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Design of Smart Flood Risk Management System: A Brunei Darussalam Vision 2035 (WAWASAN 2035) for Climate Resilience and Adaptation

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Abstract: Floods, recognized for their erratic behavior and devastating effects, are a significant threat as a natural disaster. In Brunei Darussalam, the impact of climate change is becoming increasingly evident through higher temperatures and an expected increase in annual rainfall (5.0mm per year from 2021 to 2050), highlighting the critical need for updated flood risk management techniques. In line with the climate resilience and adaptation objectives of WAWASAN 2035, this paper introduces an innovative approach—a cutting-edge flood risk management framework that utilizes the capabilities of big data analytics, sophisticated machine learning algorithms, and smart Internet of Things (IoT) sensors. Traditional methods, which rely on numerical and physical data modeling, often do not provide precise short-term flood forecasts. Our suggested framework uses machine learning to analyze real-time flood forecasting, sensor data, and enhance warning systems, addressing the shortcomings of traditional approaches. The key advantage of this approach is its potential to drastically decrease flood-related damages, protect lives, and boost the resilience of infrastructure. This proposal is not only in aligns with Brunei's vision for a safe and climate-adaptable future but also marks a significant step forward in adopting innovative and sustainable flood risk management solutions amidst an evolving climate.

Keywords: big data; climate change; flood modelling; Internet of Things; machine learning; risk management

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1. Introduction

Throughout history, natural disasters have consistently impacted human societies across the globe. Additionally, human-induced disasters, including terrorist attacks and chemical, biological, radiological, and nuclear threats, also pose significant risks to natural ecosystems and human populations. The looming threat of various hazards and disasters is a major concern for both governmental bodies and individuals within communities. Addressing these challenges, ensuring public safety, and enhancing societal resilience to both foreseeable and unforeseen disasters are crucial responsibilities for any developed society [1]. According to the International Federation of Red Cross and Red Crescent Societies (IFRC) in their 2018 World Disaster Report, the past decade has witnessed 3,751 natural calamities, including floods, earthquakes, landslides, and tsunamis, leading to financial damages estimated at around 1,658 billion USD and affecting nearly 2 million lives [2]. In Brunei, climatic observations have recorded a steady increase in average temperatures by 0.25°C per decade since 1970, alongside a notable rise in rainfall, intensifying by 100mm per decade [3]. Future climate projections for Brunei anticipate a temperature increase of 0.4°C per decade over the next 30 years, with annual rainfall expected to rise by 5.0mm from 2021 to 2051 [3]. These concerning trends highlight the urgent need for comprehensive planning and preparedness to tackle the impending challenges posed by climate change in the near future.

The era of big data has significantly transformed the landscape of natural disaster management, offering unprecedented opportunities for visualization, analysis, and prediction of natural disasters [4]. This shift has fundamentally altered the approach of human societies towards natural disaster management strategies, with a focus on minimizing human suffering and economic damage [5]. One of the key challenges in natural disaster management is the decision-making process [6]. The objective

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of disaster risk management is to safeguard individuals and their properties, health, livelihoods, and productive resources, along with preserving cultural and environmental heritage [7].

Furthermore, research in disaster management is critically important, highlighting the pressing need for further exploration to enhance our understanding and innovation in preventing, mitigating, and managing disasters. Concurrently, we are navigating through the era of the Big Data revolution, which promises to alleviate the impacts of disasters by providing essential real-time information access [8,9]. The incorporation of Big Data Analytics as a tool aims to effectively manage, employ, optimize, and reveal valuable insights from climate change data, particularly for water-related disasters [6]. Machine learning techniques are increasingly being utilized alongside vast data reservoirs to fill existing data voids, offering unprecedented insights that manual analysis could not achieve. Consequently, there's a demand for an innovative and intelligent flood disaster management system equipped with alert and early warning features [10]. By merging big data analytics with machine learning (ML) [11], and the Internet of Things (IoT), this approach will forge a novel and robust framework for flood disaster management, focusing on enhancing flood readiness and prevention strategies. Among many types of disaster, floods are common in many countries. According to the World Meteorological Organization (WMO), flooding remains the third biggest disaster in the world. Based on research conducted by the Institute of Environmental Studies, more than 60% of world cities will be vulnerable to flooding in the next 30 years as a result of climate changes due to the effects of the sea level rise [12,13]. Flood prediction models are of significant importance for hazard assessment and extreme event management. Robust and accurate prediction contributes highly to water recourse management strategies, policy suggestions and analysis, and further evacuation modeling. Thus, the importance of advanced systems for short-term and long-term prediction for flood and other hydrological events is strongly emphasized to alleviate the damage [14].

