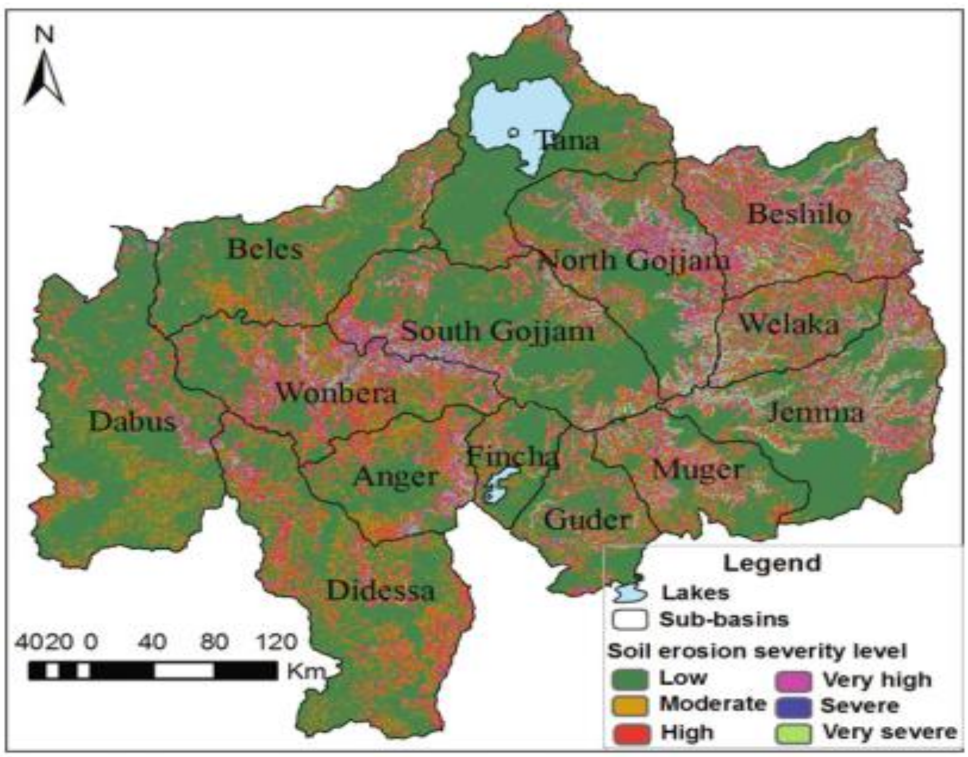

Figure 2: Potential soil erosion hazard in the Upper Blue Nile River Basin (Organic *et al*., 2015)

The magnitude of soil erosion in the upper Blue Nile Basin is spatially variable and severe to very severe soil erosion was predominantly observed in the northeast, east, and southern parts of the basin including Beshilo, Welaka, North Gojjam, Jemma, and Muger sub- basins (Organic *et al*., 2015) as seen in Table 1.

Table 1. Soil erosion severity level for sub-basins of Upper Blue Nile River Basin (Organic *et al*., 2015)

Sub-basins	Area (10^3 km^2)	Soil loss (t ha^{-1} yr^{-1})	Severity Level
Tana	15	4.9	Low
Beshilo	13.2	32.7	High

9.9			Low
14.4		23.7	High
Dabus	21	7	Low
South Gojjam	16.8	15.6	Moderate
Jemma	15.8	24	High
Welaka	6.4	27.5	High
Wonbera	13	18.7	Moderate
Fincha	4.1	9.1	Low
Anger	7.9	13.7	Moderate
Muger	8.2	22.1	High
Didessa	19.6	9.2	Low
Guder	7	13.8	Moderate

