CHAPTER - I

INTRODUCTION

Earth, the only planet in the solar system has been bestowed with a very unique element, water, which is, perhaps, the most precious gift from Nature, since time immemorial. Water in different forms not only helps existence and sustenance of life on the planet, it also plays a vital role in maintaining the mobility of the rock cycle and the cycle of erosion of the different agents of erosion and in transforming and re-creating the different landforms on the surface of the earth. Global water circulated through the processes of evaporation, condensation and precipitation leads to runoff, which in turn, leads to origin of streams and rivers, which form vital agents of erosion, transporting sediment laden water from their respective places of origin to the hydrosphere, like blood vessels of a living body.

The journey of a river from its source to its destination, the mouth, is marked by several smaller runoff channels combining to form a single channel of considerable width and depth, as well as, capacity to supply water and sediments to the stretch of area washed by the main river channel and its tributaries constructing and re-constructing a variety of landforms and playing important role in economic activities of humans and influencing growth and development of human civilizations all along their respective courses. Human civilization began with development of agriculture and permanent settlements along river valleys throughout the earth. With the expanding knowledge of utilization of fertile river valleys to serve the needs of the society, the degree and magnitude of human intervention is ever increasing, affecting the tenuous balance between humans and the environment, leading to several interlinked problems, specially, in developing countries.

Defining 'watershed'- *Watershed* in geomorphology has been defined as "that area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community (Powell, 1869)." Therefore, *watershed* indicates a drainage basin of any shape and size. A watershed is very important for main process of movement of water in the hydrologic cycle, from the atmosphere to the hydrosphere, through the lithosphere. In the present day world, where economic development and the several developmental processes are undertaken, especially in developing and underdeveloped countries, watershed management is of vital importance, for sustainable development. Movement of water within a watershed is controlled by certain pre-determined factors, like geological structure of the watershed, relief, climatologic factors, including precipitation, infiltration capacity, soil and natural vegetation; watersheds adjacent to each other, located within the identical climatic/ natural vegetation region may display differences due to variation in any one of the factors mentioned above. Factors controlling movement of water within a watershed are closely linked and work as a single unit in controlling movement of water within the watershed; changes/ alterations in any one is bound to affect all others and flow of water within the system is affected. Fluvial dynamics is reflected through activities of erosion, transportation and deposition done by the trunk stream and the different tributaries within the watershed. Alteration in any one of these affects the fluvial dynamics of the drainage basin as a whole, and results in increased ecological vulnerability, disruption of hydrologic balance of a region, increased incidents of soil erosion, avulsion, river bank collapse and floods. As such, watersheds are found to have fragile ecological balance; in many parts of the earth, watersheds are located wholly or partially between two zones with completely different natural regions. Therefore, this unique location, termed ‘threshold zones, makes the study of watersheds, important, for water resource management, agricultural planning and regional planning.

1.1: The Problem:

The humans invented techniques of land utilization in different river basins of the earth; this required study of river behavior and rainfall, indicating fluctuation or rise in water levels of the rivers in different parts of the year according to which agricultural calendars were made. Economic growth, development and prosperity of countries depended much on the level of utilization of river valleys. First civilizations had grown up in river valley regions; plains and river valleys have had the highest population concentration. Battles were fought for occupation of river valleys by different human races.

Riverine plains have always been preferred for agriculture and building settlements. With increasing distance from large rivers and river valleys, availability of drinking water and for irrigational purposes generally becomes scarce; therefore, value of land, as well as, population density decreases with increasing distance from riverine tracts. The less favourable areas, like forests, grasslands, rugged and hilly terrain, located generally at head of watersheds, remain sparsely populated or even, unoccupied. A vivid account of land valuation and land use planning, based on distance from the River Ganges during Chandragupta Maurya's reign may be found Kautilya's Arthashastra. Methods of sustainable water storage for use during drought was also not unknown by people of the early civilizations.

