

HYDRO-MORPHOLOGICAL ASSESSMENT OF SANGU RIVER AND AFFORESTATION FOR DRY SEASON FLOW AUGMENTATION

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ABSTRACT

The Sangu River is a trans-boundary perennial river flowing through the Chittagong Hill Tracts of Bangladesh. With an average annual rainfall of 3114 mm concentrated in a short monsoon period, the river experiences high seasonal variability, leading to severe flooding in the wet season and significantly reduced flows or near drying in the dry season. Non-rainy days comprise 77% of the dataset. The maximum recorded rain in a day is 317 mm/day, which was recorded in the year 2015, which was a wet year. The study does a comprehensive hydrological analysis, finds LLW (lowest low water level), and calculates design flow for designated high flow events (1 in 25-year return period event) from peak over threshold flows. Through Log-Pearson Type III analysis, the dependable water level is found to be 4.19 mPWD (90% dependable) and 4.15 mPWD (97% dependable) for Bandarban station. Selecting peak water levels above a threshold, which is called POT, or peak over threshold, extreme values are identified. These values undergo frequency analysis (return period calculation). Through this, the design flood water level is identified as 14 mPWD in Bandarban, and the design flood event is identified as a 1 in 25-year return period flood. The design flow (1 in 25-year return period) is used in the hydrodynamic model (MIKE 1D) to observe flooding in present bathymetry. In monsoon it overtops at the middle (around Bandarban), and in the dry season there is almost zero draft upstream. This research concludes that dry season flow maintenance in the steep hill rivers requires integrated watershed management with afforestation for soil moisture retention, reduced soil evaporation, and increased evapotranspiration—thus ensuring groundwater recharge and flow in Chara and Jharna throughout the year, which can in turn support the 30% base flow of Sangu even in the dry season. It is seen that the recession of baseflow takes around 100 days (for the flow to reach the stream), whereas subsurface flow takes 10 days and direct runoff/overland flow takes about 1/3rd of a day to drain out through the outlet of the catchment. Afforestation not only mitigates soil erosion but also promotes evapotranspiration; ultimately, it augments river flow during dry seasons through soil water retention. This can create benefits by supporting local livelihoods with non-timber forest product supply, carbon dioxide sequestration (hence supporting climate mitigation), and mitigating flood risks in the downstream.

Keywords: : *Sangu River, dry season flow, design peak flow, afforestation, hydrological characteristics*

1. INTRODUCTION

The physiography of the Chittagong Hill Tracts is much different from the rest of the country, which in turn makes the rivers flowing through this region special in their own nature. Sangu is a trans-boundary river shared with Myanmar. The river is strongly influenced by tidal action at the downstream stretch, having a maximum tidal range of 4.93 meters. The Sangu River is perennial and meandering. The river flows through the Bandarban and Chittagong districts and then falls into the Bay of Bengal. Sangu has a length of 294 km with an average width of 119 meters. Dry season water usage for local irrigation and fisheries requirements is an important aspect to consider, as the natural slope of these rivers is very high. Local and upstream rainfall feed the rivers and surrounding waterfalls, which in turn feed the main river streams. During dry seasons, the upstream parts of the rivers are mostly dry, but during monsoons, cities like Bandarban are flooded due to the low conveyance capacity of the river or high and rapid flow accumulation (due to steep riverbed slopes). The paper investigates the hydro-morphological characteristics of the Sangu River, calculates a design flow (1 in 25-year return period) for flood simulation using the MIKE 1D model, and suggests introducing afforestation in slope areas to reduce landslides and increase soil moisture retention, which in turn feeds the local Chara and Jhiri (waterfalls) that supply water to the main Sangu River. These are the sources of baseflow during the dry season, derived from rainfall that has infiltrated the ground during the monsoon. An economic evaluation of the forest ecosystem is also conducted in the paper to understand the benefits of afforestation. Figure 1 shows the Sangu River bed at Remakri (Upstream of Bandarban).



Figure 1: Sangu river bed at Remakri (Upstream of Bandarban)- photo credit: Asish Sutradhar/IWM

2. METHODOLOGY

2.1 Data Collection and Pre-Processing

Water level and discharge data for the Sangu River (Bandarban station) were collected from the Bangladesh Water Development Board (BWDB). Rainfall data from 1963–2015 were obtained from the Bangladesh Meteorological Department (BMD). Rainfall was spatially weighted using the Thiessen Polygon method to compute areal rainfall. Water level and discharge datasets were synchronized to enable development of a rating relationship. Bathymetric cross-sections, river alignment, and bankline data were extracted from field surveys conducted by IWM. These data were

used to construct the river's bed profile and to identify morphological features such as erosion, deposition, and bankline shifting.

2.2 Hydro-Morphological Analysis

Observed paired water level–discharge measurements (2015–2016) were used to develop a rating equation for the Sangu River at Bandarban. The relationship was fitted statistically and validated by comparing observed and rated discharge hydrographs. The final rating curve was used to convert historical water level time-series into discharge estimates for subsequent analysis.

