

## **Climatic and geo-spatial based assessment of drought susceptibility for Seraikela Kharsawan and Atrayee river basin of Dakshin Dinajpur districts of India**

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### **Abstract**

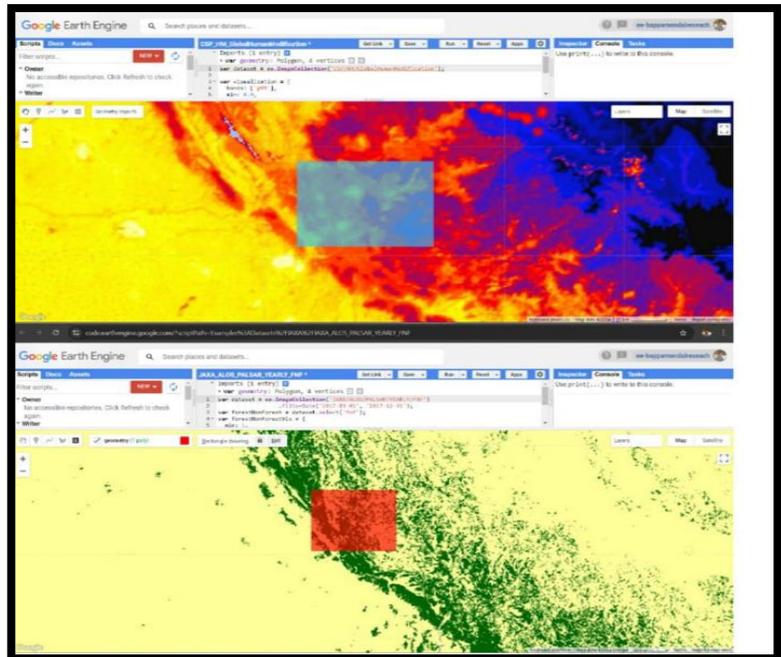
The Atrayee and Punarbhaba river basins experience severe flooding which occurs frequently throughout their territory that extends into Northern West Bengal India and Bangladesh. The Subarnarekha river creates havoc destruction in the district of Saraikela Kharsawan. The region experiences monsoon season floods because of its high rainfall combined with its shallow gradients and its restricted ability to handle river water. This project aims to study flood behavior which occurs in the Atrayee and Punarbhaba river basins through hydrological and hydrodynamic modeling techniques. The HEC-HMS modeling framework conducted rainfall-runoff modeling, while the HEC-RAS 2D modeling framework performed floodplain inundation mapping through its use of high-resolution DEM and satellite-derived data. The researchers used water level and discharge data from selected gauging stations to calibrate and validate their model. The spatial analysis examined flooding which occurred at different depths and durations across Thakurgaon, Gangarampur, and Balurghat low-lying areas which showed high flooding vulnerability. The study results show that the two river basins experience significant hydrologic connections which create high flooding risk for downstream areas that depend on rainfall from upstream locations. The study establishes three core elements which organizations must implement to achieve effective and sustainable flood risk reduction: land use management and real-time hydrologic forecasting and international cooperation. The simulation results support disaster management authorities and regional planners in developing flood risk management plans which include adaptive strategies and early warning systems.

**Keywords:** Atrayee River, Punarbhaba River, Flood Simulation, HEC-RAS, Hydrological Modelling, Remote Sensing, Floodplain Mapping.