It was understood since the early days of civilization, that living along river valleys also meant living with excessive discharges of rivers at times, commonly known as floods. Flood disasters are one of the most severe natural disasters in the world, having long-term effects on the ecosystem and the socio-economic environment. Recurrent floods and associated problems of sedimentation and soil erosion render fertile tracts infertile and unsuitable for agriculture for a considerable period of time which has detrimental impact on socio-economic development. While ancient Egyptians mastered the techniques of forecasting floods and utilizing floodwaters to obtain rich harvests, the Chinese developed techniques of river control by studying river behavior and maintaining detailed records of flood discharges long before invention of modern techniques.

With the advance of time, humans invented advanced techniques of river control, required for reducing flood hazards and annual inundation of the riverine agricultural and settlement areas and for extension of modern agricultural, industrial and urban land use to sustain the increasing population pressure on land. The only solution of flood hazard and annual inundation of riverside land seemed to be construction of dams and flood embankments along the rivers. Accordingly, dams and embankments were constructed as part of river valley projects to check flooding and annual inundation and to provide irrigation water to agricultural fields and increase agricultural output. Construction of flood embankments also enabled reclamation of riverside land for extension of agriculture and building settlements, which was necessitated by the rapid increase of population in South-east Asian countries like

India, since the 1950-s. As the riverine plains had long become overpopulated, the excess population was pushed to the hitherto sparsely populated or uninhabited rugged and forested parts of the peninsular plateau or to the infertile and forested Sub-Himalayan areas, considered unsuitable for use (Hofer, 2003; Ives and Messerli, 1989).

Pressure on unused land in India and South- East Asian countries has been increasing since the late 19th century, following the second phase of demographic transition. Population of India since then has been ever-growing and the growing population has to be supported through economic development and increase in per capita income, leading to increased GDP. The closing decades of the last millennium have seen a steady rate of population growth in India and the neighbouring countries. The decadal population growth rate of India has had remained steady and more or less unchanged since the last century, thus further reducing the man: land ratio. Increase of population since 1950, in alarming proportions as combined effects of natural increase and immigration, has pushed the already-overpopulated areas to the brink. Due to sharp rise in population in eastern and north-eastern India in the post- independence era, the excess population has been pushed to areas more commonly known as 'threshold areas' (Ives and Messerli, 1989), located at the margin of two separate natural and physical regions, often prone to hazards brought about by natural and human-induced changes. The Himalayan foothills, commonly known as *terai* in India and Nepal and *Duars* in parts of Sub-Himalayan North Bengal and Bhutan is such an area, located at the transitional zone between two major natural regions of India, namely, the Northern Mountains and the Great Indian Plains.

A considerable part of this population has been pushed into previously uninhabited or partially populated areas like the sub-Himalayan North Bengal and the higher and more inaccessible lands in the Himalayas towards the north. Virgin tracts of land in the mountain and piedmont areas were cleared for accommodating the surplus population. This marked the beginning of a new set of interlinked problems, namely, deforestation, landslides, deposition of the debris into river channels downstream, annual flooding in downstream areas during the peak of the summer monsoon; the situation is reversed when water levels of rivers recede during the pre-monsoon period. Paucity of water hinders crop cultivation during this part of the year. All these processes are linked together in a burning cause and effect situation, leading to environmental and socio-economic disorder at environmentally fragile areas, like the Himalayan foothills, covering parts of the districts of Jalpaiguri and Alipurduar of West Bengal.

For bringing in economic development, building up of requisite infrastructure, like, efficient transport and communication system, power supply are essential, which requires in turn, certain alterations in age-old land use systems and river training, if and wherever necessary. However, ardor for achieving industrial and economic development within a short time has generated certain cause-and-effect situations, especially in areas with fragile ecological balance, located at Himalayan and Sub-Himalayan watersheds. The present research work concentrates on the growing consciousness about conservation of our natural environment and sustainable development, in view of depletion of natural resources due to increasing population throughout the globe, especially, in developing or upcoming regions of the Indian subcontinent.