River morphology was evaluated using surveyed bed levels (the survey data and cross-sectional data were collected from the Institute of Water Modelling (IWM)). The longitudinal bed slope of the river was computed. Minimum dry-season water levels from the last three years were used to identify LLW conditions (Lowest Low Water Level). A frequency analysis using Log-Pearson Type III distribution was implemented to estimate 90%, 97%, and 99% dependable water levels. Dependable levels were validated against historical minimums. These values represent the water levels that the river is unlikely to fall below in dry periods.

Historical water levels (1961–2016) were screened to extract extreme water levels exceeding a predefined threshold. Extreme value analysis was conducted to estimate return periods. A 25-year return period flood was selected as the design event, corresponding to a water level of 14 mPWD at Bandarban. Using the developed rating equation, design water levels were converted into a discharge hydrograph, forming the input boundary condition for hydrodynamic modelling.

A one-dimensional hydrodynamic model was developed using MIKE 1D software to simulate river flow under both monsoon and dry-season conditions. Bathymetry, cross-sections, bed slope, and Manning's roughness values were incorporated from field surveys. The upstream boundary was given from the design hydrograph (25-year event). The downstream boundary was given water level conditions influenced by tidal effects.

Two core scenarios were modelled

- a) Design a flood scenario to evaluate overtopping and flood risk.
- b) Dry-season scenario to assess navigation depth, draft limitations, and hydraulic connectivity.

Model results were assessed to determine-

- a) Flooding behaviour around Bandarban during monsoon.
- b) Critically low depths in upstream reaches during dry months.
- c) Spatial patterns of hydraulic stress linked to the river's steep slope.

Few hydrological estimates were done, such as:

- a) Separation of flow (baseflow, subsurface interflow, direct runoff/overland flow)
- b) Time of concentration: time for separated flow to go from highest point to sink in the catchment-baseflow, subsurface flow, direct runoff

Further peer-reviewed literature and global studies were reviewed to evaluate the effect of forest cover on:

- a) Soil moisture retention
- b) Groundwater recharge
- c) Evapotranspiration
- d) Local precipitation feedback
- e) Stability of chara/jhiri systems

Special emphasis was given to findings by Bruijnzeel (1990), Fearnside & Ferraz (1995), and Garcia et al. (2018). Forest ecosystem services were evaluated economically using FAO ESA Working Paper 04-01 (Cavatassi, 2004) benefit assumptions.

3. RESULT AND ANALYSIS

3.1 Hydrological characteristics

The average rainfall of the area is 3114 mm per year (calculated by the Thiessen Polygon method) from BMD (Bangladesh Meteorological Department) stations. The temporal distribution of the rainfall is extreme over a hydrological year, as dry seasons prevail for six months (December to May). Hence, the river can go dry in winter/ the dry season, and it floods in the summer/wet season. From the entire historical dataset (years 1963 to 2015), non-rainy days comprise 77% of the dataset. The maximum recorded rain in a day is 317 mm/day, which was recorded in the year 2015, which was a wet year. There is a chance of river flood from May to September due to continuous heavy rain, but a rather chances of flash flood in the drier months due to quick, intense rainfall on some days. The relative location of Sangu with other eastern hill rivers and Thiessen polygons is shown in Figure 2.

