Urban Digital Twins for Flood Management and Forcasting in Thailand

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***Abstract*—Thailand has a long history of severe flood events, but the recent disaster in Hat Yai marks one of the most extreme yet, with the region experiencing its heaviest rainfall on record. The ongoing disaster underpins the critical need to improve Thailand's flood-management systems. This document critically evaluates the existing flood-monitoring approaches in the country, which include physical sensor networks (rain gauges and weather radars) and hydrological simulation tools such as AHP and SWAT. Although these systems provide technically robust and reliable data, they have slow update cycles, operate in isolation, and lack access to other crucial data sets during flood events. Urban Digital Twins are dynamic virtual replicas of physical cities or urban areas and they offer a promising solution. This paper argues for the adoption of Digital Twins in Thailand by integrating existing flood-forecasting and management systems with alternative datasets, such as crowdsourced data, to create a unified platform that enhances proactive response and decision-making during crises. However, significant limitations remain, particularly in lower socio-economic urban areas like Hat Yai, where technical infrastructure is not as developed as in Bangkok. To address this, the paper outlines future directions using low-cost IoT infrastructure and Synthetic Aperture Radar (SAR) technology to mitigate the financial barriers to implementing a Digital Twin.**

I. Introduction

Thailand experiences a monsoon-dominated climate and regularly suffers from severe flooding. In recent news, the southern province of Hat Yai has faced its most devastating rainfall yet [1], resulting in over 145 deaths, widespread displacement and long-term economic disruption. At the national scale, the 2011 mega-flood in Bangkok remains one of the most catastrophic disasters in Thailand's modern history [2], with more than 800 people killed and over 14,000 businesses affected. These events highlight an urgent need for more robust and proactive flood-monitoring and management systems. As the current situation in Hat Yai unfolds, identifying stronger predictive and organisational tools has become more critical than ever. Over the past decade, rapid urban expansion and intensified agricultural land use have magnified exposure and vulnerability to floods, particularly as growing cities expand without sound engineering practices or proper maintenance of mitigation infrastructure[2]. Although Thailand has implemented several flood-forecasting and management systems, ranging from physical sensor networks to hydrological simulation models, these systems remain constrained by slow update cycles, limited integration and narrow data-collection scopes. Most existing models focus primarily on environmental measurements and lack the real-time, multi-layered data required for dynamic decision-making during rapidly evolving flood events. These challenges reinforce the need for Thailand to modernise its flood-monitoring and forecasting ecosystem. Digital Twins (DTs), virtual replicas of physical environments that integrate real-time data, dynamic simulation, forecasting and decision-support tools, are emerging globally as powerful platforms for urban climate resilience. This paper evaluates the potential of Digital Twins in Thai cities as a next-generation flood-management system capable of addressing the limitations of current models. It examines the use of alternative datasets beyond physical environmental measurements to enable real-time situational awareness and discusses how DTs can provide a unified platform for currently fragmented and disorganised teams responding to flood crises.

II. Related Works

In this paper, we will be covering four types of literature. The first type of literature covers the existing flood forecasting models currently being used in Thailand, drawing on the technology that they use and the limitations it has. This is important as it sets up the base layer for a Digital Twin implementation while looking at its limitations and how DTs are able to make up for it. Chitwatkulsiri and Miyamoto discuss the current technologies used in Thailand such as rain gauges and weather radars but also their limitations and their incapability for real-time data and sparse distribution[3]. Sakmongkolijit et al provide insights into how flood susceptibility maps are made in a study on the Chi River Basin[4]. Prasanchum and Pimput use SWAT modelling to reliably simulate streamflow. Both these studies have strong technical capabilities, providing data that could be the foundation for a DT implementation[5].

Second type of literature is to do with alternative sources of data that a Digital Twin can utilise such as crowdsourced data. Adam et al. explores gathering data using citizen sensors and its critical role in geoinformatic disaster management[6]. Yuan and Fan's study looked at Hurricane Harvey in Texas, specifically at how the credit-card transaction data and the patterns that emerged facilitated in identifying worst-hit areas[7]. This ties into the idea of using alternative sources other than environmental data to refine the information available about disasters that unfold.

Our third type of literature looked at a system that was a partial DT already. Chitwatkuisiri et al's study in Sukhumvit, Bangkok looked at its drainage system and how its real-time procedures and analysis showed promising DT implementation[8]. It was missing one crucial aspect, however: integration. Bunwan et al's study showed that the disorganisation of different parties involved in a flood in Nakhon Si Thammarat, highlighting the need for a single, unified platform to help speed up disaster response times[9]. Emerging work about Federation Learning by Mouhsine et al. could help solve fragmentation of collaboration by providing a method to share data securely and privately[10].

Lastly, this type of literature revolves around socio-economic vulnerable communities and regions where Sae-jern et al has identified Hat Yai to be particularly vulnerable[11]. We discussed the implications of this and future research works in areas such as low-cost infrastructure [12] or satellite technology where physical infrastructure is not needed [13].

