ABSTRACT

River bank erosion is a natural process, without it, river won't change its course. The eroded materials are one of the several sediment sources of any channel. Formation of many fluvial landforms like floodplain, natural levees, bars, shoals etc. depend on the materials that are carried by rivers in different period of time. But people always try to control river in its situ position by constructing various structural measures like embankment, spurs, dyke, etc., to minimize damage done by bank erosion. Having this in mind, the present research work has done to upper course of river Mahananda (25.6 km) in Darjeeling district. Although this district receives highest total amount of rainfall (Total annual rainfall > 2500 mm) in West Bengal but is considered flood free. Rising river bed, failure of erosion protection measured during monsoonal period, landslide, deforestation from upper part of the basin etc. are some very crucial problems in the study area. Large sum of money (Average 3 crore annually by Irrigation & Waterways Department, Siliguri Division) is being spent each year for erosion protection work but problem remains the same. Keeping in view of the above mention problem, the study on bank erosion of upper Mahananda basin has been carried out for better understanding of the nature, causes and consequences of bank erosion. Main objectives of the study were to identify the major bank erosion sites, causes and mechanisms of it, to examine its relation with the overall hydraulic characteristics of the area and finally suggest some conservational measures to solve the above mentioned problems.

Bank erosion sites were identified by two methods, namely, direct method and indirect method. The direct method uses pin array techniques and measuring distance between bank lines to some permanent structure. The indirect method uses satellite images (2011-2018) of the study area and other archival sources. Regular photographs, cross-sectional survey, regular field visit (2015-2018) was done to identify annual bank erosion rate. Q-GIS software 2.18 and 3.14 were used for the mapping of spatio-temporal identity of the riverbank erosion. Total 23 points were selected for insertion of erosion pin array. Total eroded material was measured by the technique (2016) was 85.77 m^3. This method gives idea of erosion pattern from entire bank profile, but it is highly location specific. The second techniques is the measurement of the horizontal distance from permanent structure to bank line. This is very useful & easy method and 32 sites were selected based on the exposure sign of bank erosion during field survey. Rate of bank erosion measured by this method is 1.1 m/yr.

Different types of bank erosion were identified during field survey, such as undercutting (most dominant), block slumping, overtopping, etc. There are three main factors which are involved in the riverbank erosion in the study area. High velocity of water flow, which is mainly contributed by higher rainfall and gradient, non-cohesive bank materials characteristics, shifting of thalweg line and formation of bars, in case of anthropogenic activity bed material extraction plays most vital role. Cross profile of the river bed change drastically within very short time, even within hours, because they are using gigantic machineries. Administratively, the study area falls in two blocks and one Municipality, namely Kurseong, Matigara and Siliguri (M) and the population pressure on the basin is increasing geometrically, e.g., 27%, 53% and 46% respectively, as per 2001-2011 census report. Growth rate of population in Kurseong is 48.6%, 49.6%, 27% during 1981-1991, 1991-2001, 2001-2011, which are much higher than the national level which was 23.56% in 1981-1991 and 21.34% in 1991-2001. This population growth in the fragile part of the basin is not good sign for the environment.

There are several factors involved in bank erosion e.g., flow velocity, closeness of thalweg, bar formation, etc. Depending on location site, one or more factors dominate others and this was studied on 27 selected sites. A weightage table was prepared listing all possible causative factors. Initially, each factor was given equal value of 100 points, then weightage was given to each factor depending upon their role in erosion. Weightage was given based on the condition of river channel during the monsoonal month of the year 2017 and 2018. Chapter 5 deals with relationship between bank erosion and channel hydraulic parameters, i.e., channel width, depth, velocity, discharge, etc. Textural analysis of 14 samples from different sites shows that almost 80-85% of bank materials are composed of sandy materials. Large fraction of these materials is composed of pebbles, cobbles and boulder. Hence, the river bank is more prone to erosion due to weak chemical bonds. Flow velocity is non-uniform across the cross-section, it generally increases from the bank to the center of the channel except for sites having non-uniform depth and turbulence flow. Flow velocity suddenly increases when tributaries join with the river Mahananda. The small tributaries of river Mahananda (Gulma *Khola* and Champasari *Jhora*) supply enormous volume of water during monsoon.