The Sub- Himalayan North Bengal has experienced a steady rate of population increase during the post-independence period. Large tracts of land bordering the forests in the mountain and the foothills, river islands and riverbank areas subjected to inundation annually, were cleared for accommodating the surplus population and reclaimed for different primary economic activities like agriculture, mining and quarrying and/construction and extension of settlements and roads (Tiwari, 2000). A new set of interlinked problems followed, including deforestation and/or clearance of original cover of natural vegetation, increased slope wash and runoff in areas of steep slopes during peak of monsoon, followed by sheet wash and soil erosion and finally landslides in the higher hilly regions and flooding further downstream. A completely reverse situation may be found during the pre-monsoon months, when water level of rivers recede, and cultivation in many parts of *Duars* is hampered due to scarcity of water. The processes are interlinked, leading to a vicious cycle of cause-and-effects situation, finally leading to environmental and socio-economic disorders in Sub-Himalayan North Bengal, especially Jalpaiguri district (Froelich et al, 2000).

The present investigator has been studying and examining the effect of environmental degradation in the fluvial dynamics in the Jaldhaka- Duduya watershed to formulate the strategy for remedial measures, which will be of immense importance in tackling the problems like floods, riverbank erosion and avulsion in Sub-Himalayan North Bengal.

1.2: <u>The Area under Study</u>:

The Jaldhaka- Duduya Watershed which is the selected area under study is situated between the watersheds of River Tista in the west and the watershed of the River Torsa in the east. The area covers the northern and eastern parts of Jalpaiguri district and north-western part of the Alipurduar districts. The area situated at the foothills of Eastern Himalayas, is drained by the River Jaldhaka and its tributaries, which are rivers of the Brahmaputra basin.

The Jaldhaka- Duduya Watershed area in Jalpaiguri and Alipurduar districts of West Bengal stretches from the Himalayan foothills at the Indo-Bhutan border to alluvial floodplain of Jalpaiguri district, up to the boundary of neighbouring Koch Bihar district in the south (27°05′N to about 26°30′N); from the Jaldhaka river in the west (88°50′E) to the Mujnai river, a tributary of the Torsa river in the east (89°00′E). The study area includes a minuscule portion of the Himalayan foothills in the extreme north, the piedmont region immediately south of the foothills, marking the threshold between the Himalayan foothills and the coalescing alluvial fans of the Jaldhaka and Torsa rivers, locally known as *Duars*. South of the coalescing alluvial fans, one finds the floodplains created by the combined action of rivers of the Jaldhaka- Duduya Watershed.

The selected field area covers both areas lying within the Sikkimese- Bhutanese Lesser Himalayan zone of India and Bhutan, with altitudes varying from about 3900m- 2000m above MSL at the source of the major rivers of the area, to the riverine plains merging into low floodplains of Lower Brahmaputra Basin, with elevations decreasing to < 50m at the confluence of these two rivers, lying within the floodplain region of North Bengal, gradually merging with Lower Brahmaputra Basin of Bangladesh. The climate is, in general, of the moist tropical monsoon type (Am), according to Köppen's scheme of climatic classification. The area includes the piedmont zone in the north, situated at the base of the Bhutanese Himalayas, the alluvial fan surface at the central part and the floodplain at the extreme south.

The selected study area consists of River Jaldhaka, the trunk river and its left bank tributaries as well as, several burgeoning rivers emerging from the junction of the piedmont zone and the alluvial fan surface. The study area has been divided into two watersheds, namely, River Jaldhaka and River Duduya, which is also a tributary of the Jaldhaka, on the basis of the respective drainage networks of the two rivers and their tributaries.