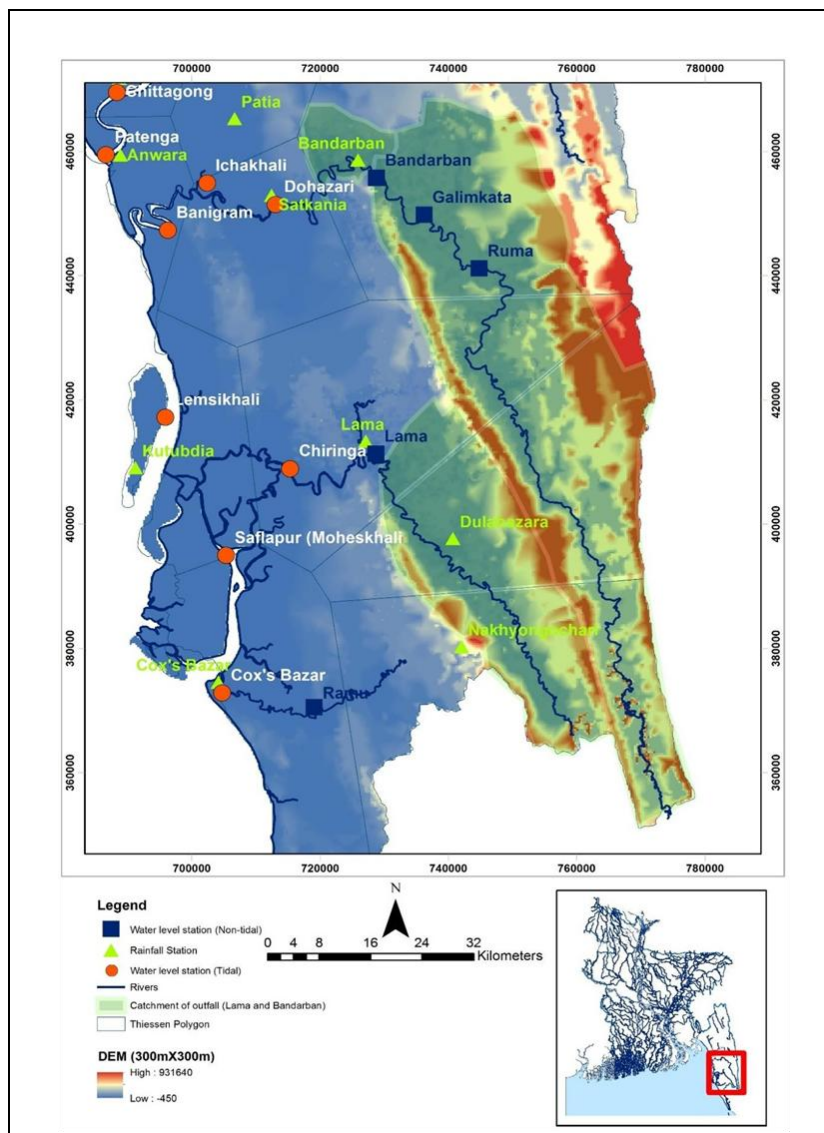


Figure 2: Location of the Sangu river and weighted rainfall calculation

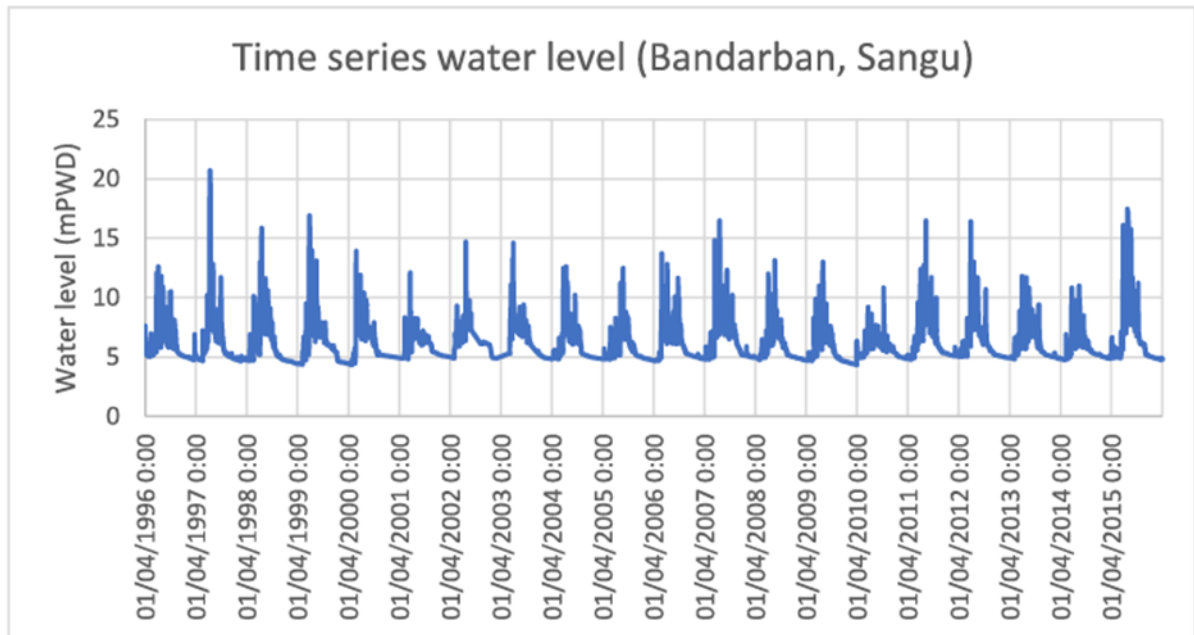


Figure 3: Water level at Bandarban (Sangu)

Water level data for the Sangu River are plotted in Figure 3. The rating equation is identified for Sangu from collected water level and discharge data of the same period (year 2015-16). The rating curve is shown in Figure 4. The rated discharge data is then calculated from the rating equation and with water level time series (observation), and they show very similar trends and peaks to the observed ones, which confirms a good fit (Figure 5).