Implementing good climate change policies is part of the Brunei Darussalam vision 2035 (WAWASAN 2035). Climate resilience and adaptation is number 8 on the list of strategies Brunei Darussalam outlined to achieve the 2035 aspiration on climate change. The design and implementation of water-related natural disaster management in Brunei Darussalam through the use of Big Data analytics, machine learning (ML), and the internet of things (IoT) could help it achieve its climate vision and also save lives and properties.

The absence of comprehensive, intelligent flood alert and early warning systems in urban and rural settings, especially in developing and under-developed nations, poses a considerable challenge. Despite its extensive rainforest coverage, Brunei Darussalam, like the rest of Borneo Island, has been facing the impacts of climate change over recent decades. As a nation vulnerable to coastal flooding, intensified by climate change, Brunei's scenario highlights a broader global issue. The slow pace of manual data analysis, prone to human error, inadequate coordination among public agencies, and insufficient infrastructure exacerbate the risk of flooding. Moreover, the need for more effective flood disaster management strategies and the limitations of traditional flood modeling techniques, such as numerical and physical data-driven models, emphasize the need for innovative solutions. These conventional methods have been criticized for ineffectiveness in short-term prediction due to inaccuracies, complexity, computational demands, and lack of robustness.

This research proposes the development of an intelligent flood risk management system that utilizes high-precision IoT sensors and integrates Big Data analytics with Machine Learning to enhance flood prediction accuracy. The aim is to provide a conceptual framework for a decision support system based on real-time data analysis. The study's objectives include a thorough review of existing literature and technologies relevant to intelligent flood preparedness and prevention systems. It also proposes the creation of an advanced alert and early warning system that employs predictive Big Data analytics, machine learning, and IoT technologies. This conceptual design is expected to significantly improve flood prediction accuracy by utilizing real-time data from intelligent IoT sensors and establishing a system that can effectively communicate and manage flood-related data. The proposed system aspires to identify patterns and insights that could enhance future

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flood resilience, mitigate potential damage, and save lives and properties through more accurate predictions by analyzing extensive datasets from past flood events.

2. Background

2.1. Big Data

The concept of big data has been endemic within computer science since the earliest days of computing. Big Data originally meant the volume of data that could not be processed (efficiently) by traditional database methods and tools. Each time a new storage medium was invented, the amount of data accessible exploded because it could be easily accessed. Even if we have the storage capacity to store our data, the available data analytics tool cannot handle data; it is still Big Data. This has led to a growing interest in developing tools capable of automatically extracting knowledge from data [15]. Data are collected and analyzed to create information suitable for making decisions. Hence data provide a rich resource for knowledge discovery and decision support. A database is an organized collection of data so that it can easily be accessed, managed, and updated [16]. "We define "Big Data" as the amount of data just beyond technology's capability to store, manage and process efficiently. These imitations are only discovered by a robust analysis of the data itself, explicit processing needs, and the capabilities of the tools (hardware, software, and methods) used to analyze it" [17].

2.2. Big Data Analytics

Big Data Analytics refers to the process of collecting, organizing, and analyzing large data sets to discover different patterns and other useful information. Big data analytics is a set of technologies and techniques that require new forms of integration to disclose large hidden values from large datasets that are different from the usual ones, more complex, and of a large, enormous scale. It mainly focuses on solving new problems or old problems in better and effective ways [18].

Big Data Analytics is categorized into four primary types: Descriptive Analytics shows current data trends; Diagnostic Analytics investigates the causes of those trends; Predictive Analytics forecasts future events using historical data, data mining, and AI; and Prescriptive Analytics suggests actions based on predictions. This study will concentrate on utilizing Predictive Analytics for its capacity to predict future situations.

2.3. Big Data Analytics in Disaster Management

Big Data and crisis analytics are a term used to refer to the analysis of large data sets for disasters. Due to advances in ICT and processing of large data sets, the ability to respond to disasters is at an inflection point, big data tools can today process large amounts of crisis related data (e.g., user-generated, sensors) to support more effective disaster response [19,20].Big Data analytics hold enormous potential for disaster management.