The Jaldhaka- Duduya Watershed consists of two watersheds, namely,

1. The Jaldhaka Watershed covering the northern and north-eastern parts of the study area, with the Jaldhaka as the trunk river, that generates from the Bidang Lake, at an altitude of 4350m above MSL, in Sikkimese Lesser Himalayas. The river is known as Dichu in Bhutan. The river follows a general north-south direction, up to the 100m contour near a small village called Gadher Kuthi, in Dhupguri Block of West Bengal, after which it follows a general south-easterly direction. The river flows into the Brahmaputra in Bangladesh. Total length of the river is 209 km. Total catchment area of Jaldhaka is 5502 sq. kilometer, of which 3753 km is in West Bengal. The area is washed by left bank tributaries of the Jaldhaka, of which, the Daina, and the Chamurchi are the major tributaries, originating from the Bhutanese Lesser Himalayas. Minor tributaries of River Jaldhaka are Jiti and Ghatia, originating from the Bhutanese foothill zone. The Jaldhaka and Daina are joined by smaller, perennial tributaries, like, Kumlai, Jhumur, Singimari and Daikhowa, originating from the junction of the piedmont zone and alluvial fan surface. The Jaldhaka has shifted its course several times, following long and continuous rains or catastrophic rainfall in its catchment areas, as proven by available records. Tributaries originating from the alluvial fan surface mark the former courses and spill channels created by such events. Nascent

2. The Duduya Watershed forms the north-eastern, eastern and south-eastern parts of the Jaldhaka- Duduya Watershed. It includes parts of Jalpaiguri district and the adjacent parts of Alipurduar district covering the north-eastern, eastern and south-eastern parts of the study area. The upper catchment of the watershed covers small parts of Bhutanese Lesser Himalayas and the Foothill zone. The major part of the Duduya Watershed covers the riverine plain and floodplain zone of Jalpaiguri and Alipurduar districts. River Rethi and its tributaries, the Sukreti and Dimdima, originate from the Lesser Himalayas and the Bhutanese foothill zone, flowing in easterly and southerly directions. The Rethi and its tributaries flow through wide but dry beds, which have been etched deep at certain parts of the piedmont zone, bordering the Bhutanese Himalayas. The beds of Rethi and its tributaries are partially filled up during the monsoon months, but they dry up soon after the rains cease. The Rethi and its tributaries flow through wide but dry beds up to the 100m contour, after which combined flow of groundwater-fed rivers coming from the west as Duduya, join Rethi/ Khanabarty and flow southwards as Duduya, to meet the Jaldhaka River south of Falakata town of Alipurduar district. Rethi, Dimdima and Sukreti rivers mark the head of the Duduya Watershed which narrows down towards south. South of Dalgaon Tea Garden, (26° 40′N and 89° 05′E) widths of the rivers decrease and they become perennial. The point beyond which the rivers become perennial marks the junction between the piedmont zone and the alluvial fan surface.

The Jaldhaka- Duduya watershed has experienced catastrophic events of accelerated deposition during the post-Pleistocene period. The watershed has mostly been deforested during the last few decades and the clearings of steep slopes have been used for activities, ranging from mining, extension of settlements, extension of agricultural land, plantations and transport lines, disrupting the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfall or during rainstorms, during the peak of monsoon, innumerable landslides are caused, transporting huge amount of sediment to the rivers (Starkel and Sarkar, 2002; Starkel et al, 2008). Most of such landslides have never been treated scientifically with proper protective measures and as such those are in the habit of expanding their territories during monsoon. These often add more and more silt to the rivers, which are incapable of transporting the loads efficiently under existing hydrological conditions, especially areas beyond the foothill zones. Anthropogenic interferences in the form of recent mining activities in Bhutan and India have further aggravated the problems; de-vegetation of slopes of Lesser Himalayan zones and the Foothill zones have increased slope wash, leading to rapid increase of water levels and overflowing, even in the several smaller streams.