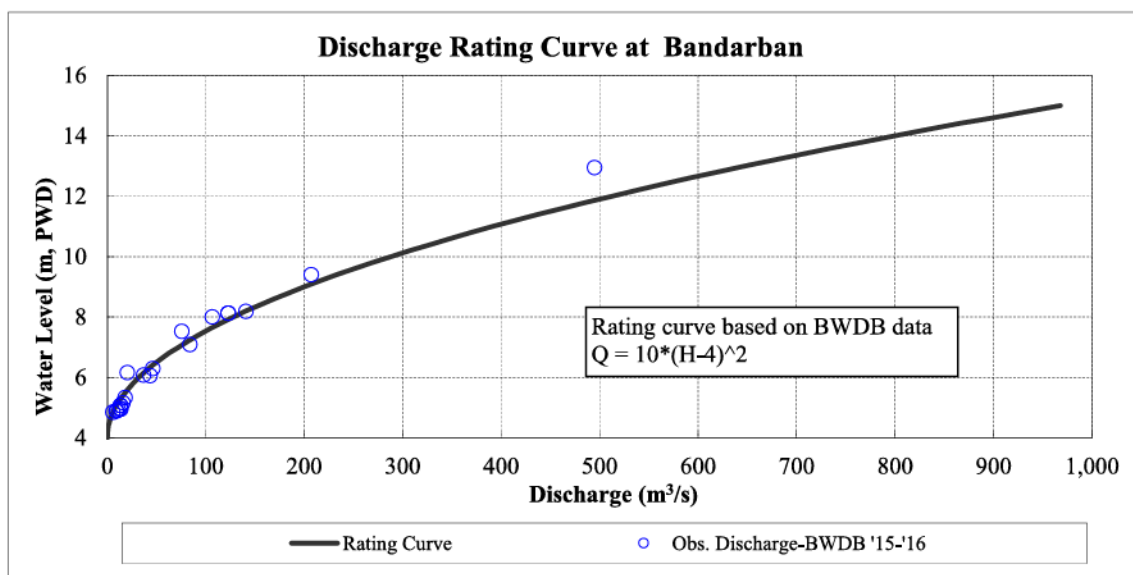


Figure 4: Rating curve for Sangu (prepared from water level and discharge observation data of Bandarban of 2015-16 provided by BWDB)

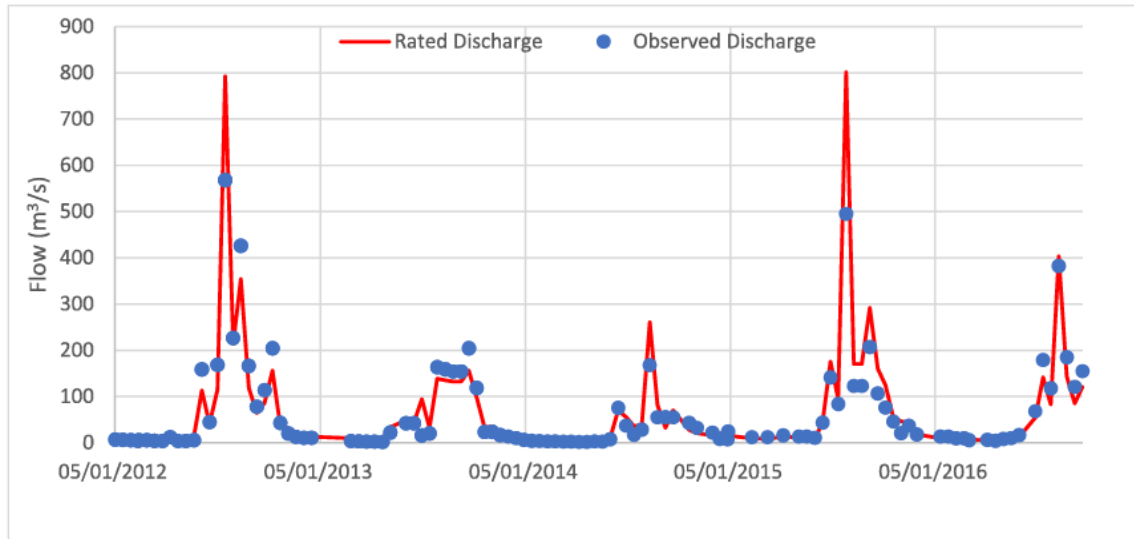


Figure 5: Rated discharge of Sangu vs Observed discharge of Sangu river

3.2 Morphological characteristics

Sangu is a long, meandering river with a mostly stable bankline, with occasional erosion and deposition, flowing a long path of 297 km inside Bangladesh. The river Sangu is predominantly sandy (bed material) in the downstream and has a gravel bed in the upstream, with huge boulders in the uppermost upstream regions. The Sangu River shows bankline shifting in recent years in the downstream regions. Some erosion and accretion are also observed. The rivers have a steep bed profile. Sangu has an average bed slope of 18 cm/km (Figure 6). The rivers have narrow sections in the upstream and broader sections in the downstream. From bed profile analysis it is found out that the slope is 18 cm/km (bed slope).