III. Critical Analysis

There are a number of flood-monitoring models that Thailand currently relies on for flood forecasting and management, ranging from the simple physical sensor networks to hydrological simulation tools. While these models provide high accuracy, reliable information in their specific basins and conditions, they are limited by slow update cycles, sparse sensor coverage and a lack of integration between agencies. In this section, we critically evaluate existing Thai flood-management systems and argue for how Digital Twins can be built on top of these existing systems to extend to be a unified, real-time decision-making platform. We examine the drawbacks of implementing a DT and how its deployment affects different socio-economic contexts.

A. Current Flood Forecasting Systems

Thailand currently employs a range of traditional flood-monitoring systems that combine physical sensor networks and hydrological simulation tools. Precipitation is a crucial data value that is taken by two measurement tools: rain gauges and weather radars. Rain gauges are ground-level measurements of a circular region of 20cm while weather radars provide high-resolution areal precipitation estimates (about $1km^2$) [3]. Bangkok's Department of Drainage and Sewerage of the Bangkok Metropolitan Administration leverages these tools in a radar station operating to monitor and track storms. While these systems deliver reliable data under normal conditions, they are limited by slow update cycles and operational delays. Weather radars are only capable of detecting a storm with a short lead time of a few tens of minutes before heavy rainfall occurs, reducing the time for proactive flood response. Another limitation of this system is the sparse distribution of rain gauges, particularly among more difficult terrain such as mountain ranges, meaning that we could be missing out on important data that could be influencing floods.

Using the various data gathered about the physical environment, Thailand has developed multiple predictive modelling approaches capable of simulating flood behaviours within river basins. One such study on the Chi River Basin, Thailand, produced a validated high-accuracy flood susceptibility map [4]. An Analytical Hierarchical Process was used to gain hydrogeomorphological parameters such as soil type, drainage sensitivity etc. and ranked to provide the flood susceptibility map. They were then able to validate this generated map with satellite-based flood maps using binary-classification. Similarly in the Loei Basin, Northeastern Thailand, used models such as SWAT (Soil and Water Assessment Tools) that can reliably simulate streamflow and flash-flood behaviour. Given that Loei has very complex terrain, the study applied daily SWAT simulations to analyse streamflow validated with R^2 and PBIAS values. The study found that as traditional agriculture was replaced with other types of plantations (such as sugar cane and rubber), the levels of streamflow changed, increasing the risk of flash floods [5].

Although these systems demonstrate strong hydrological accuracy and reliability, their usefulness in real-time decision making is limited. Most rely heavily on physical and environmental attributes while overlooking societal contributions and socio-economic factors that influence actual flood impacts. Additionally, these models are typically deployed independently, operating in isolation within specific research organisations meaning that information gathered is not exchanged or available on one platform. As a result, Thailand‘s flood management ecosystem is technically robust but lacks real-time capabilities and integration. These limitations create an important opportunity for Digital Twins to unify existing tools and ingest all the data gathered from them to address those limitations.

B. Alternative Data Sources

While Thailand's traditional hydrological models provide insights into environmental values, effective flood management requires insights into not just environmental impacts but societal impacts. A DT aims to not only provide a representation of hydrological processes but also behaviours and patterns in communities as they develop. This makes integration of alternative and unconventional datasets crucial.

Nabil Adam et al. explored the potential of citizen sensors to enable geoinformatics in disaster management contexts, where patterns can be revealed in analysing data collectively [6]. A study done in the context of Hurricane Harvey, 2017 in Texas brilliantly used location-based and credit-card transaction data in spatial analyses to determine the worst affected areas, enabling an appropriate response to those in need[7]. They used fluctuations in CCTs, comparing the data in drugstores and grocery stores to a baseline that was established 3 weeks before Harvey and defined that hardest disaster impacts to be where there was a drop of fluctuations.

Nabil Adam et al, discusses crowdsourced information in the context of spatial computing, where heterogeneous geospatial data streams are integrated to support real-time situational awareness [6]. This perspective supports the foundations of DT and its potential in Thailand, a platform where it is continuously updated to reflect multi-layered data as it evolves during a crisis. By building a DT on top of the existing physical infrastructure (sensor networks, radars, etc.), Thailand can incorporate richer datasets to feed into the DT and become a comprehensive platform for coordinating emergency response, resource allocation and management.

C. Urban Digital Twins and Integration

Thailand's existing flood-modelling systems are technically robust but operate independently, making it challenging for efforts to be coordinated. A Digital Twin has the potential to unify these tools into a unified and continuously updated platform. A study done in Sukhumvit shows promise of real-time urban drainage procedure, a system that was built once it was realised that the current urban drainage systems were not capable anymore to cope with climate-change-driven rainfall. Utilising the rain gauge system around Bangkok, they were able to make a procedure that consisted of acquiring rainfall data, rainfall run-off modelling and flood inundation mapping[8]. Although designed as a drainage-response mechanism, this system demonstrates key characteristics of an urban DT, with underlying infrastructure already in place. It's main limitation, however, is its inability to integrate with other models.

