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A Brief Study Of Rainfall Patterns And Hydrological Implications In Associated Area Of Kolkata, West Bengal, India During The Monsoon Period (2011-2020)

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Abstract: This paper conducts a comprehensive analysis of rainfall patterns and their hydrological implications in Kolkata, West Bengal, India, spanning the monsoon period from 2011 to 2020. The study employs data from the Centre of Hydro technology and Remote Sensing (CHRS) and the India Water Resources Information System (India-WRIS). Advanced geospatial tools, including ArcGIS, ArcMap, and HEC-HMS, are utilized, coupled with BHUVAN's land-use and land-cover data, and the curve number from TR-55 by the USDA Soil Conservation Service (SCS), now Natural Resources Conservation Service (NRCS), serving as a basis for estimating runoff potential based on land use and soil type. The study focuses on the analysis of rainfall variability, identification of precipitation trends, and assessment of hydrological responses to rainfall events. Additionally, HEC-HMS is employed for hydrological modeling, simulating runoff and streamflow dynamics under varying rainfall scenarios. The findings reveal that the peak discharge in most subbasins and reaches around Kolkata occurred in 2014, with some experiencing peak discharge in 2015. During this period, peak discharge reached approximately 1000 - 1300 m^3/s in Reaches 21, 18, 31, 30, 28, 27 and 26 (generated in HEC-HMS) with a recorded rainfall of 374.12 mm in July 2014 in the city and also the city's basin registered a peak discharge rate of 50.3 m^3/s in the same time. Analyzing recent trends, it is observed that the city typically receives rainfall ranging between 300 mm to 400 mm, suggesting a consistent peak discharge of maximum of 50m^3/s during each monsoon season.

Index Terms – SCS, HEC-HMS, TR-55, Hydrological Modelling, Peak Discharge.

I. Introduction

Variability in rainfall pattern is one of the important factors in climatology of an area, rainfall plays a key-role in socio-economic development of any region. Urban areas, such as Kolkata in West Bengal, India, face significant challenges in managing hydrological dynamics influenced by changing rainfall patterns.

In West Bengal, pre-monsoon rainfall is essential for supporting agricultural activities, especially for crops like rice, tea, mangoes, and jute. Its effects on cities might be contradictory, posing both opportunities and difficulties. It offers a brief reprieve from the intense summer heat, but it also brings risks including hail, lightning, flooding, strong winds, and waterlogging.

Against the backdrop of global climate change, variations in rainfall have the potential to disrupt the geobiology of an area, exerting direct and indirect impacts on its inhabitants.

Thunderstorm activity is the cause of the precipitation in West Bengal during the pre-monsoon months of March, April, and May which make up around 15% of the rainfall that falls each year. More than half of thunderstorm activity in Gangetic West Bengal is caused by Nor'wester, which are produced when two distinct air masses collide: a hot, dry air mass from the northwest and a relatively cold, moist air mass from the Bay of Bengal. When there is an appropriate triggering effect, the buoyant air mass rises and becomes saturated with moisture during mixing (Chatterjee et al. 2015).

The unrelenting growth of human settlements in West Bengal is driving urbanization, which is destroying local forests and changing radiation patterns and the terrain. The shift from rural to urban settings dramatically alters thermal and dynamic properties, resulting in the formation of unique microclimates. India, a country that is developing quickly, is seeing an impact on rainfall due to urbanization, which is particularly noticeable in the eastern cities. Studies examine the impact of urbanization on pre-monsoon rainfall by contrasting patterns from before and after independence as investigated by Mitra et al. (2012).

II. Objective

The primary objective of this study is to assess and compare the annual monsoon rainfall patterns in Kolkata for the period spanning 2011 to 2020 and calculate the peak discharge in the respective year of the subbasin model. Utilizing satellite data of the Kolkata region, the research aims to find relation between the rainfall patterns and the peak discharge observed during the same period in monsoon i.e. July to September.

III. Methodology

The methodology for this research involved a multi-step process to analyze monsoon rainfall patterns in Kolkata. The Digital Elevation Model (DEM) data for the research area was obtained from the USGS Earth Explorer [link: https://earthexplorer.usgs.gov/], which was then imported into HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System). Subsequently, the streams were delineated within the HEC-HMS platform, and three outlets were designated at key locations: 1) East Kolkata Wetlands, also connected to the Ichhamati River in the east; 2) Piyali River in South 24 Parganas; and 3) the Ganges near Haldia.

