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Geospatial Analysis and Management Strategies for the 2022 Rapti River Flood: A Case Study of Balrampur District, Uttar Pradesh

Vipul Kumar Mishra
Research Scholar
M.L.K. P.G. College, Balrampur (Affiliated to- Siddharth University, Kapilvastu, Siddharth Nagar, Uttar Pradesh)

Abstract: *The terai region of Uttar Pradesh is perennially vulnerable to hydro-meteorological disasters, yet the flood events of October 2022 represented a significant deviation from historical norms. This study presents a geographical and analytical examination of the flood dynamics in Balrampur District, driven by an unprecedented late-monsoon rainfall anomaly. Integrating primary river gauge data with multi-temporal Satellite Synthetic Aperture Radar (SAR) imagery, the research analyzes the hydrologic response that led to a new Highest Flood Level (HFL) of 106.070 meters. The study identifies 52,433 hectares of inundated land and assesses the impact on 406 villages. Furthermore, it evaluates the "channelization" of administrative resources, specifically the use of Emergency Operation Centres (EOCs) and targeted boat deployment. The findings suggest that the interaction between retreating monsoons and Western Disturbances is creating new flood risks, necessitating a shift from reactive relief to predictive, data-driven disaster management.*
Key words- *Balrampur flood 2022, Management of flood, Rapti River*

I. Introduction

Floods in the Gangetic plains are a recurrent phenomenon, traditionally dictated by the Southwest Monsoon (June to September). However, recent climatic shifts have altered the temporal distribution of rainfall, leading to severe late-season flood events. The flood of October 2022 in Uttar Pradesh is a prime example of this shifting baseline, where heavy precipitation occurred well after the traditional withdrawal of the monsoon.

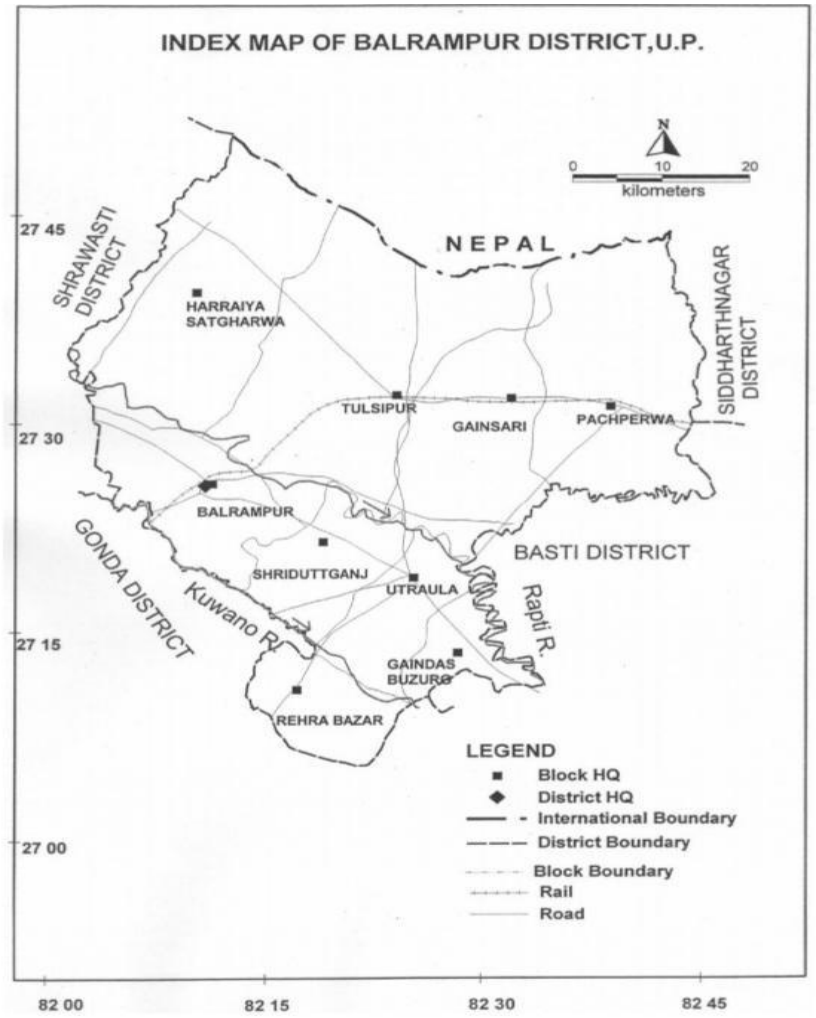
Balrampur District, situated in the ecologically fragile Terai belt, serves as a critical case study for these emerging risks. The district acts as a drainage basin for the trans-boundary waters flowing from Nepal's Siwalik range. While the region is accustomed to seasonal inundation, the 2022 event was catastrophic due to its timing and intensity. According to reports from the India Meteorological Department (IMD) and Sphere India, the floods in October 2022 affected over 1.3 million people across Uttar Pradesh, with Balrampur being among the most severely hit districts (Sphere India, 2022).