## 1.0 Introduction

Flood simulation employs different methods together with computational models to study and forecast floodwater movement during multiple scenarios (Downer & Ogden, 2004; Bates et al., 2005; Abebe et al., 2010; Bates et al., 2010; Beven, 2012; Bhuiyan et al., 2015; Guo et al., 2021). Flood risk management needs to use disaster preparedness urban design and climate resilience methods according to the research by Lindström et al. (1997) and Horritt and Bates (2002) and Hunter et al. (2007) and Neal et al. (2012) and Sampson et al. (2015) and Shirvani et al. (2020) and Li et al. (2020) and many other authors. The increasing frequency of extreme weather events, which result from climate change, requires accurate flood simulation. Flood simulations provide crucial support for assessing and managing flood risk by simulating water movement and accumulation during flood events (Teng et al., 2017; Ugoing to et al., 2019; Xu et al., 2024). Planners and policymakers will use the simulations to identify flood-prone areas and design storm water drainage systems and assess flood protection methods and develop emergency response plans. The simulations can identify critical scenarios for sea level rise and land cover changes and rainfall intensity to develop better strategies. Flood simulations enable the identification of areas that face flood risk, which allows for the implementation of important flood prevention initiatives. Emergency preparedness benefits from flood modeling, which establishes risk assessments and produces inundation maps (Sanders, 2007; Schumann, et al., 2009; Tsubaki & Fujita, 2010; Fewtrell et al., 2011). The modeling process creates realistic future scenarios because it combines climate change impacts with land-use change effects which help to develop effective policies. Current flood risk management requires modeling to predict future flood scenarios which will guide planning and policy development (Neal et al. 2009; Yamazaki et al., 2011; Zischg et al., 2017). The land use planning process will benefit from climate scenarios and hydrological models because they enable stakeholders to develop effective adaptive strategies which decrease flood dangers and boost protective capacity. The current research establishes specific flood characteristics for the study area by using multiple indicators. The dam construction changed all aspects of how floods and runoff occurred in the area. The transboundary river system will experience changes to its water distribution patterns when transboundary rivers cross the border region. An estimation of flood probability describes the likelihood which a specific flood size will take place at a particular location during a defined time frame. The flood simulation process relies on flood probability estimation because it provides essential elements which enable understanding and modeling of flood behavior across different situations. Flood models use rainfall or flow estimations that use a "probability-and-frequency" naming convention (e.g., 10-year flood, 50-year flood, 100-year flood, etc.) to simulate situations. The flood modeler uses the software to test actual flood scenarios which contain genuine flood dangers instead of testing extreme flood conditions that do not reflect real flood threat assessment. The hydrologic model requires probability estimation as a verification method for its calibration process which needs to match actual flood patterns from historical data while estimating future flood scenarios. The use of flood probability scenarios helps engineering decisions about levee and culvert and retention basin construction because it shows which flood protection structures need to withstand extreme flood conditions. The probability-based flood simulations help governments and stakeholders make

investment decisions and implement mitigation programs and assess their long-term climate resilience strategies. Flood probability estimation serves as a fundamental component of flood risk management because it ensures that flood simulation meets both theoretical standards and practical requirements for actual planning and risk evaluation and infrastructure protection. Five distinct indices have been used to evaluate the probability of flooding: the flood density index, the stress degree day index, the moisture balance algorithm after dam building, the topography behavior of floods, and the vegetation influence on floods. **Fig. 1** Flood density index



## 2.0 Materials and methods

### 2.1 Flood density index

The flood density index receives its data from Google Earth Engine information. The project investigates the use of microwave bands to assess water depth throughout different seasonal periods. The pre-monsoon period experiences alterations in both water table levels and groundwater and surface water bodies. The soil moisture level shows an average decrease while the extremely high water level patterns exhibit unpredictable behavior that results in substantial water loss. The pre-monsoon phase of the year experiences dry weather conditions together with high rates of evaporation which lead to the exposure of soil surfaces and the drying of soil making these conditions unsuitable for agricultural and vegetative growth. The situation in the post-monsoon phase stands in direct contrast to this (Fig. 1-bottom). The arrival of monsoon rains triggers substantial water recharge to both surface water and groundwater systems which leads to higher water levels shown in post-monsoon water depth maps. The newly discovered heavy rainfalls showed their spatial distribution through broad heavy rain that extended across multiple areas. The soil characteristics specific to this region exert a strong effect on the process of conversion. The soil in this region develops the capability to retain moisture for extended periods after receiving sufficient rainfall. The soil retains moisture at optimal levels for multiple days following intense rainfall which helps maintain competitive moisture conditions that sustain plant growth and agricultural activities until the post-monsoon period ends.