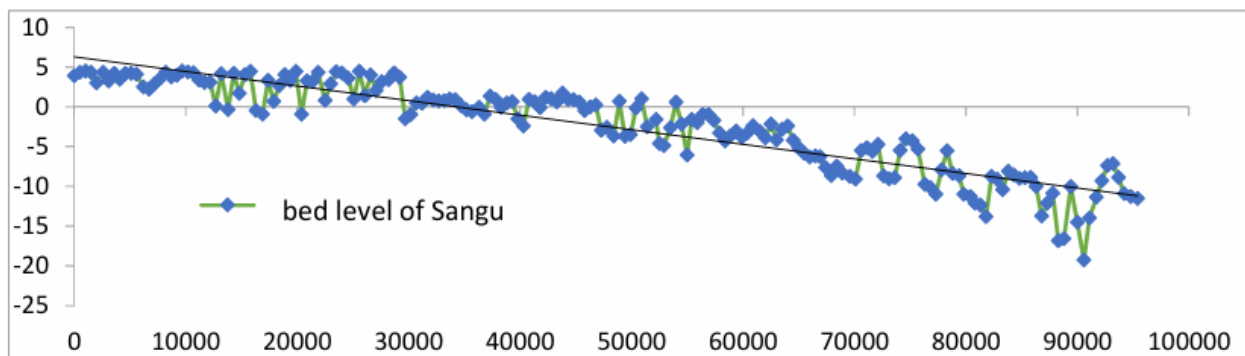


Figure 6: Bed level profile of Sangu River

3.3 Low Flow Calculation (LLW) and Design Flood Flow Calculation

LLW, or lowest low water level of the river, is identified from the minimum water level of the last 3 years and through frequency analysis of low water level (which is called dependable flow analysis). Water levels that will not go down below the level in 90%, 97%, and 99% of cases are called 90% dependable, 97% dependable, and 99% dependable flow, respectively. The method of exceedance (frequency analysis) used in this case is Log-Pearson Type III. The dependable water level is found

out to be 4.19 mPWD (90% dependable) and 4.15 mPWD (97% dependable) for Bandarban station. These values closely resemble the LLW identified from historical datasets. Selecting peak water levels above a threshold, which is called POT, or peak over threshold, extreme values are identified. These values undergo frequency analysis (return period calculation). Through this, the design flood water level is identified as 14 mPWD in Bandarban, and the design flood event is identified as a 1 in 25-year return period flood. This is an EV analysis (extreme value analysis), as it considers only peak flows over a threshold (POT). Sorting historical water level maximums for each year (years 1961 to 2016), it is seen that such water levels occurred in the year 2015 in Bandarban. Thus, using the water level time series of the year 2015 and the rating equations of Sangu, the flow data of the design flood event (25-year return period) is found out (Figure 7). The flow data is then calculated from the rating equation (for 14 mPWD water level).

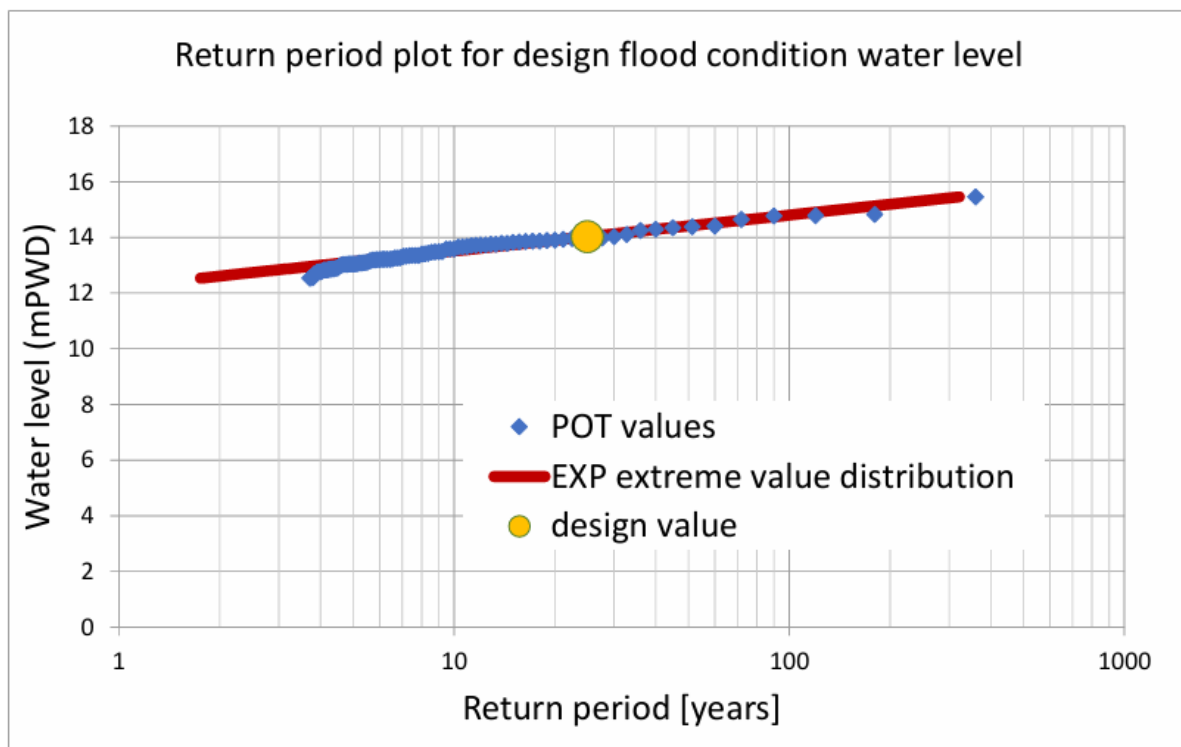


Figure 7: Design (high) Flow data estimation at 25 year Return Period (14 mPWD Water Level)

3.4 Sangu River Flow Modelling

The design flow (1 in 25 year return period) is used in the hydrodynamic model (MIKE 1D) to observe flooding or any other situation in present bathymetry. In monsoon it overtops at the middle (around Bandarban), and in the dry season there is almost zero draft upstream (Figures 8 and 9).