3.1.2 Erosion Potential Upper Blue Nile River Basin

Amdihun et. al. (2014) also reported that a large area of the basin (47%) was characterized by low erosion grade (0-2 t ha^{-1} yr^{-1}). Nearly 35% of the basin is under moderate to high soil erosion potential. The remaining (18%) areas fall under very high to extreme areas of soil erosion potential. The North East parts of the Abbay Basin (North Wollo, South Wollo, East and West Gojam, South Gondar, and North Shewa) were identified as areas of high soil erosion belts. On the other hand, the lowland areas of the Western and North Western areas are depicted as low erosion areas (Amdihun *et al.*, 2014). These shows the North parts of the Abbay Basin need more effective integrated watershed management in contrast to the Western and North-western portions of the basin and (Elnashar *et al.*, 2021) also report that 27% of the upper Blue Nile River Basin requires a series of watershed management implementations. Based on above the authors, an average of 22.5% of the Blue Nile River Basin is found under very high to extreme areas of soil erosion potential. This means 56,250 km^2 area of the basin needs effective watershed management implementations.

3.1.3 Runoff and Soil Loss along Different Stations of Blue Nile River Basin

Maximum soil loss was observed at the Anjeni station in the northern highlands of Ethiopia, Andit tid station in North Shewa, and Maybar station in the Southern Wollo Zone. This shows that amount of soil loss is very high in the central and western parts of Ethiopia. However, the amount of soil loss in the northern and eastern parties is very low. The average annual soil loss of the Blue Nile River basin from those seven stations was 5395.57 ton km^{-2} as shown in Figure 3.

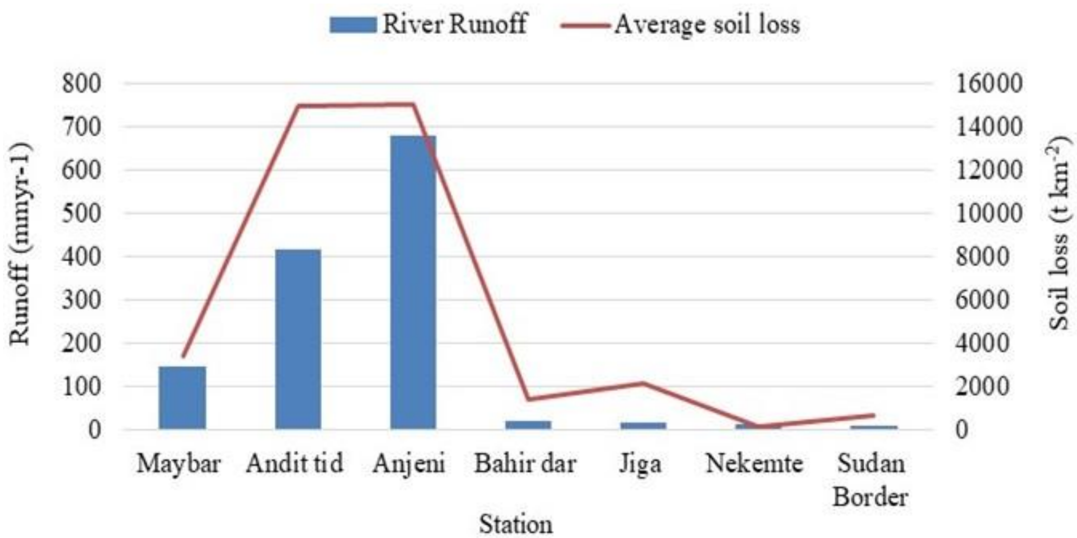

Figure 3. Measured runoff and soil loss at different stations of the Blue Nile River basin (Abdel-Aziz, 2009)

The average rate of soil loss in the upper Blue Nile River Basin varied from 16 to 67.37 ton ha^{-1} year^{-1} and it also varied from 8.25 to 100 ton ha^{-1} year^{-1} in the sub-basin of the Blue Nile basin (Tesfaye, 2022).

3.2 Sediment Yield

3.2.1 Sediment Yield of Different Watershed

On average, 16 million tons of sediment per year were transported to the Lake Tana sub basin. This load comes that flows from the four River watersheds and it has been shown that prioritizing management practices for reducing the sediment load to Lake Tana is important (Zimale *et al*., 2018). The four main tributaries of the Lake Tana subbasin are Megech, Gumara, Ribb, and Gilgel Abay watersheds, and the average annual sediment inflow to Lake Tana from such watersheds was 30.4 million tons per year (Zimale *et al*., 2018).