### 2.2 Post dam construction moisture balance algorithm

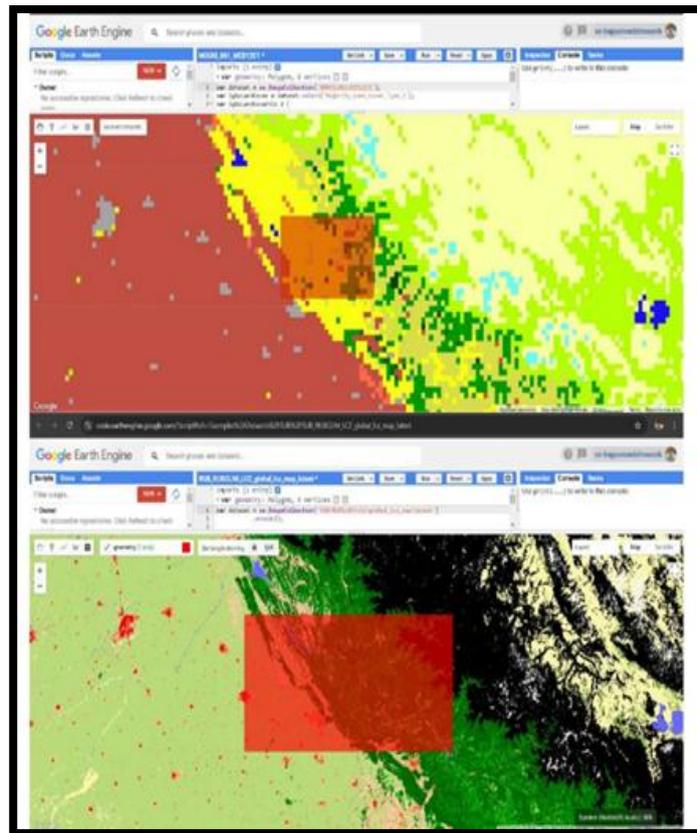
The output shows a Google Earth Engine (GEE) display which uses satellite data to demonstrate moisture balance information after dam construction work. The analysis examines changes in

moisture balance because precipitation minus evapotranspiration serves as the method to measure water resources and agricultural productivity and vegetation health and regional climate patterns. The surrounding areas display different moisture balance patterns because dam-related factors create distinct or restricted moisture balance changes. The gradient shifts from brown to green because the downstream area from the dam creates an opposing gradient which produces and maintains moisture through optimal conditions. The red AOI (area of interest) in the overlay and a distinct base layer are used to evaluate the NDVI or land classification, even if there are better ways to visualize it. The red rectangle exists close to green vegetation because post-dam moisture retention will improve vegetation growth. The dam has increased downstream moisture availability. The process will reduce drought stress which will promote vegetation growth and agricultural development. The maps display changes which land cover transformation causes while they measure increased moisture levels. The output from Google Earth Engine demonstrates how dam construction has positively affected regional moisture balance through its results. The researchers use satellite data to study moisture balance across seasonal periods. The data provide a snapshot of spatial patterns (changes happening across different areas) and also a snapshot of temporal dynamics (changes happening over time) to give a definitive understanding of how moisture availability is influenced by climatological events such as monsoon rain.

### **3.0 Results and discussions**

#### **3.1 Pre-monsoon moisture distribution**

Moisture distribution patterns throughout the algorithm's map display a broad range between completely clustered and fully dispersed moisture. The fluctuation shows how different geographic areas distribute their water resources because some areas dry out quickly while other regions experience slight rainfall. Certain regions demonstrate better retention of moisture because their soils and vegetation and landscape features enable more effective moisture preservation, whereas other areas contain materials that promote rapid moisture loss through their low infiltration and high evaporation rates (Fig. 2-top). The pre-monsoon season demonstrates a fragile moisture equilibrium because extreme temperatures lead to rapid moisture evaporation when the area receives insufficient rainfall. The different water-holding capacities of various land parcels result from their specific soil texture and land use and elevation characteristics. Dryland agricultural systems show ecological damage through disjunctive moisture patterns, which also reduce their farming potential.