Disaster management encompasses four critical, consecutive phases: preparedness, mitigation, response, and recovery. Effective disaster management hinges on the efficient handling and management of disaster-related data well before an event occurs [21]. This strategy involves the analysis of both historical data and future projections, including daily access to information on rainfall, temperature, drought, and streamflow, to forecast potential disasters. Through such analysis, it is possible to develop a well-rounded and thorough plan for mitigation, control, and prevention well in advance. This proactive approach can significantly diminish the risks associated with disasters, including injuries, health consequences, damage to property, loss of life and services, as well as the social, economic, and environmental impacts [6].

Recent applications of Big Data and information and communication technologies (ICT) in disaster management include:

- Remote sensing for monitoring natural and human- disasters.
- Governments using smartphones and mobile apps to disseminate disaster warning information to the people who are close to the possible affected areas and guide them to shelters or safe locations.

- GPS systems providing governments and humanitarian organizations with the up-to-the-minute traffic information, e.g., road conditions, so that they can promptly deliver emergency supplies to victims.
- Crowdsourcing for collecting direct feedback from injured victims in disasters, e.g. about their physical conditions, and suggest possible locations for treatment.
- Social media for sharing information about people's locations during disasters so that rescue teams can easily locate victims.
- Cloud platforms for receiving, maintaining, and sharing disaster-related information, such as locations, quantities, and description of emergency resources, so as to facilitate disaster response.

2.4. Internet of Things (IoT) in Disaster Management

The Internet of Things (IoT) plays an integral role in various aspects of our daily lives, spanning entertainment, home automation, automotive technologies, healthcare, industrial sectors, sports, and more [22]. The widespread availability of IoT technologies simplifies routine tasks, enhances interactions with our environment, and expands our social connections with people and objects [23]. The deployment of sensors to monitor conditions that may lead to disasters is a well-established practice. However, advancements in cloud computing, high-speed wireless networks, sensor technology, and data analytics have given rise to sophisticated, interconnected, and real-time systems known as the Internet of Things (IoT). This technology is particularly suited to disaster management applications, where sensors can provide timely warnings about various hazards, demonstrating the critical role IoT plays in preventing and responding to emergencies [19,24].

To date, extensive research has been carried out focusing on various aspects of flood management, including data collection, monitoring, prediction, detection, early warning systems, and data visualization, all with the goal of reducing the impact of floods through early detection. The advent of advancements in information and Internet technologies presents a significant opportunity to bolster disaster management efforts [25]. The Internet has evolved through various phases and has been referred to by several names, including the "Internet of Everything," "machine-to-machine (M2M) communication," "physical computing," and "ubiquitous computing." Currently, the Internet of Things (IoT) stands out as a pivotal technology being explored to enhance disaster management, particularly in the realm of flood management [12]. IoT technology offers considerable advantages for monitoring, tracking, controlling, and sensing environmental conditions through the utilization of real-time data.

2.5. Machine Learning (ML) in Disaster Management

There is a growing popularity and need for the use of Artificial Intelligence (AI) techniques that bring large-scale natural disaster data into real practice and provide suitable tools for natural disaster forecasting, impact assessment, and societal resilience. This in turn will inform on resource allocation, which can lead to better preparedness and prevention for a natural disaster, save lives, minimize economic impact, provide better emergency respond, and make communities stronger and more resilient [1,26].

To mimic the complex mathematical expressions of physical processes of floods, during the past two decades, machine learning (ML) methods contributed highly to the advancement of prediction systems providing better performance and cost-effective solutions [27,14].

3. Related Works

An integrated strategy for early snowmelt flood warning was proposed by Shifeng Fang et al.[28], and it focused on geo-informatics (remote sensing, GIS (geographic information system), GPS (global positioning system), Internet of Things (IoT), and cloud services. The IIS (Integrated Information System) was created as a first stage, and it could provide users with services and essential functions. The results showed that snowmelt flood simulation and early warning procedures greatly benefited. The limitation of this study includes IoT operationalization, standardization, and

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information system compatibility. An embedded system focused on machine learning and the Internet of Things was introduced by Prachatos Mitra et al. [29] to predict the possibility of flooding in a river basin. In order to collect data, the model used a modified mesh network connection geared at Wireless Sensor Networks (WSNs), and it also used GPRS to transport data over the internet. An artificial neural network was used to evaluate the datasets (ANN). The analysis results attached showed a significant improvement above the current techniques. Anbarasan et al. [30] proposed the detection of flood disaster system based on IoT, big data, and convolutional deep neural networks. Their proposed system outperformed the existing systems in precision, accuracy, recall, F-Measure, specificity, and sensitivity. The drawback of the proposed system is the use of short-range sensors.