This paper aims to: (1) analyze the hydrometeorological causes of the October 2022 flood, (2) utilize geospatial data to demarcate the extent of inundation, and (3) evaluate the efficacy of the disaster management strategies employed.

II. Geographical Setting and Study Area

2.1 Physiography: Balrampur District lies between 27°03' and 27°52' North latitudes and 82°01' and 82°45' East longitudes. The district covers a geographical area of 3,349 sq. km (Balrampur Website, 2013). The topography is characterized by a general slope from North-West to South-East, which dictates the flow of surface runoff. The region is geomorphologically divided into two units:

- **The Upland Plains (Bangar):** Older alluvial deposits found in the northern periphery near the Nepal border.
- **The Lowland Plains (Khadar):** Newer alluvial deposits in the south, which are frequently subjected to riverine flooding.



Map.1(Source - Ground Water Brochure, Balrampur District U.P.,2011)

2.2 Drainage Network: The Rapti River is the primary hydrological artery of the district, flowing for approximately 75 km through the territory. It is supported by a network of tributaries including the Suawan and Kuwano rivers. A critical factor in the district's flood vulnerability is the presence of numerous ephemeral mountain streams (gullies) such as the Bhabhar, Dhobainia, and Kharjhar (Mehrotra, 2022). These streams, originating in Nepal, contribute to "flashy" discharge—rapid rises in water levels following precipitation events in the catchment areas.

III. Hydrometeorological Analysis of the 2022 Anomaly

The 2022 flood was distinct from previous events (2017, 2020) because of its meteorological drivers. While typical floods in this region are monsoonal, the October 2022 event was driven by the interaction of a delayed monsoon withdrawal and an active Western Disturbance.

3.1 Rainfall Dynamics: Historical data indicates that peak rainfall in Balrampur typically occurs in August. For instance, the district recorded 404.54 mm in August 2017 and 413.6 mm in August 2021 (Mehrotra 2022, IMD 2022). In contrast, 2022 witnessed a massive shift in precipitation patterns.

- **September 2022:** The district received 860.60 mm of rainfall.
- **October 2022:** An unprecedented 1,074.26 mm of rainfall was recorded.

This anomaly resulted in a total annual rainfall of 2,802.26 mm for 2022, nearly triple the rainfall of typical years (e.g., 954.27 mm in 2017). The heavy rains in October were exacerbated by a low-pressure system over the Bay of Bengal interacting with mid-latitude westerlies, a phenomenon noted by climate experts as a cause for "unseasonal" heavy rains across Northern India (The Hindu, 2022).

3.2 River Gauge Statistics: The hydrological response to this rainfall was immediate and severe. Data from the Sisaighat Gauge Station on the Rapti River highlights the magnitude of the event:

- **Danger Level (DL):** 104.620 m.