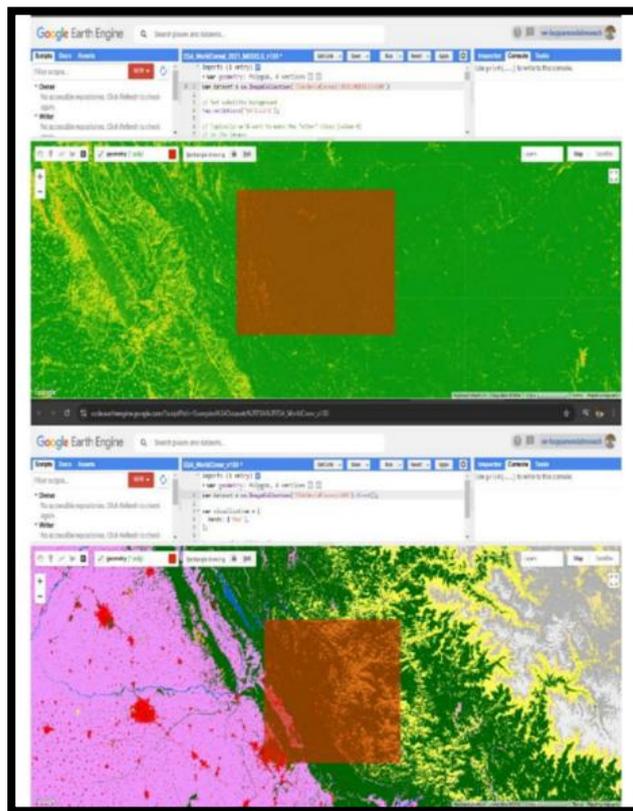
**Fig. 2** Post dam construction moisture balance algorithm

### 3.2 Post-monsoon moisture accumulation

The post-monsoon moisture map which shows moisture distribution across the landscape presents a stable pattern according to the evidence shown in Figure 2 (bottom). The two-month period of monsoon rainfall which accumulated during this time frame brought sufficient moisture to restore both groundwater and soil systems. The algorithm indicates that regional soil reaches its saturation point while the moisture balance ratio improves during post-monsoon periods. The moisture balance between two regions shows greater stability which leads to a decrease in the regional imbalance which existed before the monsoon period began. The region experiences better moisture conditions which lead to increased groundwater recharge and vegetation growth and agricultural output. The results demonstrate that researchers must consider both soil types and rainfall intensification during their studies. Rainfall serves as the primary water source for the area but the duration of moisture retention after a rain event depends on the soil's water-holding ability. Soils with higher capacity such as clay loams can retain moisture for extended periods which enables water levels from post-monsoon periods to stay in place until monsoon precipitation has nearly finished. The program uses data from satellites which provide both spatial and temporal information.

### 3.3 Topographic behaviour of flood

The pre-monsoon season brings light rain which falls in sporadic patterns and produces only small amounts of surface runoff while water gathers in low-lying areas. The drier and semi-dry conditions make it difficult to see how terrain reacts to flood situations because the rainfall does not reach enough intensity to cause major water movement events such as bank overflow or water accumulation or sudden flash floods. The post-monsoon season displays the complete opposite of how the landscape performs hydrodynamic processes. The areas inland from the coast have experienced extreme flooding because of high water levels which come after heavy monsoon rainstorms. Floods in this area follow topographical patterns because they depend on three main factors which include their initiation points and their current state and their geographical area.



**Fig. 3** Topographic behaviour of flood

The pre-monsoon season is characterized by relatively mild, intermittent rainfall, little surface drainage, and water accumulating in hollows or depressions. The drier or semi-dry conditions limit terrain visibility for flood behavior studies because the rainfall amount does not generate enough hydrological activity to produce over-stream bankflow or pooling or flash flooding events. The post-monsoon season presents an exact reverse of all hydrodynamic movements which occur

through the landscape. Inland areas experience high water tables and near-flooded conditions which follow periods of intense monsoon rains. Flood events in this area occur mainly because of topographical features which determine their starting point their current state and their area of impact.

### 3.4 Stress degree day index

The Stress Degree Day Index (SDDI) is a numerical indicator of heat stress in plants, which is employed in agriculture and environmental science. It can be computed as:

$$SDDI = (T_c - T_a)$$

Where,  $T_c$  = Canopy temperature,

$T_a$  = Ambient temperature.

