A Comprehensive Review on Technological Implementations and Innovations in Cyclone & Flood Disaster Management

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ABSTRACT

The rise of calamities like floods and cyclones as a result of climate change portrays a picture that is challenging to manage. Therefore, the need for advanced technologies in disaster management is apparent. The focus of this paper is to evaluate the application of Technology, including Geographic Information Systems (GIS), IoT based remote sensing, Flood Sensor Technology, and Artificial Intelligence, and how they amalgamate with Disaster Management Cycle: Reduction, Preparedness, Response, and Recovery. These integrated technologies greatly facilitate the prediction, monitoring, and real time analysis of disaster affecting events to formulate competent mitigation strategies and enhanced preparedness. Further optimization for AI powered platforms and machine learning models are used, facilitating better decision making and situational awareness for affected authorities' sustainable and rapid response to disasters. Post disaster recovery becomes easier and faster with the use of UAVs, drones, 3D mapping, and other Nanotechnology based devices for efficient damage portrayal of a sutured map of the affected area making infrastructure rebuilding easier. Moreover, smart disaster management systems (SDMS) facilitate communication and collaboration to reduce decision making errors formulating an easier approach for disaster remediation. The paper underscores the issue of taking account of all, specifically the most vulnerable ones. The application of these technologies increases the efficacy and accessibility of the system of disaster management and in dealing with consequences associated with natural disasters.

Keywords: Disaster Management Cycle, AI-Integrated Disaster Management Platform, Geographic Information Systems (GIS)

1. Introduction

Floods and cyclones are the most devastating natural calamities which cause many casualties, financial crises, loss of vegetation, and destruction of livelihoods. The sudden climate change in recent times has amplified their frequency and impact causing the need for advanced disaster management strategies. The utilization of modern technologies including real time data monitoring, early warning alerts and emergency response have evolved the disaster management sector. About 1.81 billion people were directly vulnerable to significant flood risks, among which 89% resided in lower and middle economic tier nations as reported in [1]. Moreover, people who reside in coastal regions or near the seas face this issue more as compared to people living in terrestrial regions which are less vulnerable to flooding, ignoring the ongoing risk to communities in these areas. This situation reflects the growing challenge of climate related disasters and the need for better disaster preparedness and adopting adaptation strategies. This review paper briefs about the recent advancements in technologies for flood and cyclone disaster management like Geographic Information Systems (GIS), remote sensing and spatial analysis, social media, global mapping, Flood Sensor Technology (FST), Flood Disaster Management System(FDMS), Internet of Things(IoT) and image processing. GIS is useful to examine areas that are more prone to flooding, analysing the hazards caused by flooding, and helping with disaster relief activities. For example, flood forecasting in Bangladesh has made use of GIS techniques to help anticipate floods and guide evacuation plans. In a similar vein, FEMA in the US maps hazards used GIS[2]. Remote Sensing technology provides accurate and rapid information on weather forecast and flood events, remote sensing technologies mainly satellite imagery are

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essential tools for disaster management. Communities may now remotely monitor and evaluate the effects of major disasters facilitated by these technologies. Floods can emerge suddenly and are colossal in size. This explains why the MODIS satellites operated by NASA are extensively deployed across India's terrain [3]. Planners are now able to analyse the satellite images to assess resources needed, damages affected, and differences in water levels. They can also distinguish the boundaries of the floods, and examine the water levels. Sentinel-1 and other satellite systems provide high resolution radar images in addition to MODIS, which are helpful for identifying floods, especially at night or in cloudy conditions[4]. This review paper aims to analyse different technologies and provide insights on the general flood and cyclone disaster management processes. Adopting technology-driven solutions to disaster management can increase the efficiency and accessibility to provide aids to a disaster.

2. Literature Review

Flood and cyclones are among the most detrimental disasters to ever exist. It can damage everything that comes in its way. Floods are caused by factors such as heavy rainfall, heavy tides and high winds when flow over river and oceans[5]. In the current circumstances, as the population increases, more trees are cut down to accommodate new houses and factories leading to urbanization. This renders coastal regions increasingly susceptible to recurrent flooding owing to the reduction of water absorption and the increase of sea level. Hence, central and state government has taken several plans such as proper management of draining system and regular checking of sewage pipes. The urban flood risk management focuses its approach to control or decrease the human loss and economic or property damages.