The Gilgel Abay basin receives the maximum rainfall resulting in the greatest discharge and sediment inflow to Lake Tana. Therefore, the participation of the community, government, and non-governmental organizations is very important to manage lake sedimentation and soil erosion. Soil erosion not only affects Lake Reservoir's capacity but also removes significant soil nutrients from agricultural land and increased soil acidity (Zimale *et al*., 2018).

Table 2. Sediment yield of the Tana Sub- basin (Zimale *et al*., 2018)

watershed	Area	Total (Mt yr^{-1})	Unit area (t ha^{-1} yr^{-1})

Megech	500	0.6	12.2
Gumara	1281	6.3	49.4
Ribe	1289	3.2	24.6
G_Abaye	1665	5.9	35.4
	Average	4.0	30.4

Toba watershed is a tributary of the Didessa sub-basin in the headwater of the Ethiopian plateau, Upper Blue Nile Basin. The annual sediment yield of this watershed varied from 0.09 t ha^{-1} yr^{-1} to 44.8 t ha^{-1} yr^{-1} with an average sediment yield of 22.7 t ha^{-1} yr^{-1} (Dibaba *et al*., 2020), and 72.9% of the Toba watershed area, have been identified as critical areas that require implementation of proper measures. The spatial average annual sediment yield distribution through the Guder watershed also ranges from 0.33 to 55.33 $ton^{-1}yr^{-1}$ with an average value of sediment yield of 27.83 t ha^{-1} yr^{-1} (Gonfa and Dereje, 2021). The sediment transport rate in Beshillo and Finchaa watersheds were 35 t ha^{-1} yr^{-1} and 36.47 t ha^{-1} yr^{-1}, respectively (Yesuph & Dagnew, 2019) and (Dibaba *et al*., 2020).

The variations of the soil loss in different parts of the Blue Nile show that sediment transport rates depended on land use land cover change, topography, and a biophysical environment. That means adapted watershed management practice may vary from one watershed to others.

3.2.2 Sediment Yield on Basin and Watershed Level

Sedimentation rates in Ethiopia at the upper Blue Nile Basin ranged from 4.2 to 18 ton ha^{-1} $year^{-1}$, and it varied from 1.1 to 43.34 ton ha^{-1} $year^{-1}$ in the sub-basin of the upper Blue Nile River basin. Based on this result, 277.5 million tons of sediment per year will accumulate from the Blue Nile River basin. Hence, it is concluded that high sedimentation rates are serious problems in the basin, and soil and water conservation measures are recommended throughout the basin to reduce both the on-site and off-site effects of soil erosion. It is also highly advised to utilize uniform techniques and a common data source for soil erosion and sedimentation rate estimation at different levels (Tesfaye, 2022).

3.2.3 Sedimentation of the Aswan High Dam Reservoir and Roseires Reservoir

Abay sub-basin within Ethiopia covers about a quarter of the area and its waters provide 57% of the main Nile River flow into the Aswan High Dam reservoir and some 72% of its sediment load. The Tekeze sub-basin within Ethiopia covers a quarter of the area and its water covers 14% of the main- Nile River flow into the Aswan high dam reservoir (AHDR) and some 25% of the sediment load. This means that 71% of the main Nile River flow and 97% of the sediment load into AHDR comes from Ethiopia. Generally, 100 and 30 million tons of sediment load into the AHDR and Roseires dam Reservoirs per year comes from

Blue Nile River Basin in Ethiopia (Abdel-Aziz, 2009). Therefore, land management in the high land of Ethiopia to control soil erosion and sedimentation of water storage structures that are found in transboundary countries like Ethiopia, Sudan, and Egypt is very important. This watershed management practice must be implemented in cooperation with such a transboundary country.