HEC-HMS was employed to generate subbasins, and the curve number was calculated based on the assumption of a ‘Hydrologic Soil Group B’, following the criteria outlined in the TR-55 manual by the USDA Soil Conservation Service (SCS), now known as the Natural Resources Conservation Service (NRCS) [link: https://www.hydrocad.net/tr-55.htm]. The lag time was then determined using the formula given below:

$$T_{LAG} = L^{0.8} \frac{(S+1)^{0.7}}{1900\sqrt{Y}}$$

where:

T_{LAG} = lag time in hours
L = hydraulic length of watershed in feet
Y = watershed slope in percent
S = maximum retention in the watershed in inches as defined by :

$$S = \frac{1000}{CN} - 10$$

where:

CN = SCS curve number for the watershed as defined by the loss method

Subsequently, the calculated curve number and lag time were incorporated into HEC-HMS along with rainfall data collected from India-WRIS (Water Resource Information System) [link: https://indiawris.gov.in/wris/]. HEC-HMS, utilizing this integrated information, provided outputs such as drainage area, peak discharge, and the corresponding year in which the discharge occurred. This comprehensive methodology ensures a robust analysis of monsoon rainfall and hydrological responses in the Kolkata region, considering both topographical and meteorological factors.

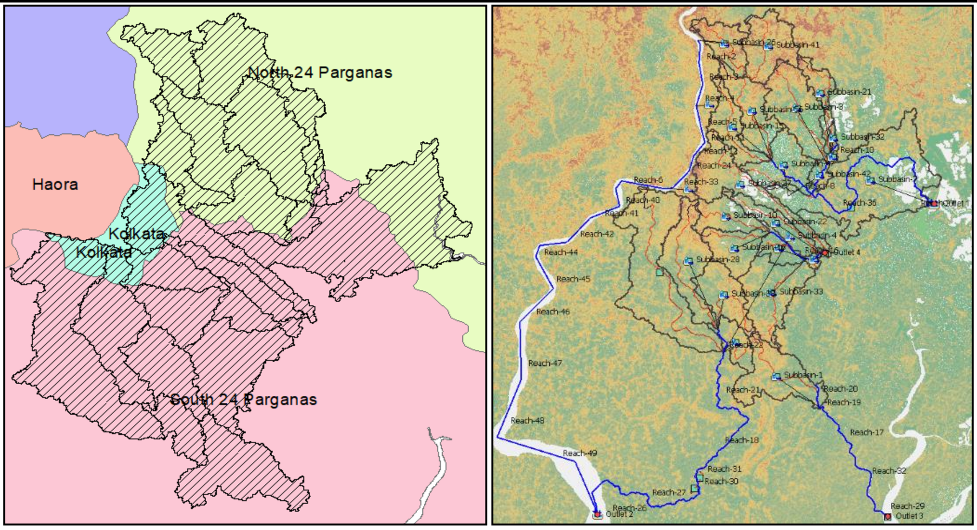


Figure 1: Sub-basin map generated by HEC-HMS

IV. DATA

The following data was collected from India-WRIS and the whole project is based upon this:

Table -1: Rainfall Data for Monsoon Period of Kolkata District (2011 – 2020)

Year	July	August	September
2011	185.90	328.90	168.80
2012	106.18	22.10	13.83
2013	235.26	394.98	199.98
2014	374.12	320.27	198.87
2015	782.61	397.18	244.51
2016	255.60	282.27	180.95
2017	549.17	420.59	260.94
2018	391.11	163.68	163.49
2019	223.71	301.97	258.35
2020	208.29	358.76	228.04

V. DATA

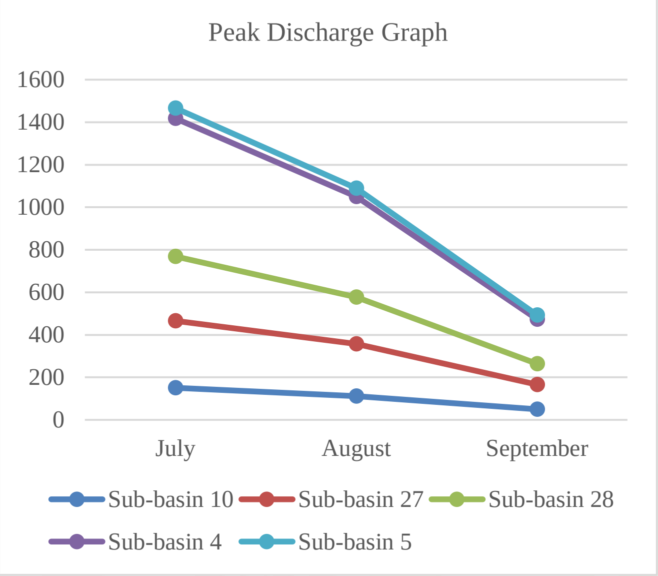
After importing the DEM file in HEC-HMS and delineating streams and selecting three outlets at East Kolkata Wetlands, Piyali River in South 24 Parganas and the Ganges near Haldia, the below subbasin map is generated from it.

