

LIST OF FIGURES

Figure No.	Description of the Figure	Page No.
1.1	Location map of the study area	3
2.1	The distribution of Geological formation of the study area	19
2.2	Physiographic divisions of the study area	20
2.3	Relief map of the study area	21
2.4	(A) Percentage of basin area under different slope range	22
	(B) Slope map of the study area	23
2.5	Overall climatic condition of Darjeeling district from 1901 to 2000	24
2.6	Soil map of the study area	25
2.7	Land use and land cover scenario of the study area	35
2.8	Percentage of area of the basin under different land use & land cover categories	36
3.1	Administrative setup along the course of river Mahananda in Darjeeling district	40
3.2	Terrace formation in river Mahananda at Gayabari tea estate, sign of vertical cutting of the channel	41
3.3	Location of classified segments of the study area	42
3.4	Types of river bank erosion found in the study area – Hydraulic action & Undercutting (a), Mass failure (b & c), slab type bank erosion, at the right bank of Palash mouza, under Matigara block	45
3.5	Documentation of erosion pin array technique.	48
3.6	Location of erosion pin (yellow dots) near Gulma Railway Bridge (A), left bank of the channel at Duramarir Chhat (B), right bank at Rupan Chhat Mouza (C), left & right bank at Palash area (D)	48
3.7	Location of the survey sites	54
3.8	Measurement of bank erosion rate by erosion pin technique,	57

	during 2016-2017	
3.9	Bank erosion rate at the surveyed sites	62
3.10	Bank erosion sites of river Mahananda in Kurseong block	63
3.11	Bank erosion sites of river Mahananda in Kurseong & Matigara block	64
3.12	Bank erosion sites of river Mahananda in Matigara block	65
3.13	Bank erosion sites of river Mahananda in Matigara block (Part of Gulmakhari, Champasari etc.)	66
3.14	Bank erosion sites of river Mahananda in Matigara block & Siliguri Municipality in Darjeeling District and part of Rajganj Block in Jalpaiguri District	67
3.15-16	Mouza-wise eroded area at left and right bank of river Mahananda (2011-2018)	69
3.17	Bank erosion sites of river Mahananda in Matigara block & Siliguri Municipality, Darjeeling District	71
3.18	Bank erosion sites of river Mahananda in Siliguri Municipality Area (Ward no. 46, 45, 2, 3, 1, 44 & 43)	72
3.19	Bank erosion sites of river Mahananda in Siliguri Municipality and some mouzas of Matigara block	73
4.1	Comparative analysis of daily gauge height (m) and rainfall (mm) from June to October, 2016 to 2018	77
4.2	Total rainfall of some regions of the upper Mahananda basin, upstream to downstream of the study area	78
4.3	Average monthly gauge height (2016-2018)	78
4.4	Relationship between amount of daily rainfall and daily gauge height of Mahananda basin in Siliguri Sub-Division	79
4.5	Longitudinal profile of upper part of river Mahananda	80
4.6	Bank material characteristics of river Mahananda in foothills zone	81
4.7	Bank profile at different sites of the study area. At right bank of river Mahananda at upstream and downstream of Gulma Rly	85

bridge (A, B), Right bank at Palash (C), Left bank upstream of Rly bridge along Mahananda Wildlife Sanctuary (D), Right bank at Palash (E), Debidanga area, bank height 4.3 m (F), Right bank near Ramghat area, Siliguri during monsoonal season (G), 150 m & 200 m downstream of 4th Mahananda Bridge at right bank (H, I). (h)right bank downstream of Gulma Rly Bridge(I)

4.8	Location of selected bank profiles and cross-sectional survey points in the study area	86
4.9	Oscillation of thalweg line between both banks at Debidanga area	88
4.10	Cross-profile at the selected locations, showing the changes in bed elevation during pre-monsoon and post-monsoonal period from 2016 to 2018	92
4.11	Location of selected bars at upstream and downstream of Gulma Railway Bridge	94
4.12	Changing areal dimension of the selected bars	96
4.13	Different types of deposition at upstream of the Gulma Rly Bridge (A, B), downstream of the railway bridge (C), Mid-channel bar at the confluence of river Mahananda and Balasan (D)	98
4.14	Changes bed profile and knick point migration in upstream and downstream due to bed material extraction activities	100
4.15	Decadal variation (2001-2011) of household in different CD blocks of upper Mahananda Basin	104
4.16	Decadal variation (2001-2011) of population of the study area	104
4.17	Land use change 300 m buffer along the bank of river Mahananda from 2004 to 2018, at Gulma, Korabari, Palash & Siliguri area, at segment I-IV	107
4.18	Permanency of houses along river Mahananda in Siliguri	105

12.03. 2021

4.19	Formation of unpair terrace on river Mahananda in Darjeeling hills (Location: Gayabari Tea Estate)	110
4.20	Percentage of weightage of the factors influencing bank erosion	112
4.21	Mechanism of bank erosion of river Mahananda at the foothills region	116
4.22	Undercutting followed by sliding and collapsing of exposed bank materials, on July 2016, at Palash Mouza under Matigara block	117
4.23	Force reduced nearly 80 times when ions are immersed in water than vacuum	118
4.24	Development of large furrow in the exposed bank during monsoonal season, at the right bank of river Mahananda, Palash Mouza	119
5.1	Variation of channel width in downstream direction	123
5.2	Variation of channel-width during monsoon and non-monsoonal period	124
5.3	Variation of the channel width in selected locations (2010 to 2017)	124
5.4	Variation of flow depth in the downstream direction	125
5.5	Comparative analysis among mean velocity, near bank velocity and bank erosion rate	126
5.6	Relationship between near bank flow depth & bank erosion rate	127
5.7	Relationship between mean, near-bank velocity and bank erosion rate	129
5.8	Variation of discharge in selected locations of the river Mahananda	129
5.9	Location of survey & Sample collection sites	130
5.10	Relationship between bank material characteristics and erosion rate in selected location of the study area	131
5.11	Seasonal variation of bank profile at different sites, right and left bank of channel, along the Mahananda Wildlife Sanctuary	134

	(A, B), left bank at Palash area (C, D), right bank, 120 m downstream of Gulma Railway Bridge (E), right bank near the confluence of river Panchanoi (F)	
5.12	Nature of river bank profile during monsoonal month, 2018	135
5.13-17	Representation of rating of different components of BEHI to the total sample unit	138
5.18-22	Relationship between different streambank erodibility parameters and BEHI Score	140
5.23	BEHI rating in selected location of the river Mahananda	141
5.24	NBS rating in selected location of the river Mahananda	143
5.25	Relationship between BEHI and observed erosion rate (m/yr)	144
5.26	Relationship between NBS and observed erosion rate (m/yr)	144
5.27-33	Status of different bank erodibility variables at the selected sites	149
5.34-40	Relationship between different streambank erodibility variables of river Mahananda and total BEVZ score.	151
5.41-42	Validation of BEVZ model with measured bank erosion rate	152
5.43	Bank Erosion Vulnerability Zonation Map of the study area	153
6.1	Cost of tenders for bank protection work on river Mahananda and its adjoining tributaries	169
6.2-3	Scenario of the structural measures that have been taken for the erosion control at segment II, III & IV	171