The exceptional growth of population in the Jaldhaka- Duduya Watershed during the last few decades brought about unique changes of the existing physical and socio-economic environment of the region. Implementation of several development projects, like construction of new settlements and introduction of urban facilities and infrastructure (construction and improvement of transport and communication facilities, extension of metalled roads and bridges to remote, interior stretches), exploitation of forest areas for generation of work, boosting agricultural growth, unplanned growth of tourism, vigorous mining and quarrying activities on the immature slopes of the Himalayas on Bhutan's side, wanton lifting of sand and boulders from riverbeds of the piedmont region on India's side, all pave way for impending never- previously-experienced disaster. The processes of change have deleteriously affected the natural ways of adjusting fluvial dynamics of modification of existing landforms and creation of new ones through various processes of erosion, transportation and deposition of higher slopes of the Himalayas, as well as the foothills and the piedmont zones.

Landslides are triggered off, mainly during the peak of the monsoon months due to continuous high intensity rainfall. Landslide debris often blocks river channels in their upstream courses. Landslide debris transported downstream by rivers and deposited at the base of the hillslope, forming coalescing alluvial fans, thus creating a megafan surface in this part of the sub-continent (Starkel et al, 1998; Starkel et al, 2000). The northern part of the study area located in the Lesser Himalayas of Bhutan and the alluvial fan area of the foothills receive prolonged heavy and high intensity rainfall during the monsoon (June- September). Coupled with melt water, this high intensity rain increases river discharge. Flash floods and riverbank erosion thus occur in this part (Starkel et al, 2008). High intensity rains in the upstream courses of Jaldhaka and

Duduya (within Bhutan Himalayas) cause landslides which block river channels temporarily, but later cause devastating floods in the lower catchment area further south. Floods in the riverside plain are of longer duration, because excessive silting raises riverbeds above the level of surrounding areas. As a result, floodwaters take more time to recede. Heavy and concentrated monsoon rains further intensify flood problems in the plains.

The processes responsible for increasing the frequency and magnitude of flood and erosion hazard in sub-Himalayan Jalpaiguri district includes; (a) deforestations in the hills and fan surface for setting up of tea gardens, settlements and development projects cause accelerated soil erosion and mass movement; (b) reclamation of wetlands/ depressions and dormant/ seasonal/ paleo-channels for extension of settlements and arable lands; (c) construction and/ or extension of transport lines and bridges and embankments across river channels and construction of small irrigation canals (locally known as *jamboi*); (d) lifting of boulders and sand from riverbeds and (e) unscientific mining of dolomite, limestone and quartzite in Bhutan leads to complete removal of hills induced unprecedented aggradation of debris in the northern part of Jalpaiguri district (Starkel, et al, 2008). Catastrophic floods of 1968, 1993, 1998, 2000, 2007, 2017 and 2020 affecting different parts of the Jaldhaka-Duduya watershed demonstrate the seriousness of the prevailing situation which also explains the backwardness of the region.

1.3: <u>Objectives of the Present Study</u>:

The Jaldhaka- Duduya watershed faces certain problems generated by interaction of several physical and anthropogenic factors. Many of these factors have their origin in upper part of their upper catchment in Bhutanese Himalaya. Extension of settlements and agricultural lands, mining and quarrying activities at the upper catchment areas and extension of modern transport lines in the region have led to deforestation of considerable parts of the watershed, which have made the landslide-prone hill slopes even more unstable (Sarkar, 1998). Lack of protective vegetal cover on the hillslopes increases intensity of runoff after heavy and prolonged monsoon rainfall occurrences, leading to slope wash and soil erosion, and finally, to landslides in upper catchments.

These lead to a chain of consequences at downstream areas in the alluvial fans and floodplains, from increase of sediment load of rivers, rising of riverbeds, and finally, to annual floods, soil erosion and lateral extension of the alluvial fan surface and loss of agricultural lands .