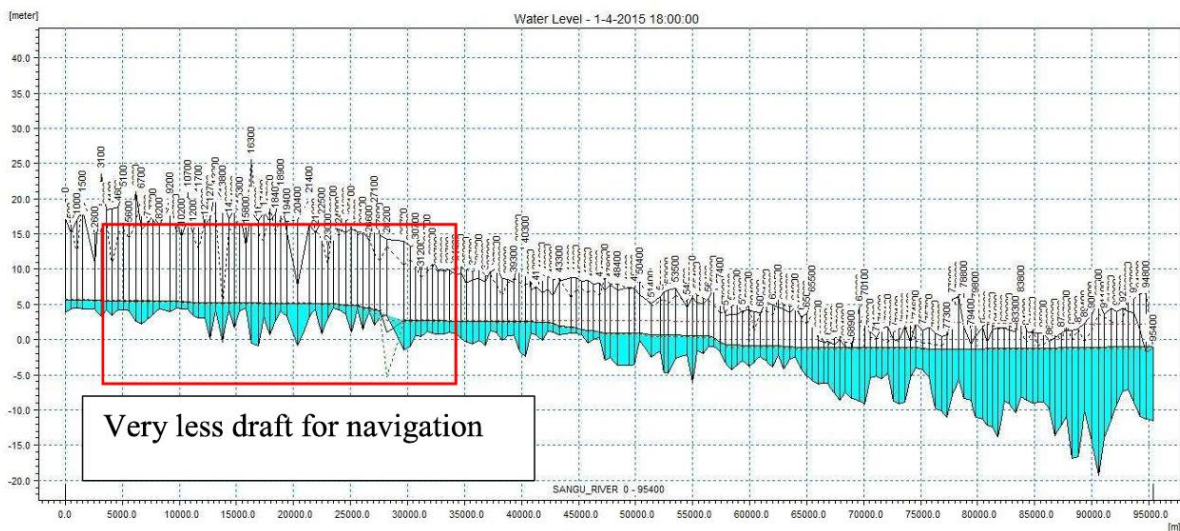


Figure 8: MIKE 1D model simulation with design flow and present bathymetry (dry season)

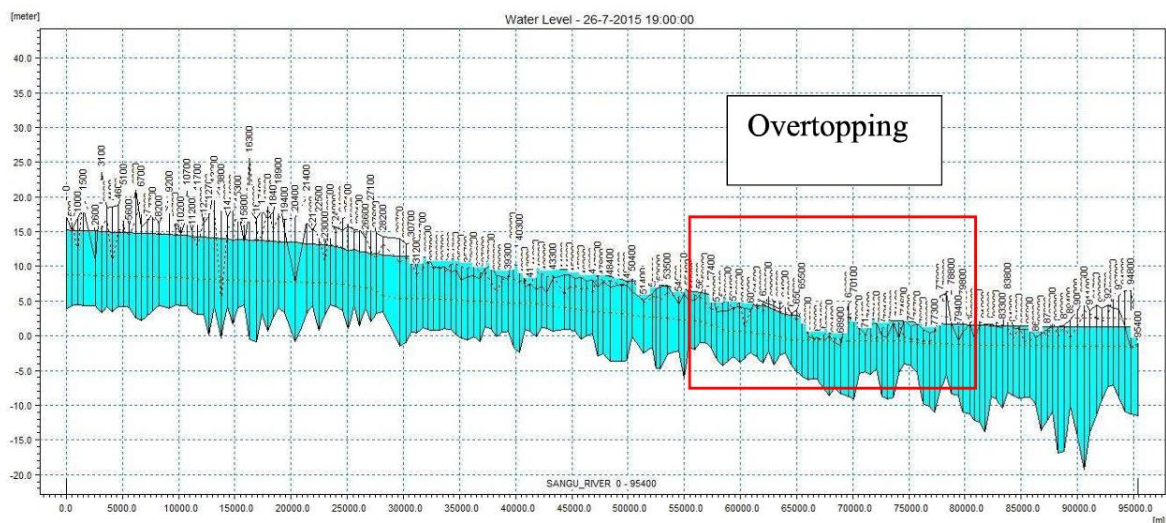


Figure 9: One dimensional model simulation with design flow and present bathymetry (monsoon)

The important factor to remember here is that the rivers are naturally quite steep (18 cm/km to 20 cm/km bed slope). It is seen from the model simulation that overtopping happens in the Bandarban chainage during monsoon, which is why we see flooding in Bandarban with present river bathymetry in a flood year (like our design flood), whereas very little draft is identified in the dry season in the upstream, where navigation is not possible.