The broader institutional context further complicates flood management. A study done in Nakhon Si Thammarat Province identified that the collaboration between multi-agencies was fragmented [9]. There was a lack of comprehension and understanding between government agencies, private sector agencies, civil society agencies, local administrative organisations resulting in delayed responses. Without a shared data platform or unified situational awareness, responses remained reactive responses rather than proactive. Introducing a DT can provide a common platform for all involved stakeholders where updated and synchronised information is available.

Emerging approaches such as Federation Learning can also be integrated into our DT as it allows models to be trained without centralising the data [10]. By enabling machine-learning models to update locally without centralised data, it can ease concerns over data privacy, security and ownership. This method provides a way for staff, response members and agencies to share model updates instead of raw, personal or sensitive data. Although this is a method has not been deployed yet, this method demonstrates how DTs can facilitate coss-agency cooperation even in data-sensitive environments.

D. Socio-Economic Limitations

Despite their incredible potential, Digital Twins face a practical challenge when it comes to implementation in high-socio economically vulnerable regions in Thailand. For example, Sae-jern et al. has identified Hat Yai, a historically flood prone city, to be economically vulnerable and lacking the same level of technological infrastructure as Bangkok[11]. This makes DT implementation challenging physically and financially without substantial support from the government. Moreover, Digital Twins require high-frequency, high-resolution data output which is not consistent for regions across the country, as most studies are specific to their basins and environment.

IV. Suggested Future Work

A. Integrated Framework

A major barrier that has been identified above is the fractured nature of data ownership and communication between government agencies and other bodies of organisation involved in the disaster mitigation. It is important that future work should focus on developing a national interoperability framework that has real-time updates of data, space for sharing and accessing information and firm collaboration structures. Testing out projects in high-risk basins such as Hat Yai to validate this framework in a real environment is an essential step forward towards urban Digital Twins.

B. Low-cost Sensor Networks

Additionally, future research should examine the feasibility of low-cost sensor networks to support provinces with limited technical capacity. For example, Kenya was able to successfully implement a low-cost IoT sensor network built on Raspberry Pi microcontrollers leading to a 40% reduction in flood-warning times [12]. Exploring a similar approach in provinces like Hat Yai can provide both a finance-friendly and technical pathway to integrating Digital Twin architectures with more flood-prone regions.

C. SAR Technology

This leads into another foundational challenge of Digital Twins and their need for consistent, high-resolution and multi-layered data. Future research should consider integrating SAR (Synthetic Aperture Radar) satellite imagery as it offers significant potential for enhancing the data ecosystem [13]. SARs are able to penetrate cloud cover and current climate and provide high-resolution images which Jiang and Zeng have used for flood mapping. This is particularly crucial for the development of DTs in regions more economically vulnerable like Hat Yai as it does not require a physical infrastructure to be built into the city. The data provided by these powerful satellite imagery also fills in observational gaps, strengthening DT capabilities and forecasting abilities.

V. Conclusion

Thailand's increasing vulnerability to flooding due to heavy rainfall, rapid urbanisation and expanding agricultural farms urgently highlights the critical need for a more integrated, data-driven system of urban resilience. While current existing flood-forecasting models, such as AHP-based susceptibility mapping and SWAT-driven simulations of streamflow, contribute high-resolution and reliable data for flood-forecasting, showcasing Thailand's strong technical capabilities. However, real-time data limitations with unvaried data sources and lack of integration between disaster relief organisations show that we need a robust digital infrastructure to help provide the right response and decision making proactively. This paper demonstrates Urban Digital Twins is able to offer a promising pathway to overcome the challenges by enabling real-time monitoring, dynamic simulation, and scenario-based decision-making tailored to complex urban environments like Hat Yai. However, the successful implementation of Digital Twins requires far more than technological adoption. Digital Twins require reliable, highly accurate,multi-sourced data, long-term collaboration between departments and organisations, and digital investment in both physical sensing networks and other modelling technologies. It is essential for the fist step towards implementing Digital Twin systems in Thailand is to first research the digital infrastructure of cities, one who have a high socio-economic vulnerability such as Hat Yai. This paper discusses two ways in which the technical capabilities gap between Hat Yai and Bangkok can be closed. One being research into low-cost IoT sensor networks and the other other using technology such as SAR where implementing physical infrastructure is not required while still being able to provide high-quality data. Overall, Digital Twins should not be viewed as a replacement for Thailand's existing modelling expertise, but rather as a coordinating layer that utilises this knowledge and expands further into features that will greatly benefit Thai people and their flooding problems. By prioritising interoperable data systems and collaborative governance, Thailand will be able to take significant steps into having a nationwide system, reducing impacts caused by these disasters.

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