2.1 Overview Of Flood And Cyclone Management:

Floods are the end result of natural or a blend of natural and human factors. Its' impact often depends on the severity of the disaster combined with the susceptibility of the affected regions. Hence, Tingsanchali et al. expressed the risk of flood as [6]:

$$Risk = Crisis \times Vulnerability \qquad (1)$$

Due to this risk involved with escalating hurdles in impact control, the flood and cyclone disaster management undergoes significant challenges in various phases. This management can be broadly classified in two stages : pre-disaster and post-disaster management[7] as shown in Fig1. The pre-disaster management processes, which include reduction and preparedness, focus on minimizing risks and preparing communities to prepare for a disaster beforehand. The post-disaster management processes, consisting of response and recovery, aims at immediate measures and rebuilding of the community.

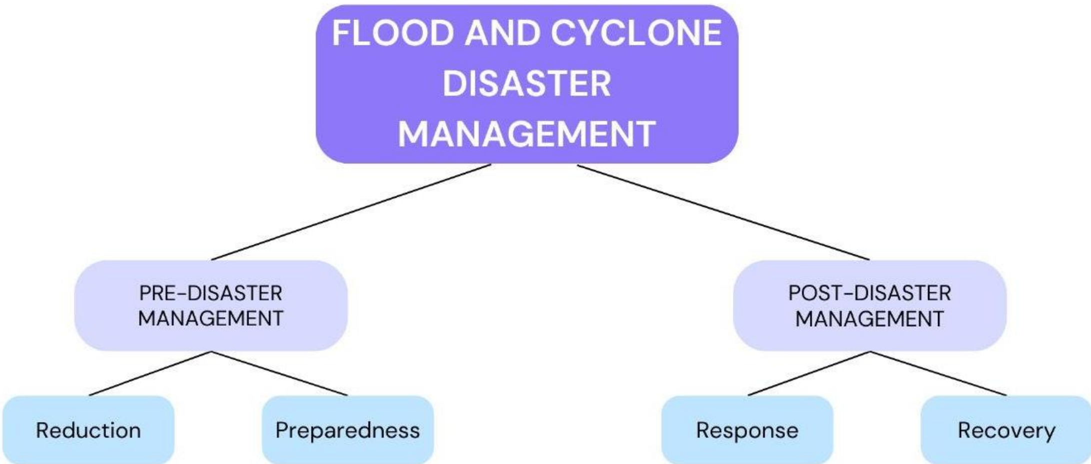

Fig.1. Diagram representation of Pre and Post disaster management

The Reduction phase refers to proactive measures aimed at minimizing the impact of floods and cyclones. Physical measures like constructing flood barriers, level control, and sea walls can prevent or reduce the extent of floodwaters.[8] The construction of storm surge barriers in coastal areas would reduce damage from cyclone impacts. New technologies like Geographic Information System (GIS) and Flood Risk Modelling are critical in areas that are likely to flood so as to design proper infrastructure. GIS working process as shown in Fig2 consists of Data Gathering (collecting spatial data), Information Saving(storing data in the databases), Data working(changing and data deletion), Data Analysis (calculating region specific harmony), and Data Visualisation (showcasing final output in the form of map or graphs). This pattern aids in creating data focussed specific spatial decisions.