3.5 Dry Season Flow in Sangu River: Chara and Jhiri

Though the river is fed by rainfall-runoff from upstream catchment in Myanmar and by rainfall from the catchment area inside Bangladesh, there is contribution of numerous chara and jhiris and ‘shoilo propats’ (sub-surface water outletting through rocks as water falls or seeping through rocks). These water is not only from monsoon-rain or dry season rain, rather also from groundwater sources as even in the driest months without any rain, these chara and jhiris remain active and keep feeding the rivers. An analysis is done to check how much of the discharge (calculated from measured water level with rating equation) comes from rainfall through rainfall-runoff analysis. Baseflow contribution is a big contribution to the rivers, as the rivers are perennial (they never fully dry out), and yet rainy season is

only five months, the other months being completely dry. Baseflow contribution consists of 30% of the total flow. The overland flow (direct from local rainfall) is 70%, of which sub-surface flow is 10% and direct runoff is 90%. The base flow itself is rainfall infiltrated into the soil and stored over a long-time period from the surrounding region. It is a matter of investigation whether all of the base flow contribution is rainfall-fed or there is aquifer contribution as well.

From analyzing the recession constant from the receding slope of the hydrograph, it is seen that the recession of baseflow takes around 100 days (for the flow to reach the stream), whereas sub-surface flow takes 10 days and direct runoff/overland flow takes about 1/3rd of a day (Figure 10).

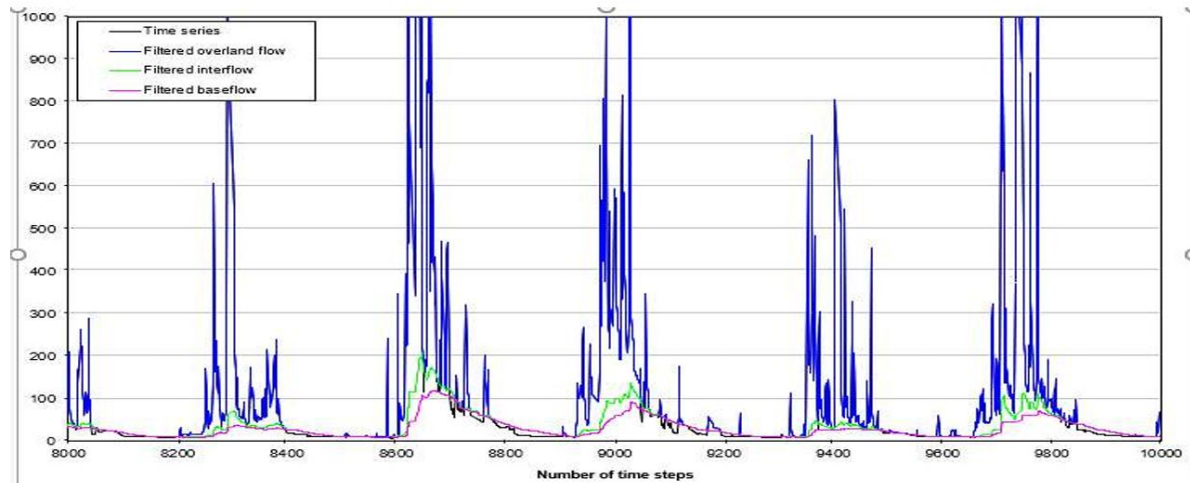


Figure 10: Baseflow and interflow separation from Bandarban station discharge (rated discharge)

Further analysis is done to identify how important this 30% baseflow contribution is. It seems during the dry season, this is the only flow available, as there is no rain. And to keep this baseflow contribution intact, the chora (seeping waterfalls) and jhorna (active and big waterfalls) must be kept alive. As has been found out in various studies, excessive deforestation causes these underground water sources to die out. Deforestation causes the soil and stone to become loose, which holds the water (soil moisture retention). Forests also create high evapotranspiration and higher local rainfall, as well as low soil evaporation due to canopy coverage from trees. A direct relation of forest cover and water availability is seen in the report (Garcia et al., 2018). It is also found out in that report that the Sangu River has faced extensive deforestation around their regions, termed as “black spots” of land degradation.

From different reports it can be found that the region is rich in aquifers. But the aquifer characteristics are such that it is low in transmissivity and is made up of tertiary sediment. High withdrawal of water hence is contributing to low water availability. Due to low availability of surface water during the dry season, groundwater is extracted extensively in hill tract regions, which is in turn reducing groundwater level. Finding potable water is becoming more and more difficult for the local people during the dry season.

3.6 Afforestation for Dry Season Flow Augmentation

Afforestation is necessary in this region to restore the dry season flow source of the rivers, that is, chara, Jharna, waterfalls, etc. As the dry season has zero to very low rainfall, the contribution of chara, which is the baseflow contribution to the river in the dry season, is very important. Different studies have identified the need for afforestation to restore land stability, reduce land degradation and landslides, increase soil water storage and canopy storage, reduce evapotranspiration and overall augment natural conditions for the chara and waterfalls that eventually contributed to dry season flow.

Fearnside and Ferraz (1995) observed that the leaf area is roughly proportional to evapotranspiration and therefore is directly connected to water recycling, precipitation, and water recharge. Thus, reforestation or sustainable forest management can lead to increased hydrological cycling, evaporation, precipitation, and recharge of groundwater and watercourses which, in turn, can avoid dry seasons (Cavatassi, 2004).