The 165 million tons per year of sediment inflow into the Aswan High Dam reservoir in Egypt comes from the Ethiopia river basin such as the Blue Nile and Atbara river basins. From this amount, 100 million tons of the sediment comes from the Blue Nile River basin, and 65 million tons of sediment is also from the Atbara River Basin (Tekeze and Angrebe River watershed). The construction of GERD across the Blue Nile River Basin in Ethiopia will have a great benefit for Sudan and Egypt by removing up to 86% of silt and sediment accumulation in reservoirs (El-Nashar & Elyamany, 2018).

Therefore, the maximum sediment source for hydraulic structures in transboundary countries is the Blue Nile River basin which shows a common understanding on integrated River management as a core solution to minimize reservoir sedimentation of GERD, and other dams in Sudan and Egypt. The Ethiopian part of the Blue Nile Basin contributes some 62% of the Nile water and is the source of a huge sediment load (122 million tons per year) in the downstream reservoir of Rosaries dam on the Ethio-Sudan border (Amdihun *et al*., 2014).

3.2.4 Impacts of Nile Sediment Reduction on Lower Nile Countries' reservoirs

Egypt scholars state that the filling of the Grand Ethiopian Renaissance dam will raise the life span of the Aswan high dam reservoir from 365 years to 593 years if the beginning of filling GERD will start by 2016 (Elsharkawy, 2020). Because a large amount of annual sediment inflow to AHDR from the Blue River Nile basin will be protected by the GERD. Reduced sediment load after the construction of GERD results in a longer lifetime of the Roseires, Sennar, Khashm el-Girba, and Merowe dams and reduces the maintenance cost of irrigation canals and water pumping stations in Sudan (Siddig & Basheer, 2021).

3.4 Best watershed Management Practices

The best watershed management practices are filter strip, soil/stone bund, vegetative strip, reforestation, and their combinations and these practices are largely under implementation in the Blue Nile basin. The lowest SY reduction was reported as 36.1% during the implementations of filter strip (FS) whereas the highest reduction was reported as 80.5% by the simulation of the vegetative strip (VS) followed by soil/stone bund (SB). Application of SB on steep slopes and reforestation of the hilly areas reported sediment yield (SY) reduction by 69.3% and 47.5% respectively. However, implementing the combinations of the BMP scenarios improved SY reduction better. The highest reduction in SY was attained by the combination of R and VS followed by SB and VS. The best watershed management practice from the different scenarios is reforestation with the vegetative strip that reduced sediment yield by 87.8% compared with baseline scenarios (Dibaba, 2021) (Figure 4).

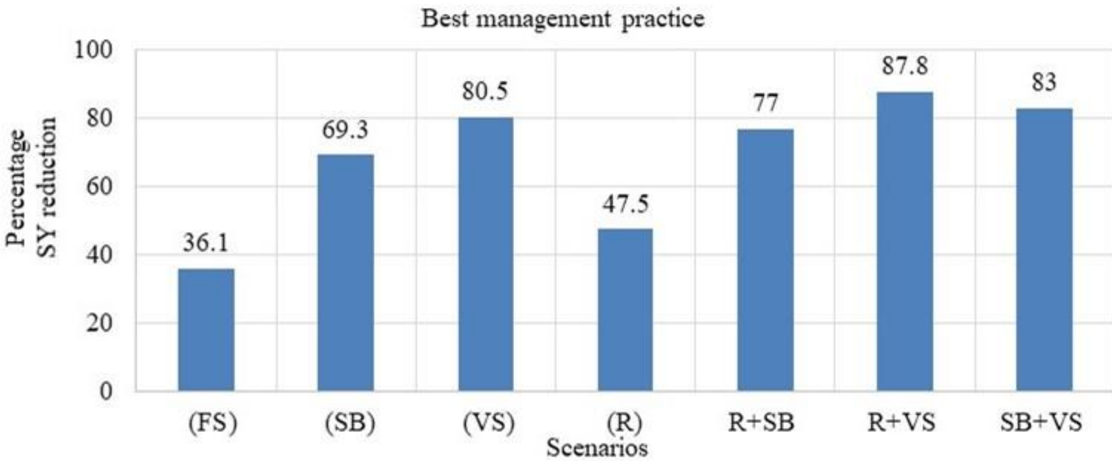

Figure 4. Watershed management scenarios (Dibaba, 2021).