With a view to the problems, currently faced by the watershed, the objectives of the present study have been enumerated below sequentially:

I. Quantitative assessment of physical characteristics of Jaldhaka- Duduya Watershed, including:

   i) Physical, structural and hydrologic characteristics of the Jaldhaka- Duduya Watershed, for explanation of factors influencing river behavior and changes/ alterations, spatially and temporally, with special reference to floods and annual inundation at specific points of the watershed. Nature of shifting river courses and shifting of confluence zones, nature of river erosion, deposition and landform studies;

   ii) Assessment of the general climatologic characteristics of the study area, including daily, monthly and annual monsoon rainfall, decadal mean rainfall, decadal changes/deviation of rainfall pattern at selected stations. Occurrences of rainstorms at different stations and their impact on river behavior;

   iii) Present land use at different parts of the Jaldhaka- Duduya Watershed, from respective source regions of Jaldhaka River and its major tributaries and percentage coverage under different categories of land use

   iv) Transformations of land use within the study area and in the fringe areas since the catastrophic floods of 1787, marking the first recorded course change of rivers of Sub- Himalayan North Bengal

   v) Soil erosion and avulsion within the study area with help of available topographic maps and satellite images

   vi) Landslides at the source regions and upper catchment areas; causes and effects of landslides on river behavior:

II. Examination of chronological transformation of river behavior in the Jaldhaka-Duduya watershed through:

i) Study of river behavior in Jaldhaka- Duduya Watershed from available records, like maps prepared by Major Rennell and journals/ accounts of British surveyors and collectors;

ii) Study of available accounts/ records of large floods within the Jaldhaka-Duduya Watershed from late 18^{th} century to the recent times, for comparison between earlier recorded floods and recent flood events and the degree of damages and changes of river behavior.

iii) Frequency of major climatologic events, like rainstorms on fluvial dynamics; comparison between frequencies in the past and present rainstorm events. Influence of rainstorms over transformation of river behavior;

iv) Shift of river courses, confluences and major course changes, from secondary sources, like published records, maps, satellite images;

v) Erosional and depositional activities of River Jaldhaka and River Duduya and major tributaries of Jaldhaka at selected stations;

vi) Past and present landuse within the Jaldhaka- Duduya Watershed.

III. Enumeration of the factors leading to environmental degradation, identification and assessment of their nature and degree of damage caused: assessment of contemporary developmental activities and flood protection measures;

IV. To assess the nature and characteristics of floods and associated problems in the Jaldhaka- Duduya Watershed, the following studies were undertaken:

i) Analysis of the impact of environmental degradation in the catchment area on the increased frequency and magnitude of fluvial hazards within the study area;

ii) Correlation of the different parameters of deteriorating fluvial environment with hydrological parameters of the rivers of the Jaldhaka- Duduya Watershed;

iii) Remedial measures for coping with the situation arising as a result of deterioration of fluvial and ecological environment will be suggested in the concluding part of the present study.

Methodology:

To fulfill the objectives, the methodology adapted by the present investigator was rationalistic, comprising of an integration of hydrologic, geomorphologic, meteorological and anthropogenic investigations. The proposed methodological framework for the study comprises of the details outlined as follows:-

Reconnaissance Survey:

The investigator obtained the basic aerial data from Survey of India topographical maps, US Military sheets, IRS satellite image, Google images and from works of individual researcher. These were used in preparing the detailed programme of the present research work. Significant changes in the fluvial network and land use pattern of the Jaldhaka- Duduya watershed were followed by comparing the old documents with the newer ones. Two sets of Survey of India topographic maps, namely, 1929-30 (1:63360) and 1964-65 (1:50000) and US Army Map Services Topographic maps were followed. It may be mentioned, that, the source regions and upper catchment areas of some of the major rivers, including the Jaldhaka, either fall within restricted areas of India, or within the Bhutanese territory. Topographic maps, especially, recent topographic maps of such regions are difficult to come by. A list of topographic maps followed in the course of the present study is given below:

i) Survey of India topographical sheet no. 78B/13 of 1929-30; 1:63360;
ii) Survey of India topographical sheet no. 78B/14 of 1929-30; 1:63360;
iii) Survey of India topographical sheet no. 78F/1 and 78F/2 of 1928-30 and 1972; R.F. 1: 63360 and 1:50000;
iv) Survey of India topographical sheet no. 78B/14 of 1964-65; 1:50000;
v) Survey of India topographical sheet no. 78F/N.W and 78E/S.W of 1928-30; 1:126720;
vi) Survey of India topographical sheet no. 78F/2 of 1972; 1:50000;

vii) US Army Map Service Topographic Map No. NG 45-4, series U502, 1:250000, 1955;

viii) US Army Map Service Topographic Map No. NG 45-8, series U502, 1: 250000, 1955.