Relationship between Bank erosion rate and mean velocity and near bank velocity was done, which shows that near bank velocity plays more important role for bank erosion than mean velocity of the channel. Bank Assessment for Non-point source Consequences of Sediment

(BANCS) model have been used to estimate bank's susceptibility to erosion. When BEHI value compared with actual bank erosion rate of corresponding area, then only 42% relationship was found hence a different model named bank erosion vulnerability zonation (BEVZ) was used in which 7 factors that are highly associated with the bank erosion are considered. A landward strip of width 5 m parallel to bank is used for the preparation of vulnerability zonation. This demarcation was done based on the extent of highest erosion affected portion of the river bank. The overall BEVZ rating was divided into 5 groups, out of 32 sites, 31% have fallen on moderate hazard zonation, followed by the very highly vulnerable zone (25%). A vulnerability map was prepared based on the BEVZ value, where very highly vulnerable zone was identified at the left bank of the river along 'Mahananda Wildlife Sanctuary' and around 80-140 m length on the right bank at Debidanga. The zonation model was validated by comparing with the actual bank erosion rate and it was found that the model is good for prediction of erosion. The zonation model basically based on field survey but the parameters are very simple and easy to measure. Anyone can change the weightage of the parameters according to their role of the occurrence of the event.

Chapter 6 enlists the problems faced by local people and the measures taken by the local authority to check the problem. Attempts have been made to give some comprehensive and innovative approach for mitigating the problem. There are both direct and indirect consequences of the bank erosion. Failure of erosion protective measure (e.g., Spur, Embankment, etc.), land loss, damages of houses, loss of vegetation, loss of agricultural land, lives, collapse of railway bridge, road bridge, breaching of metalled road, embankment, etc. create lots of problem in the socio-economic life of local people. Example – Breaching of Champasari Embankment in 2012, damages of SH-12 Road bridge and toy train line over river Panchanoi in 2015, breaching of embankment in Dimdima Busti area in 2016, failure of erosion protection measures in Gulma in 2017, 2018, etc. A case study was done on the impact of flood on social life, impact of embankment breaching incident in Champasari region and was found that 300 m embankment breached on night of 15th August of 2012. Since, factors of bank erosion vary from site to site, so, method of bank protection work also varies from place to place or bank materials to materials. A single conservational measure is not suitable for all cases.

Most of the alluvial rivers in the Sub-Himalayan region have experienced rapid sedimentation problem in the form of bed load. Rapid encroachment of active floodplain area,

land use change, decrease river depth, over-grazing, extensive deforestation from the upper catchment and bank side area are some contributing factors for sedimentation of the rivers. Keeping in view of the problem, some conservational measures have been proposed, like change in land use practices, plantation of some specific plant which are well suited in the bank side area, such as Amliso plant which is used as a cleaning tool in houses, locally called *'ful Jharu'*, Kharahi, Vetiver grass, Tiger grass, Hedera helix (local name *Tilcore)*, all types of legume family plant, cover plants, etc. They can be grown on severely degraded marginal land also. Only those constructions that cause minimum stress on river life should be encouraged to be constructed. To reduce the energy of high velocity flow, small check dam should be constructed in different parts of river channel, so that water can be stored and distributed in different places which may also help for ground water recharging. At present, almost all tea gardens of this area are facing water deficiency problem in non-monsoonal period. The sprinkler irrigation depends on underground water. If the concept of bank protection method can be linked to irrigation sector, then the multidiscipline concept may be helpful in future. Natural area of the river bed should be free from any construction activity. Continuous monitoring at least twice in a year by BLRO, local government authority, like councilors in the urban area, panchayat in rural area is highly required to check any type of encroachment on river bed. Finally, a river is an interconnected system, land use practices in both upstream and downstream will be determined by the success of any erosion protection measure. In this context, co-ordination among different Government Departments, like Forest Department, Irrigation Department, Agricultural Department, Tourism Department, Local Divisional Government body and also compilation of various research activities on the topic is necessary.

(RESEARCHER) (SUPERVISOR)

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