Where: FS, SB, VS, and R stand for filter strip, soil/stone bund, vegetative strip, and Reforestation

The percentage of sediment yield reduction by the stone bund soil conservation structure varies from 72 to 100% with an 86% average value, and the experiment was conducted in Ethiopian and Eritrean highlands (Asmamaw, 2015). Corroborates water harvesting structures and other water management structures like terracing are very fruitful technology to increase the availability of water under different climate conditions in the Jemma watershed of the upper Blue Nile River Basin. However, terrace and other physical soil and water management structures are implemented on about 42% of the watersheds of the Jemma sub-basin up until 2016 (Worku *et al*., 2020). Currently, existing and prioritized water management structures need to be regularly maintained since there is a study that shows a decrease in the effectiveness of such structures after a certain time. Therefore, management status in the Jemma watershed shows that there are no successful management practices in other watersheds in the Blue Nile River Basin.

The best effective soil and water conservation structures were soil bunds, reforestation with vegetative strips, and water harvesting structures with terracing (Asmamaw, 2015; Worku *et al*., 2020). Dagnenet *et al., (2018)* reported that soil trenches also trenches in grazing lands are more effective and it can conserve 55% of runoff due to temporary water storage in the short trenches the experiments were conducted at the Guder watershed in the upper Blue Nile (Sultan *et al*., 2018). The gully rehabilitation and forestation together would save 828 tons of soil in a year as watershed level per one gully and the experiment was conducted at the Anjeni watershed in the upper Blue Nile River basin (Ashagre, 2014). Effective and sustainable soil erosion management requires not only the prioritization of the erosion hotspots but also the prioritization of the most effective management practices (Dibaba *et al.*, 2020).

The effectiveness of the best watershed management practice depends on the amount of land available, local topographical conditions, and land use/land cover change in the basin, and the reforestation management practice is more important in steep areas, and filter strips and stone bunds in low slope areas of the catchment (Betrie *et al*., 2011).

4. Conclusion and Recommendation

Northeast, east, and southern parts of the upper Blue Nile River basin is highly sensitive to soil erosion that leads to sedimentation problem of reservoirs. Lake Tana and different watersheds in Ethiopia like Toba, Bishillo, and Finicha were categorized under sedimentation-prone areas and this high sedimentation yield harmed the Grand Ethiopian Renaissance Dam. This soil erosion and sedimentation problem in the upper Blue Nile River basin showed that watershed management practices were not sufficient. To increase the life span of the Grand Ethiopian renaissances Dam (GERD), the watershed management practice in the Blue Nile River Basin is important for a transboundary country like Sudan and Egypt by minimizing sediment load. Therefore, the construction of GERD has had a positive impact on Roseires Reservoir in Sudan and the Aswan High dam reservoir in Egypt.

Integrated River basin management in the upper Blue Nile among transboundary countries like Ethiopia, Egypt, and Sudan will be used to achieve water security, equitably maximizing economic and social well-being, and maintaining ecosystem sustainability. This also increases good political relationships between the transboundary countries on the Nile River. Governance measures on the upper Blue Nile River basin shall be shared with water resource users, decision and policymakers, transboundary countries, and state agencies to achieve more collaborative and coordinated actions. These upstream-downstream connections and cooperation strategies on watershed management are essential for sustainable water resources management and equitable water sharing among the Nile riparian states.

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References

Abdel-aziz, T. M. (2009). Water and Sediment Management 1- Introduction and Study Area 2- Water Resources. Rivers, 839–852.