Without afforestation, dredging of design sections alone cannot save the river of the Eastern hill region in the dry season, as these are mountain rivers and depend on mountain groundwater (baseflow/chara) in the dry season. Hence, afforestation is suggested to protect the source or chara areas.

3.7 Riverside afforestation for Flood Mitigation and Dry flow Augmentation

Plantation along the riverside has multiple benefits, such as a) contributing to the livelihood of the local people through non-timber forest product supply (NTFP) on a daily basis (bamboo for eating, tree branches for cooking, medicinal use, fruits as food etc.). b) Carbon sequestration (by removing carbon-di-oxide from the environment and helping to reduce the global warming effect) c) Giving shade to water sources, thus reducing evaporation and increasing soil moisture retention, reducing heat impact d) Improving ecological and environmental sustainability by giving shelter to flora and fauna through the forest e) reduced bank slope failure and reduced erosion f) increased soil moisture retention g) Many studies have found that trees, due to their increased evapotranspiration, cause increased water vapor saturation in the atmosphere, leading to increased rainfall. Rainfall is another important source of river water.

After the cycle of 30 years, timber can be logged, which will give direct monetary benefit to the authority. Reforestation can be done then to continue the existence of ecosystem services of trees to sustain river water sources and local livelihoods. The detailed benefit assumptions are taken from FAO - ESA working paper 04-01 (Table 1) from (Cavatassi, 2004).

Table 1: Afforestation benefit calculation (ecosystem services)

Item	Unit benefit BDT per hectare per year
C sequestration	3360
NTFP (non-timber forest product)	168
Biodiversity	2520
Medicinal plant	84
Existence value	537.6
Soil erosion and water storage management	Intangible, can be taken equal to deforestation cost** as identified by the working paper.

Benefits under this category include mainly those linked to the ecological function of forests. Documenting them is not easy (Bruijnzeel, 1990), but the main ones include watershed, soil and food protection, water and nutrient cycling, soil fertility, protection against fire, and other connected benefits such as enhancement of agricultural productivity. All these can be seen as benefits generated through a forestry project or as costs in case of deforestation (and therefore avoided costs if deforestation is avoided).

4. DISCUSSION

The results demonstrate that the hydrology of the Sangu River is defined by extremely high seasonal variability, with heavy monsoon rainfall and severely dry conditions during winter months. This variability is magnified by the river's natural steep gradient and sharply sloping catchment. The dependable flow analysis confirms that the river frequently approaches its lowest low water levels during dry months, particularly in upstream regions where channel slope is highest.

The hydrodynamic modelling clearly shows that existing bathymetry contributes to two contrasting problems: overtopping and flooding in Bandarban during monsoon and negligible navigable depth during dry season. These dual challenges indicate that structural interventions such as dredging alone cannot maintain year-round flow, particularly because the river depends heavily on baseflow.

Baseflow analysis highlights that 30% of flow originates from groundwater-fed sources, including chara, jhiri, and waterfalls that remain active even in non-rainy periods. The recession characteristics (baseflow \approx 100 days) confirm that these sources sustain the river during long dry spells. However, multiple studies cited in the paper indicate widespread deforestation, degradation of slope forests, and over-extraction of groundwater in the hill tracts. This degradation reduces the soil's ability to store water, weakens the aquifer, and diminishes the natural mechanisms that supply baseflow to the Sangu River.

Thus, the findings point to afforestation as a crucial intervention, not only for maintaining slope stability and reducing landslides but also for enhancing soil water storage capacity. Increased forest cover can improve natural infiltration, increase groundwater recharge, and revive chara and jhiri systems. These effects directly support dry-season flow augmentation, which dredging activities alone cannot achieve in such steep, mountain-type rivers.

Moreover, riparian afforestation offers ecological, hydrological, and socio-economic benefits. It reduces evaporation, improves canopy shading of water sources, contributes to carbon sequestration, and supports local livelihoods through non-timber forest products. The long-term economic valuation presented in the paper underscores that forest restoration is a cost-effective approach to sustaining the river's perennial nature and supporting its multiple users.

Overall, the study concludes that slope-area and riverside afforestation is a foundational requirement for restoring the natural hydrological cycle of the Sangu River. Without it, dry-season flow will continue to decline, affecting navigation, domestic water use, and ecological health.

5. CONCLUSIONS

The three rivers are the lifeline of the eastern hill hydrological region, and Sangu is the lifeline of both the eastern hill and Chittagong. The rivers need to be fully functional—hydrologically and morphologically—throughout all the seasons to be beneficial for local people in terms of various aspects of river water usage, especially for local navigation. Dredging may be one of the ways to control flooding during the monsoon, but it does not ensure low flow augmentation in the dry season, as these are steep rivers. Instead, planned afforestation along the banks will increase canopy coverage, reduce soil moisture evaporation, and enhance water retention, which will improve groundwater infiltration and strengthen the Chara and Jhiri network to remain active even in dry seasons—connecting them to the base flow of the river.

ACKNOWLEDGEMENTS

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