The index displays the temperature difference between the air and the canopy. The plant experiences more heat stress the higher the SDDI, typically as a result of reduced transpiration brought on by things like high atmospheric demand or water scarcity. The pre-monsoon months from March to May in South Asia experience high solar radiation, which causes atmospheric temperatures to rise and evapotranspiration rates to increase. Plants experience soil moisture stress because of insufficient rainfall and deficient irrigation which fails to restore the moisture lost from the soil. Plants typically close their stomata to minimize water loss, which results in decreased transpiration rates. The canopy temperature will increase beyond the normal air temperature according to figure 4-top. During the post-monsoon months, rainfall will restore soil moisture, which allows plants to take up water in sufficient amounts. Plants can maintain their stomata in an open position, which allows transpiration to proceed, and thus the process will cool the canopy while keeping its temperatures near or below the surrounding air.

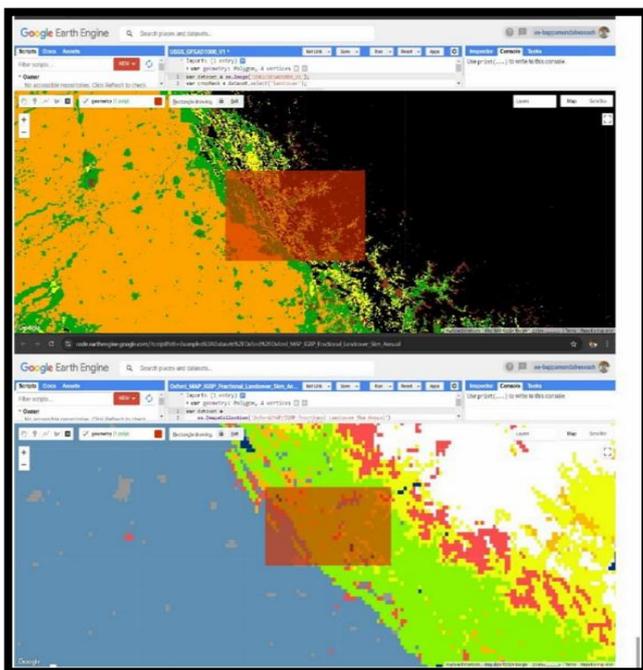


Fig. 4 Stress degree day index

The post-monsoon period showed lower SDDI values because of reduced heat stress conditions which created a stronger relationship between canopy measurements and air temperature. The SDDI values show how environmental factors such as soil moisture and solar radiation impact plant physiological activities which demonstrate their effect on SDDI movements before and after the monsoon. The SDDI monitoring system provides farmers with advance notice of crop stress which helps them manage irrigation schedules and their farming activities to minimize yield losses resulting from heat and moisture stress.

### 3.5 Vegetation influence on flood

The control of flood processes depends on vegetation because it helps prevent flooding through its ability to intercept rainfall and enhance water absorption and its ability to strengthen soil roots and its ability to delay water runoff from surfaces. The effectiveness of these processes in a landscape depends on how vegetation spreads throughout the area. The pre-monsoon season brings dry conditions that cover vast vegetation areas with extremely thin plant cover and soils that contain only minimal moisture. The areas with low plant cover experience their main vegetation loss because of dry periods that follow show temporary soil wetness. The plant life is capable of preventing soil erosion while it collects water from the initial rainfall. The re-growth of vegetation in certain locations after the initial rains enables the creation of a hydraulic barrier that stops overland water flow (Fig. 5). The vegetation spatial arrangement exists as a flood control system which functions during both monsoon seasons and their subsequent periods. The seasonal change in vegetation strength creates a buffer effect that protects against flooding when rainfall levels exceed a specific threshold. The protection of natural flood control systems should receive priority access to all essential components that maintain operational dam systems. The establishment of a protective cushion that enhances flood resilience would occur through the integration of ecological infrastructure into different environments.