Amdihun, A., Gebremaria, E., Rebelo, L., & Zeleke, G. (2014). Modeling Soil Erosion Dynamics in the Blue Nile (Abbay) Basin: A Landscape Approach. Research Journal of Environmental Sciences, 8(5), 243–258. https://doi.org/10.3923/rjes.2014.243.258

Ashagre, B. B. (2014). SWAT to Identify Watershed Management Options : Anjeni Watershed, Blue Nile SWAT TO IDENTIFY WATERSHED MANAGEMENT OPTIONS : A Thesis Presented to the Faculty of the Graduate School of Cornell University in Partial Fulfillment of the Requirements for the. July 2009. https://doi.org/10.13140/2.1.2987.3602

Asmamaw, D. K. (2015). A critical review of integrated river basin management in the upper Blue Nile river basin: the case of Ethiopia. International Journal of River Basin Management, 13(4), 429–442. https://doi.org/10.1080/15715124.2015.1013037

Awulachew, S., Merrey, D., Kamara, a, Van Koppen, B., Penning de Vires, F., Boelee, E., Makombe, G., &. (2005). Experiences and Opportunities for Promoting Small-Scale/Micro Irrigation and Rainwater Harvesting for Food Security in Ethiopia. 98. http://www.lk.iwmi.org/pubs/working/WOR98.pdf

Ayana, A. B., Edossa, D. C., & Kositsakulchai, E. (2012). Simulation of sediment yield using SWAT model in Fincha watershed, Ethiopia. Kasetsart Journal - Natural Science, 46(2), 283–297.

Betrie, G. D., Mohamed, Y. A., Van Griensven, A., & Srinivasan, R. (2011). Sediment management modeling in the Blue Nile Basin using SWAT model. Hydrology and Earth System Sciences, 15(3), 807–818. https://doi.org/10.5194/hess-15-807-2011

Bitew. (2013). Status of Small-Scale Irrigation Projects in Amhara Region, Ethiopia. 6(1), 1–11.

Chang, H. (2006). FLUVIAL-12 Mathematical Model for Erodible Channels Users Manual. 858, 66.

Coviello, V., Vezza, P., Angeluccetti, I., & Grimaldi, S. (2015). Reducing the impact of soil erosion and reservoir siltation on agricultural production and water availability : the case study of the Laaba catchment (Burkina Faso). Case Studies for Developing Globally Responsible Engineers.

Dibaba, W. T. (2021). The status of soil erosion in the Upper Blue Nile Basin : Identi cation of hot spot Areas and Evaluation of Best Management Practices in the Toba Watershed.

Dibaba, W. T., Demissie, T. A., & Miegel, K. (2020). Drivers and implications of land use/land cover dynamics in Finchaa Catchment, Northwestern Ethiopia. Land, 9(4), 1–20. https://doi.org/10.3390/land9040113

Dutta, S. (2016). Soil erosion, sediment yield and sedimentation of reservoir: a review. Modeling Earth Systems and Environment, 2(3), 1–18. https://doi.org/10.1007/s40808-016-0182-y

El-Nashar, W. Y., & Elyamany, A. H. (2018). Managing risks of the Grand Ethiopian Renaissance Dam on Egypt. Ain Shams Engineering Journal, 9(4), 2383–2388. https://doi.org/10.1016/j.asej.2017.06.004

Elnashar, A., Zeng, H., Wu, B., Fenta, A. A., Nabil, M., & Duerler, R. (2021). Soil erosion assessment in the Blue Nile Basin driven by a novel RUSLE-GEE framework. Science of the Total Environment, 793, 148466. https://doi.org/10.1016/j.scitotenv.2021.148466

Elsharkawy, A. (2020). Effect of Grand Ethiopian Renaissance Dam (GERD). On the Life Span of Kobry El-Kobbah , Cairo , Egypt 11 th International Conference on Civil and Architecture Engineering ICCAE-11-2016 Effect of Grand Ethiopian Renaissance Dam (GERD) on the Life Span. October.