- **Previous High Flood Level (HFL):** 105.540 m (recorded in 2017).
- **New HFL (2022):** On October 10, 2022, the river peaked at **106.070 m**, exceeding the previous 50-year record by over 0.5 meters.

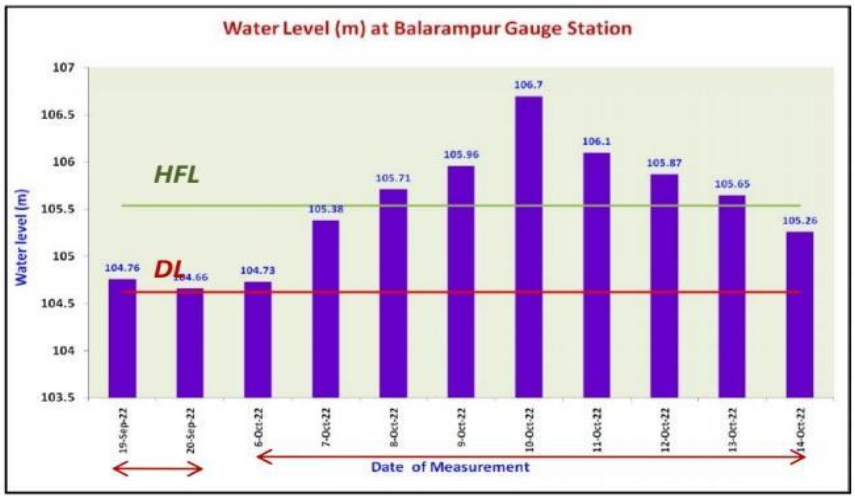


FIG.1 (Source - Central Water Commission,2022)

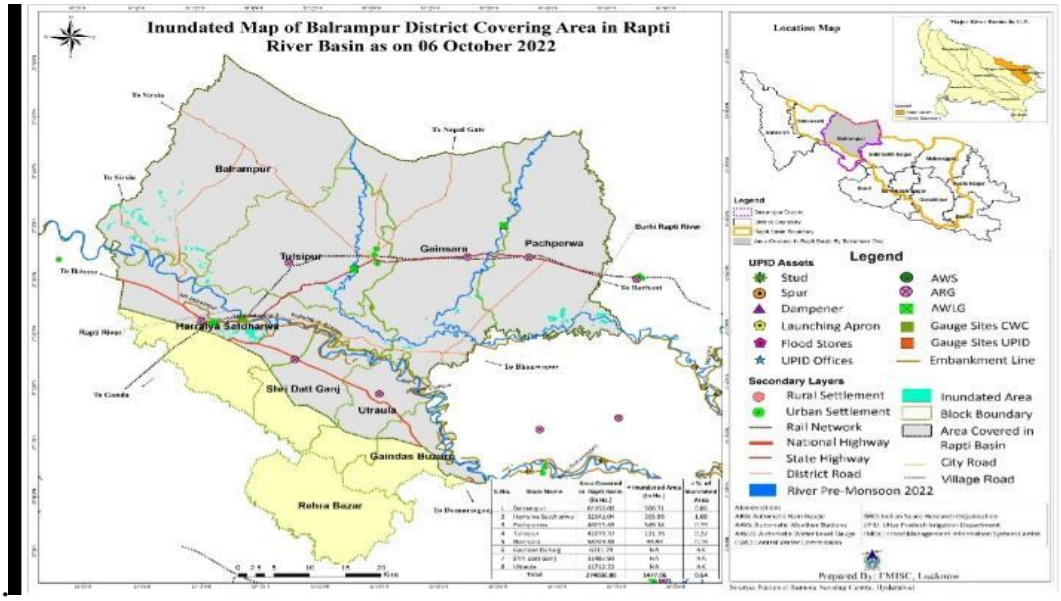
Crucially, the river remained above the danger mark for 10 consecutive days (October 7–15, 2022), creating prolonged hydraulic stress on embankments and levees (IMD, 2022).