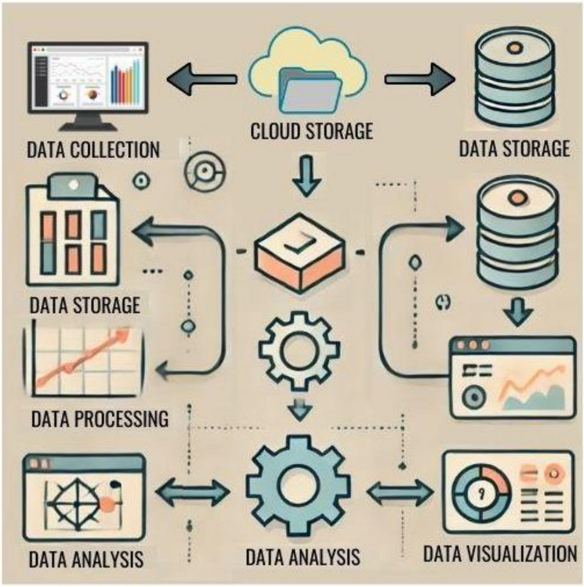

Fig.2. Process of Geographic Information System

In addition, an Early Warning System (EWS) is created to find and alert society about dealing and minimising the impacts of natural disasters, providing ample time for preparation and vacancy drives. It blends information from the meteorological department, seismic, and other kind of sensors to showcase threats like floods, tsunamis, and cyclones. This system guarantees on time alerts, protecting lives and minimising the damage impact. At the community level, people can be better prepared for impending disasters, such as floods, by using social media and mobile apps including Flood Warning Apps, which increases public awareness. The integration of technology into policy such as the provision of real-time flood data and hazard mapping for urban planning, also facilitates risk reduction of floods and cyclones.

Then, Preparedness focuses on ensuring communities and authorities are ready to respond effectively when disaster strikes. This includes creating evacuation plans based on real-time data from remote sensing and IoT devices that monitor water levels and weather patterns[9]. Remote sensing technology includes the use of image generated by satellite, drones and terrestrial sensors to collect information about Earth's surface and atmosphere. This technology allows the analysis of environmental changes, weather change correlation and disaster effect parameters. It aids disaster management by providing real time data that increases the exactness of hypothesis and response result.

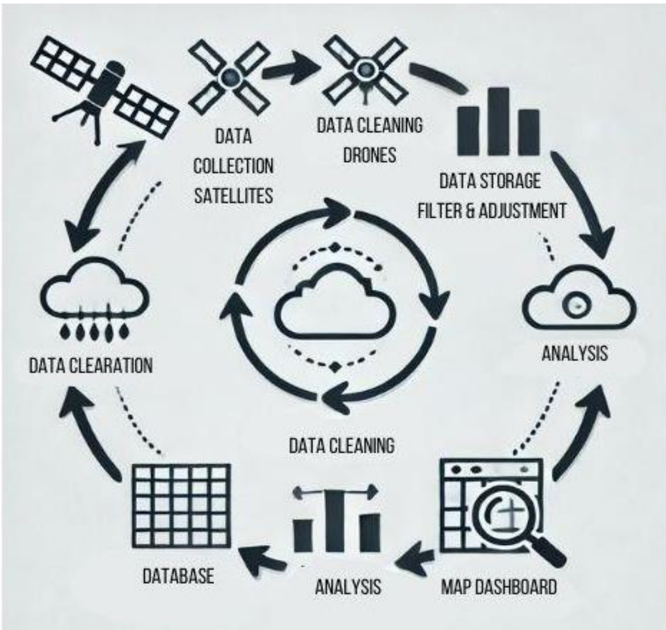

Fig.3. Process of real-time data using Remote Sensing

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Forthcoming floods can be predicted using mobile applications, drones, and even SMS texting, allocating resources to places that require assistance the most. Along with these steps, it is also very essential to administer CPR and first aid training as well as virtual training to the general population so that they are prepared to deal with emergencies. Finally, satellite phones and the internet are highly useful to allow uninterrupted communication on a crisis. This situation is especially helpful where conventional systems are expected to malfunction.

Furthermore, Response means the steps that are taken during a disaster and immediately after, to minimize the damage on lives and infrastructure. It includes an evacuation plan, which makes use of drone and GPS technology to determine the best routes for evacuation and the location of trapped people. Use of Unmanned Aerial Vehicles (UAVs) along with heat imaging to find survivors in hard-to-reach places is just one of the new technologies expanding the scope of rescue and recovery In addition, robots can perform search and rescue missions in partially collapsed structures [10]. Integrated resource management systems based on sensors and the IoT facilitate the effective management of food, water, and medicine by tracking real time data. Social media monitoring and crowdsourced data can also play a vital role in identifying places that require urgent rescue efforts, which can be coordinated through the internet.

