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**Climate Variability and Flood Hazard in Bhagirathi Sub-basin of West Bengal: A Geospatial Approach**

**Abstract**

Climate variability has caused extreme weather events (floods, droughts, and cyclones, etc.), food insecurity, water resource crisis, loss of biodiversity, huge destruction of asserts and loss of lives. It involves the changes occurring at smaller time scale e.g., seasonally, monthly and yearly while climate change seeks to address the changes in climatic anomaly at longer time frames (Thornton et al., 2014). Climate variability can affect the regional climate to a greater extent (Rind et al., 1989; Murphy and Timbal, 2008). Flood is a natural phenomenon causing devastation at a very large scale, disrupting normal life and raising social, economic and ecological vulnerability. Centre for Research on the Epidemiology of Disasters (CRED) has defined flood as *"being a state of rise of water level in a coastal areas, lakes, streams and channels"*. Recent consequences of flood have raised concerns for exploring the causes of climate change induced flood across the world (Kay et al., 2011; Schaller et al., 2016). A concerted effort has been made in this work to analyze the climate variability, flood frequency, flood hazard susceptibility and vulnerability in the Bhagirathi Sub-basin of West Bengal.

This work is based on both statistical and geospatial analyses. Primary and secondary sources of data have been used in this study. A close examination of various vulnerability domains i.e., socio-economic and ecology have been incorporated in the study. Systematic literature review was carried out to examine the existing gap in flood vulnerability assessment. Pattern of climate variability was also ascertained using non-parametric test. Statistical analyses were carried out in SPSS and RStudio softwares. Geospatial analysis was carried out in an integrated geographic information system (GIS) platform using ESRI ArcGIS 10.3 and ERDAS Imagine softwares. Flood frequency was analyzed at two stations i.e., Ganga 51 and Ganga 193 stations using Gumble's method of flood distribution. Entropy information theory was used to examine the flood susceptibility in the Sub-basin. Ecological vulnerability and risk were examined using site specific indictors. Analytical Hierarchy Process (AHP) was used to analyze the ecological vulnerability in the Bhagirathi Sub-basin. Perception analysis of the sampled households was also carried out to examine the socio-economic status of households, level of

vulnerability and adaptation. Vulnerability and adaptation were examined using the different indicators. The composite vulnerability index calculation was based on 7 domains namely quality of life, social, economic, health, ecological, losses to floods and adaptation.

The review revealed a gap existing between methods and approaches for evaluating flood vulnerability which can be incorporated by using multidimensional approach. Significant trends in meteorological variables were identified in the study area. Hmax and Mmax were found decreasing while Mmin and Rh were found increasing in the Sub-basin. Insignificant trend in rainfall and vapour pressure were identified in the Sub-basin. However, extreme rainfall events have often identified at various stations. The ANOVA results demonstrated that rainfall, vapour pressure, Mmin and Mmax were significantly associated for different seasons. The peak discharges for both the stations were significantly associated with reduced variates. Expected flood from 2 to 1000 years have also revealed a steady increasing trend for both the stations. Flood susceptibility analysis revealed that about 92 per cent area of the Sub-basin was susceptible to floods. Most of the area of the Sub-basin (81 per cent) was under high ecological vulnerability followed by very high vulnerability (9 per cent), very low vulnerability (5 per cent), low vulnerability (4 per cent) and moderate vulnerability (1 per cent).

Ecological risk analysis revealed that nearly 37 per cent area of the Sub-basin was under low risk followed by high (35 per cent), moderate (20 per cent), very high (5 per cent) and very low (3 per cent) risk. Very high vulnerability and risk were identified around built-up areas which were associated with high inundation and disturbance. The Sub-basin is identified socially, economically and environmentally vulnerable to floods at different levels where the physical and environmental factors have minor contribution to the flood vulnerability. Most of the sampled households possessed low socio-economic status. Households with low income were under debt and paid high interest rates to support their needs. The composite vulnerability assessment acted as analytical tool helped in identifying the priority areas for lessening the degree of vulnerability. Structural (embankments, levee and dams) and non-structural (forecasting, early warning and land use monitoring) flood measures were proposed for lessening the flood vulnerability. Integrated approach involving government agencies and community-based organizations is essential for effective flood management in the Sub-basin. Unbiased gender and community involvement, adequate support from government, flood insurance for individual support, strengthening the role of community based organizations and modernizing indigenous flood control methods may effectual and further enhance the response and adaptive capacity of the vulnerable communities.