Hurni, K., Zeleke, G., Kassie, M., Tegegne, B., Kassawmar, T., Teferi, E., Moges, A., Tadesse, D., Ahmed, M., Degu, Y., Kebebew, Z., Hodel, E., Amdihun, A., Mekuriaw, A., Debele, B., Deichert, G., & Hurni, H. (2015). Soil Degradation and Sustainable Land Management in the Rainfed Agricultural Areas of Ethiopia: An Assessment of the Economic Implications. http://files/1780/Hurni *et al*_2015_Land Management in the Rainfed Agricultural Areas of Ethiopia - An Assessment.pdf

Nigel, W. (2004). Integrated river basin management: A case for collaboration. International Journal of River Basin Management, 2(4), 243–257. https://doi.org/10.1080/15715124.2004.9635235

Omer, A. Y. A., Ali, Y. S. A., Roelvink, J. A., Dastgheib, A., Paron, P., & Crosato, A. (2015). Modelling of sedimentation processes inside Roseires Reservoir (Sudan). Earth Surface Dynamics, 3(2), 223–238. https://doi.org/10.5194/esurf-3-223-2015

Organic, S., Nile, B., & River, A. (2015). Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa. Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa, December 2017. https://doi.org/10.1007/978-3-319-09360-4

Shobary, A. S., Elsharkawy, A., El-Hanafy, H. E. M., & Moussa, O. M. (2021). Updating land use and land cover classes of Blue Nile basin using landsat-8 images. IOP Conference Series: Materials Science and Engineering, 1172(1), 012014. https://doi.org/10.1088/1757-899x/1172/1/012014

Siddig, K., & Basheer, M. (2021). Economy-wide assessment of the impacts of Nile sediment reduction on the Sudanese construction sector. 24th Annual Conference on Global Economic Analysis (Virtual Conference).

Sultan, D., Tsunekawa, A., Haregeweyn, N., Adgo, E., Tsubo, M., Meshesha, D. T., Masunaga, T., Aklog, D., Fenta, A. A., & Ebabu, K. (2018). Efficiency of soil and water conservation practices in different agro-ecological environments in the Upper Blue Nile Basin of Ethiopia. Journal of Arid Land, 10(2), 249–263. https://doi.org/10.1007/s40333-018-0097-8

Tesfaye, G. (2022). Soil Erosion and Sedimentation Rate in the Blue Nile River Basin of Ethiopia. American Journal of Environmental Protection, 11(1), 1. https://doi.org/10.11648/j.ajep.20221101.11

Wolancho, K. W. (2012). Watershed management: An option to sustain dam and reservoir function in Ethiopia. Journal of Environmental Science and Technology, 5(5), 262–273. https://doi.org/10.3923/jest.2012.262.273

Worku, G., Teferi, E., Bantider, A., & Dile, Y. T. (2020). Prioritization of watershed management scenarios under climate change in the Jemma sub-basin of the Upper Blue Nile Basin, Ethiopia. Journal of Hydrology: Regional Studies, 31(October). https://doi.org/10.1016/j.ejrh.2020.100714

Yesuph, A. Y., & Dagnew, A. B. (2019). Soil erosion mapping and severity analysis based on RUSLE model and local perception in the Beshillo Catchment of the Blue Nile Basin, Ethiopia. Environmental Systems Research, 8(1), 1–21. https://doi.org/10.1186/s40068-019-0145-1

Yilma, A. D., & Awulachew, S. B. (2009). Characterization and atlas of the Blue Nile Basin and its subbasins. 236.

Zimale, F. A., Moges, M. A., Alemu, M. L., Ayana, E. K., Demissie, S. S., Tilahun, S. A., & Steenhuis, T. S. (2018). Budgeting suspended sediment fluxes in tropical monsoonal watersheds with limited data: The Lake Tana basin. Journal of Hydrology and Hydromechanics, 66(1), 65–78. https://doi.org/10.1515/johh-2017-0039