Lastly, Recovery focuses on rebuilding and restoring communities after a disaster. This includes the restoration of livelihoods, infrastructure reconstruction, and debris removal. Technologies like 3D mapping and drone imaging are very efficient in assessing damages as well as planning rebuilding efforts. In knowing the geospatial damage, robotic technologies efficiently reconstruct critical infrastructure, including roadways, bridges, and power transmission lines. Robots can also be utilized for debris removal in hazardous or inaccessible areas. With the aid of satellites and IoT sensors, vegetation regrowth and ecosystem restoration can be monitored steadily. Precision farming technologies such as drones and soil sensors tremendously helped farmers bring back their incomes by boosting crop production and countering soil erosion.[11] These technologies speed up the recovery process after disasters but prepare them for disaster with precise planning enabling improved fuelling of crops. Thus, these important phases as shown in Fig4 in the cycle of disaster management result in effective risk mitigation and hazard control systems.

Fig.4. Important Phases of disaster management

2.2 Technologies used for Flood and Cyclone Management:

Spatial analysis along with remote sensing are among the various technologies which could be used to prevent flood and cyclone disaster in the future, which further provide valuable information at every stage of cyclone disaster management. Spatial analyses and remote sensing data combine to provide the necessary knowledge on environmental condition changes. Additionally, satellite remote sensing is crucial for monitoring tropical cyclones[12]. Acquiring recurrent high spatial (less than 5m pixels) satellite images prior and upon a flood and cyclone is quite a prevalent application of remote sensing [13]. Pre-disaster techniques such as InaSAFE, CAPRA, Risk Geo-Wiki, post-disaster innovations including crowdsourcing, social mead, VGI, recovery effort tools like HOT and Tomnod, and Global Mapping efforts, for instance, aqueduct and near-real-time warnings such as Global Flood Awareness System 'GloFAS' are leveraged [14].The hazard and disaster risks are mapped utilizing remotely sensed data like MODIS, ASTER and Landsat. On the other hand, hydrological with flood modelling are implemented to derive digital terrain data from GTOPO30, SRTM DEM, and LiDAR [15].

Geographic Information System(GIS) performs a quick analysis of the magnitude of the disaster to prompt as well as aid the adoption of appropriate measures by decision makers. The impacted fieldwork used GIS-enabled mobile application in the aftermath of cyclone Gaja in Tamil Nadu, in 2018. On 16 November 2018, Gaja created havoc in 6 districts of Tamil Nadu. GIS-enabled mobile application helped restoration of electricity to the affected region in a short period of 30 days[16]. But the limitations faced by decision-makers using GIS for real-time disaster planning include the scale of

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spatial data and the non-technical setbacks of GIS by making observations from a real-time disaster scenario in Mackay, Queensland, Australia [17]. Flood Sensor Technology (FST) is the technology which tells the range of flood in a place and accordingly one can judge or examine the effects caused by flood or cyclones .Different countries are developing various types of flood sensors using various kinds of technologies like IOT, ICT, GIS, Remote sensing (Internet of Things, information and communication technology, Geographic Information Systems) etc. to assist the flood management efficiently [18]. The use of disruptive technologies (such as Internet of Things IoT, Image processing, Artificial Intelligence AI etc.) through which smart cities (cities using disruptive technologies in infrastructure and locality) can be established to access and utilize the potential of disruptive technologies and thereby improving post disaster management [19]. Flood Disaster Management System (FDMS) is a technology that incorporates different Environmental Information Systems(EISs) and various data sources to minimize flood impacts throughout the entire process. It focuses on time consumption and minimization of unreliable operations involved in traditional management techniques [20]. Smart disaster management system(SDMS) is basically a disaster management system (DMS) further modified through the use and implementation of Information and Communication technology (ICT) which aims to accelerate the rate of information transmission and minimize the rate of error in the response phase of the calamity [21].

The risk of floods is marked on a global scale using technology like satellite and remote sensing. However, it faces limitations characterized with analysing and understanding the flood risks using just remotely sensed images. But over the years these technologies have been developed and works on tracking the recent developments in disaster management approaches that rely on image processing and machine learning [22]. Nowadays any kind of natural disaster can be minimized by using satellite remote sensing, which helps in providing a fast database to take precautions accordingly and efficiently. Now, technology towards AI is developed very frequently and rapidly which also helps in predicting floods or any kind of natural disaster [23]. The application of WAM(Wave model) is to predict cyclones earlier based upon the pattern of the air wave formation beforehand thus assisting in the pre-cyclone struck period assisting efficient disaster management and reducing the rate of casualties to the maximum [24].