IV. Geospatial Analysis of Inundation

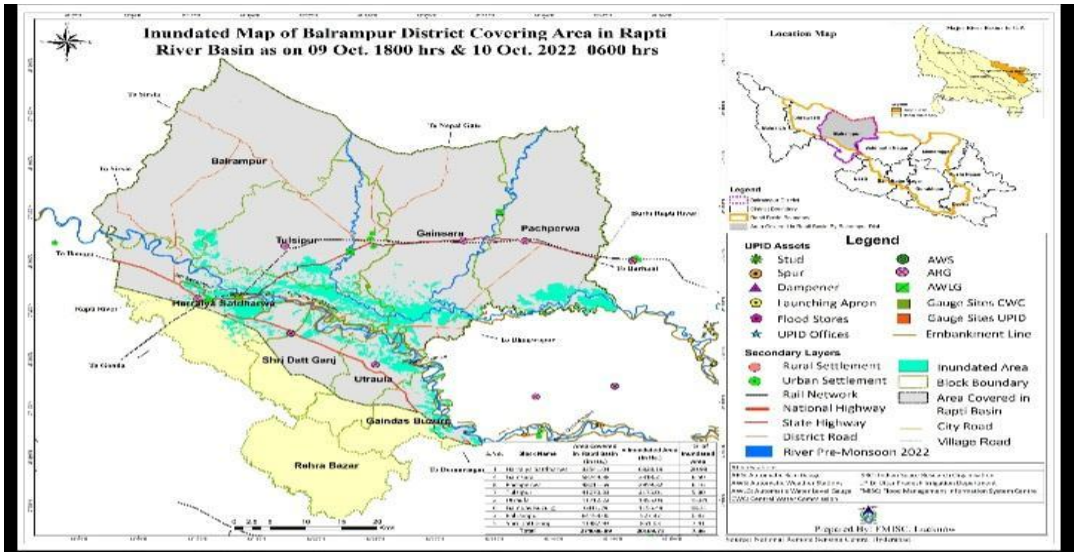
Given the extensive cloud cover associated with the storm system, optical satellite imagery was limited. The study relied on microwave remote sensing data acquired by the National Remote Sensing Centre (NRSC), utilizing Sentinel-1A SAR and RISAT-1A SAR sensors.

4.1 Spatio-Temporal Progression: The flood mapping conducted from October 6 to October 26, 2022, revealed a rapid expansion of the inundation footprint.

- **Peak Inundation:** On October 10, coinciding with the river's peak level, major inundation was observed in the Rapti Basin.
- **Total Affected Area:** The cumulative flood map indicates that **52,433.00 hectares** of land in Balrampur were submerged. This places Balrampur as the fourth most affected district in Uttar Pradesh by area, following Gorakhpur (ANI, 2022).



Map.2 (Source - FMISC Lucknow)