Moreover, Chen et al. [31] introduced an edge intelligence-empowered flooding process prediction using the Internet of things in a smart city using a bidirectional gated recurrent Unit (BiGRU) multi-step flood prediction model with an attention mechanism. They used historical data of Xixian City, Henan Province, China, collected by the IoT from 2011-2018. Through numerical studies, the proposed BiGRU model for short-medium prediction exhibits comparable performance with the support of IoT systems. However, investigating long-term flood prediction remains difficult. Khalid et al.[32] presented an advancing real-time flood prediction in large estuaries: iFLOOD, a fully coupled surge-wave automated web-based guidance system, which provides water level forecast in the Chesapeake Bay for a lead-time of 84 h twice a day displayed on a web-based public interface. Sandeep et al. [33] developed a social, collaborative Internet of Things (IoT)-based smart flood monitoring and forecasting architecture that incorporates big data and high-performance computing (HPC). IoT devices' key flood-causing and preventive features are sensed and computed utilizing big data and HPC processing. The K-mean clustering technique predicts the current state of flood and flood rating in any area, but the Holt-Winter forecasting approach forecasts the flood. The limitation of the proposed system includes using a few sensors and fundamental inference methods instead of advanced approaches like stochastic processes, etc.

4. Methodology

This research primarily utilizes a literature review and analysis of current flood disaster management frameworks to guide its methodology. Initially, the study will examine various existing frameworks for managing flood disasters and identify their limitations and challenges. In the subsequent phase, through an extensive literature review, the study aims to pinpoint the specific problems and hurdles faced by current flood risk management systems. Building on this analysis, the research will then propose a new, intelligent framework for flood disaster management. The centerpiece of this study is the development of an innovative smart flood risk management system, specifically designed to tackle the identified challenges of existing frameworks. The system will employ Predictive Analytics, powered by Machine Learning and IoT technologies, for its execution. The focus of the research is largely on the conceptualization and design of a pioneering prototype for flood management. The prototype's implementation will be conducted on a modest scale initially. Upon successful testing and refinement of the prototype, the study plans to design and deploy a finalized version of the system for broader application.

In the initial phase, IoT-based water monitoring sensors will be deployed within a laboratory setting using Raspberry Pi technology, with connectivity established to a cloud server. These sensors are designed to collect data at one-minute intervals, leading to the accumulation of substantial datasets over time, characteristic of Big Data. After accumulating data for several days, this historical data will be harvested for the purpose of training and evaluating the performance and accuracy of various machine learning models. In the subsequent phase, these IoT sensors will be strategically placed along the rivers, dams, and coastal regions facing the South China Sea in Brunei. This setup will facilitate real-time monitoring of the sensors. The concluding phase involves the comprehensive installation of IoT sensors across multiple critical locations, with their data being relayed to cloud servers through platforms such as Microsoft Azure or Amazon Web Services, serving as a conduit between the IoT devices and the server infrastructure. At this juncture, machine learning models, already trained, will be deployed to the cloud server to enable flood prediction capabilities and issue

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early warnings based on a high likelihood of flooding. To implement this system on a grand scale, collaboration with government bodies responsible for environmental preservation and emergency response is essential. This partnership will aim to identify flood-prone zones accurately. Residents in these identified areas will have their email addresses and phone numbers registered on the system to ensure they receive prompt alerts via email and SMS in the face of impending flood risks.