The resource allocation is one of the most significant aspects to cautiously handle with for the recovery phase of disaster management system. It needs transparency, traceability, and efficiency in disaster relief efforts. The implementation of Blockchain technology enhances these criteria by providing a decentralized and immutable ledger for tracking relief aid distribution. The Trump administration proposed utilizing blockchain to secure and track aid distribution to ensure security enhancement and transparency in humanitarian assistance [25]. Another aspect where blockchain can be used is for insurance models. Traditional insurance required an assessment of damages before the payout that caused delay in support efforts. Parametric insurance, however, automates payouts based on predefined conditions for disasters. This ensures instant processing of payouts without manual intervention enhanced with security and trust. Instead of relying on banks or third parties, similarly the UNHCR transferred financial aid using stablecoins on the blockchain in their blockchain based aid program for the displaced Ukrainians [26]. This technology hence can be utilized in the disaster management systems for efficient resource allocation.

2.3 Challenges in Implementing Advanced Technologies for Disaster Management:

While using advanced technologies such as AI, GIS, IoT, and blockchain can improve the disaster management systems and form strong solutions for the need of efficient systems, several barriers can underestimate their effective implementation. These challenges include technological, financial, organizational, and community related aspects and prospects requiring strategic plan and involvement. These barriers are to be discussed here with relevant examples.

Financial constraints are a major hindrance in implementation of advanced technologies in disaster management. Government struggle to set aside enough funds for training initiatives, software procurement, and infrastructure development, particularly in developing nations. Research shows that the blockchain based systems for resource allocation requires high initial investments and recurring maintenance costs, making them potentially unfeasible for low income countries [27]. International funding agencies and public-private partnerships supporting widespread adoption of disaster technological innovations may be the solution for this. Another significant hurdle is the bureaucratic inertia and policy gaps for these management systems. Technologies adoption is often hampered by the government regulations and administrative practices that lag behinds technological developments. The bureaucratic inertia to adopt the emerging technologies instead of the conventional methods appear as barriers in efficiency of such systems. A study on disaster governance showed that the integration of AI and IoT driven early warning systems is delayed by obsolete legislation and bureaucratic opposition [28]. Development of flexible disaster response guidelines and inter-agency collaboration can accelerate technology adoption.

Inadequate training of the emergency response teams and limited engagement from the community in adopting these solutions also poses as a critical barrier in the effective implementation of these systems. A lot of disaster response personnel are inadept at handling advanced tools such as GIS based simulations and IoT driven predictive modelling. In the same way, local communities who are crucial in response and recovery process struggle with technological literacy, privacy concerns and change aversion. A survey in Asia evidenced that 70% of the emergency response officials lacked the necessary training to operate these technologies, constraining the effectiveness of AI based disaster simulations in real-world situations [29]. According to the studies on crowdsourced disaster data integration, communities were found to be reluctant to disclose real time information in regards of the data authenticity and misuse concerns [30]. The widespread adoption of innovations in this field is severely hampered by these gaps in technical expertise and community trust. This requires the need for capacity building programs which includes technical training for responders and public awareness campaigns to earn public trust.

3. Conclusion

Modern technology has come up as a need in dealing with the various effects of global warming, with the use of infrastructure, remote area flooding as well as cyclone disaster management. GIS, remote sensing, flood sensor technology, and IoT are crucial for risk mitigation, and preparation, response, and recovery of disasters. The tools enable effective resources allocation and accurate monitoring of the situation, which makes sound decision making possible. AI-driven platforms can help identify solutions based on machine learning, and offer them in the most optimal way, thereby enhancing the situational awareness of the communities and helping them respond much faster. Such technology enabled systems can greatly reduce the human and economic losses accompanying natural disasters. In the future, ongoing advancements in these technologies will further help improve disaster management potential. The blend of AI and machine learning (ML) with real-time data will grant for predictable analysis, enabling pre-warning systems to be more accurate for disaster forecasts. Moreover, the evolution of autonomous systems, such as drones and robots, will improve performance in disaster responses and recovery, particularly in dangerous or inaccessible areas. Building of more high technology flood sensors and IoT networks will allow for a nonstop monitoring, providing almost instant insights into real-time problems and chaos. There are so many possibilities in giving aid to fuel development of blockchain technology that not only improves security but also prevents disasters from resulting in unequal allocation of resources. As times changes, these technologies will start aiding communities in combating the ever-worsening impacts of climate change.

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