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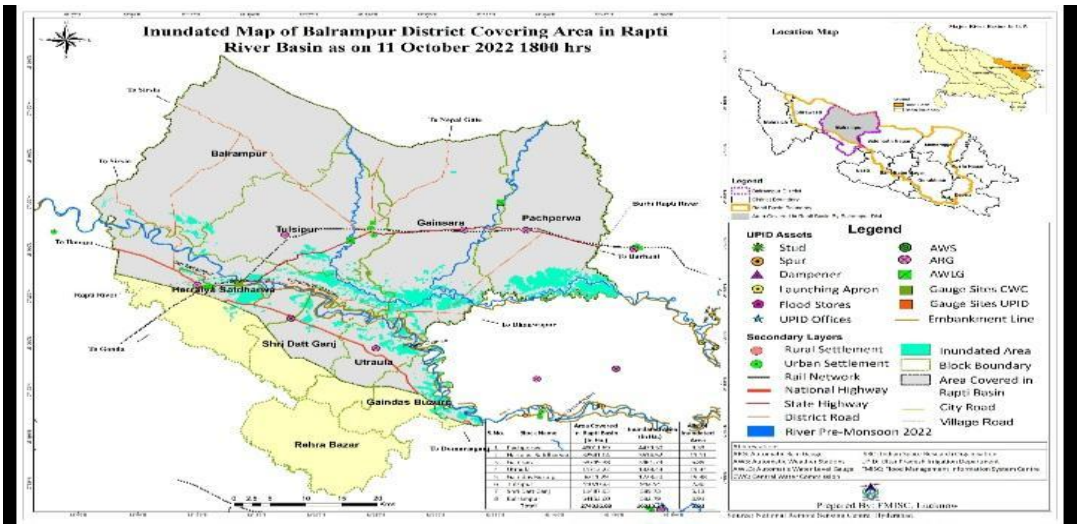
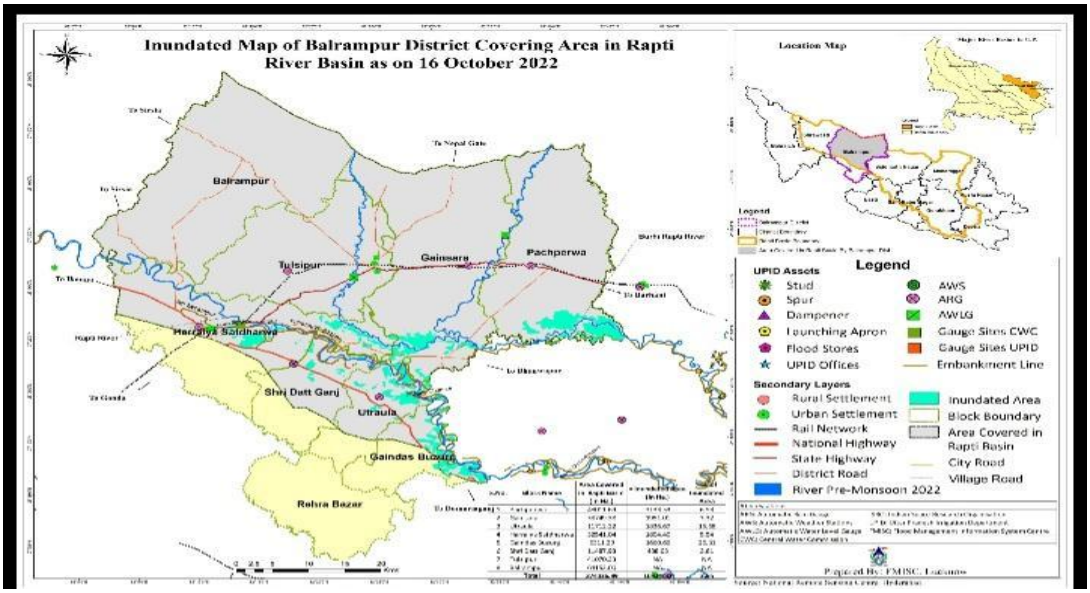
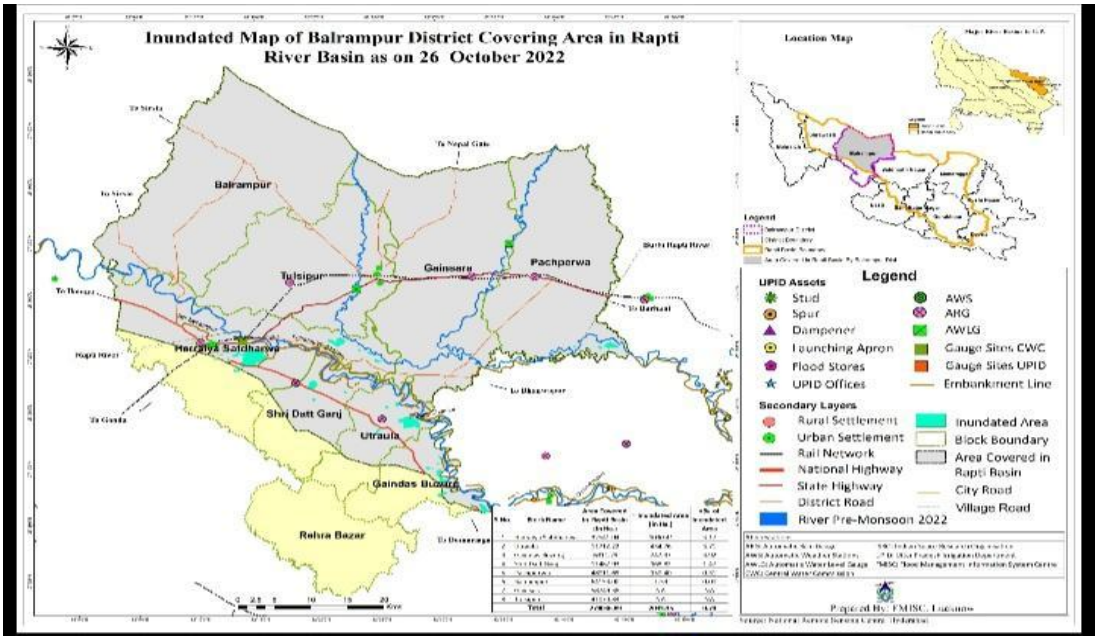