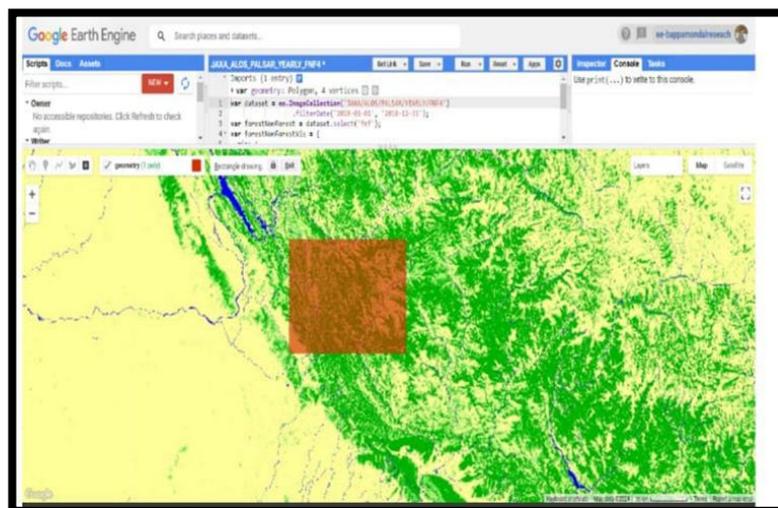


Fig. 5 Vegetation influence on flood

### 3.6 Flood simulating factors

Flooding models serve three purposes which include flood prediction and flood management and flood impact reduction according to hydrologists. The study of flood hydrology and flood simulation includes a topographic and meteorological distribution of all characteristics which determine flood behavior. The key topographic elements include slope and the sediment transport index (STI) and focal flow and the stream power index (SPI) and flow accumulation. These characteristics help to show the topographic features and water flow patterns which affect flood behavior. Slope serves as an important factor for hydraulic studies because it shows the steepness of the terrain. As the slope increases overland flow speed to downstream areas increases together with flood discharge volume. The lower slope side experiences slower flow which results in increased infiltration that helps to reduce flood impacts. Flood modeling uses slope parameterization to identify areas with rapid flow and monitor those areas to assess erosion potential together with flash flood risks. The sediment transport index combines slope and area sources which provide a measurement tool that evaluates sediment movement capacity throughout the environment. During floods high STI values predict potential storm conditions which lead to increased overland flow that causes sediment erosion and movement. Focal flow calculates water flow density which moves toward a designated point in the landscape, and the method uses digital elevation models (DEMs) for its calculations. Focal flow shows you the areas where water travels through its detection system. The results of this parameter show the flood hazard area because the focal flow pattern shows where water will collect. Areas with strong focal flow movement show potential sites where water will gather. The high focal flow areas show potential locations where water will flow to create erosion sites and gully formation areas. The stream power index measures how strong water erosion becomes by using slope and specific catchment area as its base measurement. The system measures sediment energy through its ability to transport sediment on channels and to make them move. SPI enables flood simulations to identify water channels which possess sufficient force to create major geomorphic changes by either widening or deepening their channels. SPI identifies unstable channels which become high risk during floods thus increasing the flood danger for areas downstream. The definition of flow accumulation describes how many cells upstream contribute to a single cell in a digital elevation model. The system shows how much water could reach a specific location. High flow accumulation areas show two main patterns which include channelized flow and depressions that will collect major water during storms. The system serves as the main requirement which identifies potential flood areas. The complete flood extent and flood intensity prediction needs flow accumulation data together with land use information and raindrop measurements. Flooding conditions in a specific area require multiple parameters which include slope, STI, focal flow, SPI and flow accumulation. The relief features of an area enable researchers to determine how water flows through the landscape, how sediments move through the environment and how energy gets distributed, which are essential for creating flood models to predict when and where floods will occur.

#### 4.0 Conclusion

Flood modeling of the Atreyee and Punarbhaba river systems delivered vital information regarding hydrological performance and flood patterns and the spatial distribution of flooding in the border floodplains between northern West Bengal and adjacent Bangladesh. The study used hydraulic modeling and hydrologic modeling together with remote sensing and GIS technology to assess both the extent of flooding and the changes in runoff patterns over time. The two rivers experienced simultaneous flood peaks because they shared the same catchment area and existed close to each other. The combination of low channel slopes and siltation and floodplain encroachment led to an increase in flood length and flood extent. The flood scenarios demonstrate that the areas surrounding Balurghat and Gangarampur and Thakurgaon experience high flooding risk which threatens both livelihoods and infrastructure and agriculture. The flood modeling simulations serve as an effective tool for planning flood preparedness and response activities because the model validation proved its reliability by matching actual recorded data. Bangladesh and India need to work together at the basin level through transboundary partnerships because this approach will enhance data sharing and water resource management and development of sustainable flood control solutions.

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