Topographic maps published by US Army Map Service of 1:250000 R. F. was consulted for areas for which SOI topographic maps of 1:63360 or 1:50000 scales could not be obtained.

NRSA Satellite images in printed form on a scale of 1: 50000 covering the study area from 1996-2009 were studied to detect features of fluvial dynamics, including significant features of erosion and deposition along the major rivers; land use characteristics of the present time have been studied from these satellite images. Assessment of chronological land use transformation vis-à-vis change in river network in the Jaldhaka- Duduya Watershed was done through the above-mentioned processes.

Scheme for data collection:

The scheme for data collection was carried out in two phases. Firstly, different relevant data were collected from primary sources, i.e., from direct measurement in the field from time to time. Secondly, relevant data were also collected from different organizations such as Geological Survey of India (GSI), Survey of India (SOI), National Remote Sensing Agency (NRSA), Central Water Commission (CWC), North Bengal Flood Control Commission (NBFCC), Irrigation and Waterways Department, Indian Meteorological Department (IMD), Flood Meteorological Office, Jalpaiguri etc., and also from previously published reports. Rainfall (daily and annual rainfall) data were collected from selected tea gardens situated within Jaldhaka-Duduya Watershed and IMD website (www.imd.gov.in) and previous published works.

Field survey:

i) Catchment experiments- Drainage basins of individual tributaries of Jaldhaka, as well as Jaldhaka itself, for comparison of relief, soil and vegetation, especially, the prevalent landuse. The relief, soil, vegetation of the basins of Jaldhaka, Daina and Rethi were selected for making comparative studies of effects of changes in landuse. While the basins of Daina and Rethi show marked changes in landuse patterns, the basin of Jaldhaka has not recorded significant changes of landuse change till the writing of the report.

ii) Measurement of cross section of selected rivers within the area-channel cross-sections were useful in noting the amount of riverbank erosion, sedimentation, course shifts, course changes or avulsion caused by the rivers.

iii) Soil and vegetation surveys were undertaken, choosing sampling sites in similar positions in the landscape, collecting samples for laboratory tests to note possible changes.

iv) Questionnaire surveys were carried out in different parts of the area to find out human response on effects of recent developmental activities on present river behavior and land degradation.

However, it must be mentioned in this context that due to the proximity of the selected watershed to at least two international borders posed certain hardships; S. O. I. topographic maps of certain parts of the selected study area, surveyed and published during 1960-s and 1970-s are not available. Some of the available S.O.I. topographic maps are 1929-30 editions with 1: 126720 and 1: 253440 R.F. The present researcher had, thus, been compelled to study certain features and LULC changes from already-published books and journals and compared them with pre-existing landscape of the Jaldhaka- Duduya Watershed. Since topographic maps published by S. O. I. in recent years are available, the same were identified from LISS-III and FCC images published by NRSA. Data on river behavior, including data on daily river discharge, suspended load, etc. are highly classified and not available, hence. The present researcher had to measure river discharge at certain points.

<u>Data Processing</u>:

As mentioned earlier that annual and daily rainfall data were obtained from IMD website and various tea gardens situated within Jaldhaka- Duduya Watershed and hydrologic and geomorphologic data have been collected from various sources. The reliability of data collected from secondary sources will be checked statistically, which are as follows:

- <u>Mean rainfall and standard deviation of annual rainfall</u> for ≥ 20 years would be calculated for selected stations to find changes in rainfall, if any. Normal mean rainfall would be estimated for the given stations for a given time period.
- <u>Years of excessive and deficient rainfall</u>, to tally excessive rainfall with flood occurrences. Trend analysis of rainfall pattern for the selected stations would be made, for the given time periods.