Map 4 (Source - FMISC Lucknow)



Map 5 (Source - FMISC Lucknow)



Map 6 (Source - FMISC Lucknow)

Rapid flood mapping and monitoring was done by NRSC from 09-08-2022 to 26-10-2022 (36 flood maps); to provide real time flood inundation maps, to Disaster Management Support Organizations working at State or Central level.

From 06-10-2022 to 26-10-2022; Inundation maps for 6 days are shown above i.e., Map 1.4 to Map 1.8, for Balrampur District.

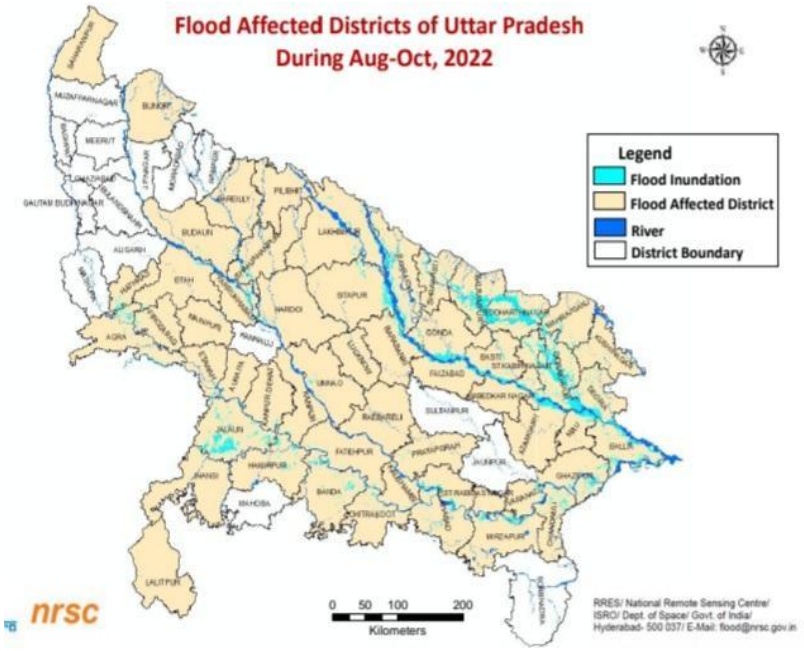
On 10th of October 2022, major inundation can be seen in Map 1.5.

At the end of flood season after 26th October 2022, a cumulative Spatial Flood Inundation map is prepared and district wise flood inundation area Statistics were estimated.

we found maximum inundation in Gorakhpur district, of total inundated area 78430.00 ha. The extension of total inundated area in Balrampur was 52433.00 ha.