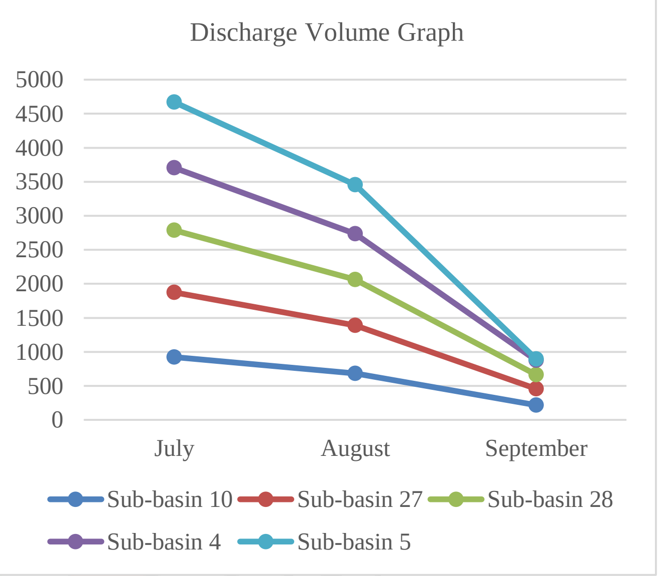
After inputting the rainfall data (Table-1), the below results are generated-

Table -2: Results generated from HEC-HMS

Hydrologic Element	Sub-basin 10	Sub-basin 27	Sub-basin 28	Sub-basin 4	Sub-basin 5
Drainage Area (KM^2)	39.20	81.10	79.00	169.60	12.40
Peak Discharge (July)(m^3/s)	150.90	315.20	302.10	649.00	48.50
Peak Discharge (August)(m^3/s)	112.20	245.50	220.20	473.10	39.20
Peak Discharge (September) (m^3/s)	50.60	116.10	97.30	208.90	19.30
Peak Discharge (m^3/s)	150.90	315.20	302.10	649.00	48.50

Time of Peak (July)	2014	2014	2014	2014	2014
Time of Peak (August)	2012	2012	2012	2012	2012
Time of Peak (September)	2012	2012	2012	2012	2012
Time of Peak	2014	2014	2014	2014	2014
Volume (mm) (July)	925.96	947.21	916.08	916.08	963.64
Volume (mm) (August)	683.57	704.34	674.02	674.02	720.62
Volume (mm) (September)	218.98	236.64	211.42	211.42	251.83





From this above data table, it can be seen Subbasin-5, (approximately spanning from Howrah Bridge in the north to Borobazar in the east, encompassing Andaman Docks, Kolkata Port Trust in the southwest, and extending to Alipore Zoo in the southeast). Despite possessing the smallest drainage area among all subbasins in the Kolkata district, measuring around 12.4 Km² as calculated by HEC-HMS, Subbasin-5 stands out with an exceptional runoff discharge volume of 963.64mm over the course of the year with a peak discharge of 48.5 m³/s in 2014-2015. The elevated runoff volume, despite the limited drainage area, emphasizes the significant influence of local topography, land-use patterns, and proximity to water bodies on the hydrological response. The heightened peak discharge and runoff volume in Sub-basin 5 raise concerns about potential implications for the surrounding environment. The elevated runoff can lead to increased soil erosion, sediment transport, and alterations in water quality within the subbasin. The ecological balance of the adjacent river, influenced by the substantial discharge, may also experience shifts, impacting aquatic ecosystems and biodiversity. Additionally, the heightened runoff may pose challenges for urban infrastructure and drainage systems, necessitating adaptive measures for flood mitigation and sustainable development in the region.

VI. Future Scope of Work

From the data generated above this project can be further extended to –

a) Spatial Distribution: Analyze the spatial distribution of peak discharge and runoff volume across different subbasins. Identify areas with consistently high or low values and explore the factors contributing to these patterns.
b) Seasonal Variability: Investigate the seasonal variability within each monsoon year. Identify specific months or periods within the monsoon season that contribute significantly to peak discharge and runoff.

c) Extreme Event Analysis: Identify and analyze extreme events, such as unusually high or low peak discharge years. Understanding the circumstances surrounding extreme events can contribute to improved flood and drought management strategies.
d) Climate Change Impact Assessment: Consider integrating climate change scenarios to assess potential impacts on peak discharge and runoff. This can provide valuable information for future planning and adaptation strategies.
e) Water Resource Management: Explore how the generated data can contribute to effective water resource management strategies, including reservoir operation, flood forecasting, and drought preparedness.

VII. CONCLUSIONS

The findings reveal that despite its relatively small drainage area, Subbasin-5 in Kolkata exhibits remarkable runoff discharge volumes and peak discharge levels, particularly notable in the year 2014-2015. This anomaly underscores the intricate influence of local topography, land-use patterns, and proximity to water bodies on hydrological responses within urban areas.

The heightened runoff volumes observed in Subbasin-5 raise concerns regarding potential environmental implications, including increased soil erosion, sediment transport, and alterations in water quality. Furthermore, the elevated peak discharge poses challenges for urban infrastructure and drainage systems, necessitating adaptive measures for flood mitigation and sustainable development.

This study underscores the importance of holistic approaches to water management, encompassing both meteorological and topographical factors, to ensure the resilience of urban areas like Kolkata in the face of evolving climatic conditions and rapid urbanization. Effective water resource management strategies, informed by robust data analysis and predictive modeling, will be paramount for fostering sustainable development and resilience in the years to come.

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