

## ABSTRACT

A watershed or a drainage basin consists of a main or trunk river, with several tributary river channels, both perennial and non-perennial, converging with the trunk river and spreading both water and sediments throughout the area covered by the entire network of channels. Movement of water and sediments, controlled by several geologic, physiographic, meteorological and anthropological factors may be affected by alterations in any of these factors, affecting thus, the entire fluvial dynamics of the watershed itself. This applies especially to watersheds located in areas, having a propensity to delicate ecological balance. Watersheds located between physical units with different structural and physiographic characteristics, or threshold regions are marked by more frail ecological balance, having long term effects on economy and livelihood of an entire region. The Jaldhaka- Duduya Watershed situated at the heart of the Eastern Himalayan Foothills known as *Duars* or *Dooars*, covering parts of Jalpaiguri and Alipurduar districts of West Bengal, India provides a typical example of such an area. Interaction of physical and anthropogenic factors leading to land degradation, riverbank erosion and soil erosion, causing hardships for the agro- based economy of the watershed. Qualitative and quantitative assessment of the problems through reconnaissance surveys, extensive field surveys were done to study the both the causes and effect of environmental degradation on river behavior within the selected study area.

The Jaldhaka- Duduya watershed, is made up of two broad physiographic regions, which may be stated as micro- thresholds, located within a short longitudinal distance (<100km). These are the distal alluvial fan surface region of the northern plains in the north and the floodplain of Jaldhaka and Duduya in the south has marked differences in rainfall regime, soils and natural vegetation, clearly visible within relatively short distance from the mountain front, which marks the northern boundary. The piedmont terraces lying at the base of the mountain front marks the active alluvial fan surface.

The Jaldhaka River, originating from the Lesser Himalayas of Sikkim, is the main river of Jaldhaka, while River Duduya originating from the piedmont terrace

region lying at the base of Himalayan Foothills is the main river of the Duduya watershed. The northern part, constituted by quaternary deposits of various sizes forms the entire piedmont and the escarpments bordering them. The floodplain consists of mostly sandy soil, mixed with silt, with slight increase of clay at the extreme south. The Jaldhaka and its major tributaries flow through north-south trending faults and fault lineaments which were created due to neo-tectonic activities in Bhutanese Lesser Himalayan zone. The Rethi, which constitutes the Lesser Himalayan and the piedmont section of R. Duduya, also follows quaternary fault lineaments. Relief zones of the Jaldhaka- Duduya watershed show rapid change of elevation within small distances; a very small area in the extreme north in Sikkim with >4000m elevation from sea level, forming the source region of Jaldhaka. About 25% of the northern and north-eastern part of the watershed located in Bhutan's territory, has 2500-1000m elevation from sea level, marking the source regions of the major tributaries of Jaldhaka, namely, Daina, Chamurchi and Rethi Rivers. More than 50% of the Jaldhaka- Duduya watershed has 50-100m above sea level, forming the southern floodplain.

The Jaldhaka- Duduya watershed experiences tropical warm and moist climate, receiving copious monsoon rainfall. High rainfall mostly occurs due to formation and stationing of the monsoon trough over the neighbouring Sikkim or Bhutan Himalayas, or from low pressure areas, which are created during the monsoon, bringing in heavy and clustered rainfall or causing rainstorms. Monsoon rainfall received at the northern part, situated at the base of the mountain front, is more than twice the monsoon rainfall received at the floodplain section in the south. Due to such variations of rainfall six rainfall zones may be found within a north-south distance of 100 km and west-east distance of <50 km. High intensity rainfall received during rainstorms lead to flash floods in different parts of the Jaldhaka-Duduya watershed.

Simple statistical techniques have been used to identify characteristics of rainfall within the watershed, for which both rainfall data collected by selected tea gardens and data collected from registered website of Indian Meteorological Department have been used . Parameters like seasonal and daily rainfall, average 24hour rainfall frequencies, maximum 24 hour rainfall have been used. Time

series analysis of annual rainfall of some selected tea gardens of the area show little or no variation for the first decade (1923-1952), distinct rising trend during the second decade (1971- 2000) and finally, a clear decreasing trend for the third decade (2001-2019), which is further substantiated by calculation of standard deviation of decadal rainfall. Annual rainfall has decreased throughout the watershed, as proven by mean rainfall calculated for the post- 2000-s period. There is, thus, a change in rainfall pattern within the Jaldhaka- Duduya watershed; the prevailing change is increasing frequencies of rainstorms, occurring both in the piedmont and floodplain sections.

Longitudinal profiles constructed for the Jaldhaka and the major rivers of the watershed reveal variations of relief and degree of concavity. Least square regressions were done to fit longitudinal profiles, showing elevation-distance data, which show concavity for all rivers and breaks of slope, indicating tectonic control, except Duduya, which originates from the piedmont terrace. The Stream-length Gradient Index (SLGI) developed by Hack was also used to calculate degree of structural control on the rivers, which indicate youthful stage for major rivers, except Duduya. Transects constructed across major rivers at selected sites and at selected time intervals, bring out preponderance of braiding activity in Jaldhaka, Daina and Rethi Rivers, with propensity of bank attrition and toe erosion, especially, following rainstorms or periods of clustered monsoon rainfall. Evidences of north- south shifting of the confluence of Jaldhaka and Daina is noted from satellite images and Google maps. Only River Duduya has a comparatively stable channel, with comparatively lower degree of bank erosion.

Increased sedimentation within the channels of major rivers and their tributaries, specially rivers with source regions lying deep within the Bhutanese Lesser Himalayan zone causes increased braiding, accumulation of lag deposits within channels in the piedmont and alluvial fan sections, lying within Indian territory. This is found to occur due to unplanned mining activities, mainly within Bhutanese territory, gratuitous lifting of sand and gravel from beds of Daina and Rethi within Indian territory, resulting in steady raising of beds of both tributaries and the trunk river itself, increasing thus, the risk of floods, during periods of active or vigorous monsoon or during rainstorms. Rapid urbanization in and

around the Jaldhaka- Duduya watershed, necessitating construction and refurbishment of communication network of the region, construction and extension of settlements and tea garden areas in upper catchment and source regions of rivers, have increased amount and frequencies of slope wash, slope failures and landslides, debris being transported downstream, choking smaller channels and further increasing sedimentation and braiding activities. All of these have led to fertile agricultural lands becoming flood- prone and barren for considerable periods. Thus, general land and environmental degradation throughout the watershed has set in, affecting the chiefly agrarian economy of the area.

Hydrographs could, however, be constructed only for Jaldhaka, which is the main river of the watershed. It is observed, that, rainstorms lasting for two or three days at maximum, are capable of triggering peak discharge resulting in flood flows followed by a series of events, ranging from soil and riverbank erosion, or even avulsion, which decrease rapidly, almost immediately after rainfall decreases or stops altogether. Return period of floods with very high discharge has remained the same, but return period of floods with medium to moderately high discharge seems to be increasing during recent years. Risk of floods has increased during recent years due to environmental degradation, in spite of the changing rainfall pattern, that indicates somewhat decreased annual rainfall. Flooding and inundation have become annual phenomena, for bigger and smaller rivers alike.. Popular measures of protection from floods, like construction of flood embankments have been successful, only initially.

With increasing demand for regional development, need for improved transport and communication system, improved housing and certain amenities cannot be denied to local people. Sustainable development measures for regional development, with minimized effects of the delicate ecological balance are suggested for the Jaldhaka- Duduya watershed.