4.2 Vulnerability Zoning Using the satellite-derived flood extent, the study classified the affected villages into vulnerability zones:

- **High Water Level Zone:** 136 villages (Severe impact).
- **Medium Water Level Zone:** 107 villages (Moderate impact).
- **Low Water Level Zone:** 163 villages (Low impact). Total affected villages stood at 406, with the Tehsil of Utraula being particularly vulnerable, recording 126 inundated villages. Media reports from the time corroborate this, with outlets like *The Print* and *ANI* reporting over 200 villages affected and National Highway 730 being submerged, cutting off critical logistical routes (ANI, 2022).



Map.2 (Source - Satellite Based Analysis, NRSC Report , November 2022)

V. Management Strategies and Resource Channelization

Effective disaster management in such scenarios relies on the "channelization" of resources—directing aid based on empirical data rather than ad-hoc distribution.

5.1 Emergency Operation Centres (EOC) The district administration activated a 24x7 Flood Control Room (Toll-Free: 1077). A decentralized approach was adopted, utilizing school teachers to lead village-level feedback teams. These teams communicated directly with Gram Pradhans and Asha workers to identify specific needs (food packets, medicines). Between October 6 and 18, 401 specific complaints were registered and addressed, showcasing a successful model of community-based information gathering (ANI News, 2022).

5.2 Resource Deployment The deployment of rescue assets was highly correlated with the vulnerability mapping described in Section 4.

- **Boat Deployment:** A total of 526 boats were deployed. Significantly, **119 motorboats** were allocated to Balrampur Tehsil alone, compared to fewer in less inundated areas. This indicates a data-driven understanding that the high-velocity currents in Balrampur Tehsil required motorized solutions over traditional country boats (ANI News, 2022)..
- **Rescue Forces:** The operation involved the coordinated deployment of 2 NDRF teams, 3 SDRF teams, and 7 PAC (Provincial Armed Constabulary) teams (ANI News, 2022)..

5.3 Infrastructure Failure and Response: The structural limits of flood control were tested when the Balrampur-Bhadaria Embankment faced water levels 30 cm higher than its design capacity. On the night of October 9, a 120-meter stretch was damaged by "backrolling" waters. The administration's response involved "war-footing" repairs using heavy excavators (Poklen) during the active flood phase. This highlights a critical lesson: pre-disaster maintenance must account for new climate baselines, as emergency repairs are both costlier and riskier.

VI. Discussion and Recommendations

The 2022 flood was a "black swan" event that exposed the limitations of relying on historical flood data for future planning. The shift in peak rainfall to October suggests that the traditional "flood season" protocols (usually ending in September) need extension.

6.1 Strategies for Profitable Resource Utilization: To ensure optimum utilization of resources in future disasters, the following strategies are proposed:

1. **Revising HFL Benchmarks:** All future infrastructure projects (roads, embankments, bridges) must use the 2022 HFL of 106.070 m as the new baseline design parameter.
2. **Pre-Disaster Strengthening:** Investing in raising the height of the Balrampur-Bhadaria embankment is a "profitable" measure compared to the recurring cost of relief and crop compensation.

3. **Automated Early Warning:** The 10-day high water duration provided a window for evacuation. Future systems should integrate NRSC satellite alerts directly with village-level WhatsApp groups managed by the teacher-led teams, reducing the latency between detection and evacuation.

VII. Conclusion

The October 2022 flood in Balrampur was driven by a complex interaction of hydro-meteorological factors exacerbated by climate change. The district received nearly 300% of its typical annual rainfall, leading to record-breaking river levels. While the administrative response was robust—characterized by the strategic deployment of over 500 boats and the novel use of teachers for intelligence gathering—the event underscores the need for structural adaptation. By leveraging geospatial technologies for real-time monitoring and adhering to new hydrological baselines, disaster management authorities can move from reactive mitigation to proactive resilience.

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