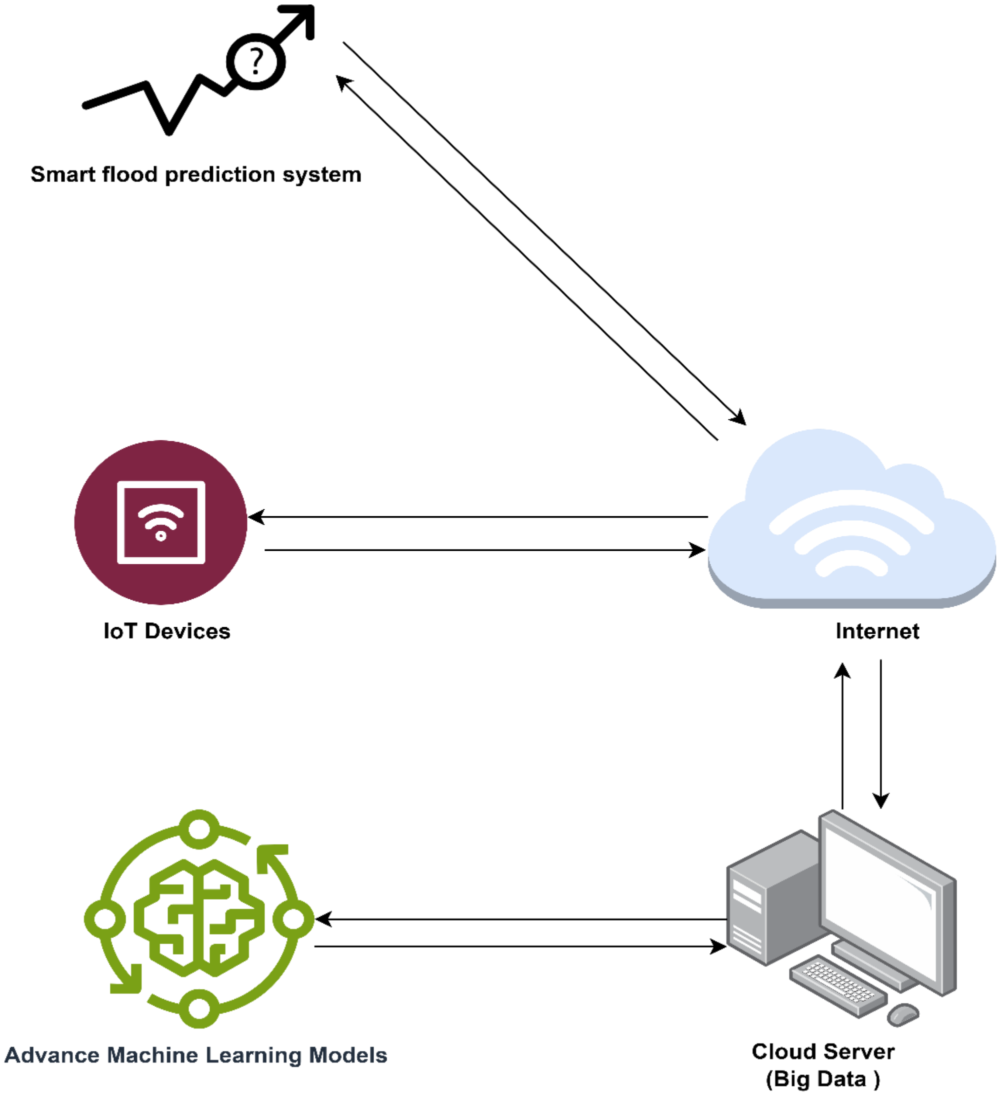

Figure 1. Proposed smart flood risk management system.

5. Conclusion and Feature Work

In conclusion, this research presents an innovative, intelligent flood risk management framework for Brunei Darussalam that is aligned with the climate resilience and adaptation goals of Vision 2035. By harnessing the capabilities of big data analytics, machine learning algorithms, and Internet of Things sensors, the proposed system aims to significantly enhance real-time flood forecasting and early warning capabilities compared to traditional flood modeling techniques.

Implementing this intelligent system prototype and its eventual large-scale deployment has the potential to drastically reduce the impact of floods through accurate predictions and alerts. It marks an essential step for Brunei in leveraging advanced technologies to boost preparedness and minimize damages from increased flooding resulting from climate change. The system's ability to analyze volumes of sensor data and identify predictive patterns can inform long-term strategies for climate adaptation.

While the initial prototype will be limited in scope, expanded collaborations with key government agencies such as the Brunei Darussalam Meteorological Department, the Department of Environment, Parks, and Recreation, and the Water Resources Unit within the Public Works Department will facilitate its broader installation across flood-prone regions. This will enable real-time monitoring, swift emergency response, and targeted warnings to vulnerable communities. In the future, we aim to refine the system based on real-world testing and make it an integral part of Brunei's climate resilience efforts. This project underscores Brunei's commitment to pioneering sustainable solutions aligned with its vision for a climate-adaptive future.

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