- <u>Daily rainfall patterns</u>- Amount and frequencies of 24 hour rainfall of selected stations to be studied to find frequency of occurrence of heavy and extremely heavy rainfall as well as variations within the Jaldhaka- Duduya Watershed.

- <u>Mean and highest 24 hour rainfall and periods of clustered rainfall</u>, to link such events with fluvial dynamics of the selected watershed.

- <u>Rainstorms or extreme events</u>, to mark flash floods affecting pockets of the Jaldhaka- Duduya Watershed in different years; estimation of frequency and magnitude of flash floods at different parts of the watershed.

The following methods would be applied in the processing the hydrological data of the selected rivers:

- <u>Rating Curves</u>- A set of typical rating curves between stage and discharge for the river under consideration at a particular site will be developed. Three types of rating curves will be prepared. An attempt would be made to develop mathematical equation of each rating curve. Help of computer programming and various software packages would be used in preparing the rating curves.

- Sediment Analysis- An attempt has been made to calculate the quantity of total sediments (coarse, medium & fine) discharge through the rivers under study. The investigator has attempted to develop relationships between discharge and size of particles (sediments) transported by rivers. Power and exponential equations have been used for this purpose and to explain relation between quantity of sediments and discharge during annually, as well as, monsoon and non- monsoon periods, through multiple correlation coefficient and ANOVA.

- Flood magnitude and frequency analysis- Statistical analysis through probability analysis (Weibull Distribution and Gumbel Distribution calculation)

- Estimation of return period of floods – Estimation of return period of floods has been made through the conventional method of Weibull's Formula for estimation of recurrence interval of floods. Percentage probability of floods has also been calculated by using Weibull's Formula.

Methods for Interfluves Analysis

Data for sub-basins will be collected from Survey of India topographical maps and compiled for a systematic qualitative analysis of the basins. However, due to non-availability and restricted nature of S.O.I. toposheets of parts of the study area, the investigator used the US Army Topographic maps (1: 250,000) no-s. 45-8 and 45-4. Both bivariate and multivariate analysis would be performed, that include

- Correlation Analysis;
- Linear and Log-linear Analysis;
- Power and Exponential Analysis;
- Multiple and Partial Analysis.

Morphometric properties of catchments, like slope, relief, drainage, and dissection have been done, based on available topographic maps published by Survey of India

The investigator has analyzed the nature of the terrain, geomorphology of the study area using DEM to be developed using SRTM data and through the application of standard methods. Attempt has also been made to analyze the land use pattern, land use transformation, using Survey of India topographical maps, satellite image, government reports and individual works under GIS platform.

Methods for assessing catchment degradation

The land/soil degradation was assessed quantitatively through FAO/UNEP/UNESCO (1978) and Sarkar (1998) models based on the following diagnostic criteria:

- Climatic erosivity (R)
- Topographic erosivity (L.S.)
- Soil erodibility (K)
- Biological erosivity (C.P.)

Assessment of landslides and related phenomena were done based on the information gathered both from primary and secondary sources. A number of case studies were performed by the investigator to apprehend the nature, processes and mechanisms. The investigator has applied check list method to study landslide degradation including hazard zoning in the Jaldhaka-Duduya watershed.

For reference work, and secondary data sources, the investigator has consulted available books and journals at the libraries of University of North Bengal, Geographical Society of India, Calcutta University, G. S. I. Library and British Council Library, Kolkata. A Minor Research Fellowship of U.G. C. enabled her to purchase a few reference books and journals and cover a portion of expenditure incurred in field work. The data collected from field work have been processed, analyzed and finally to provide suggestions to maintain harmonious process response relation between different segments of the Jaldhaka- Duduya Watershed.

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