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COMPARATIVE ANALYSIS OF STORMWATER MANAGEMENT TECHNIQUES: CASE STUDY OF MALAYSIA, JAPAN AND THE NETHERLANDS

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ABSTRACT

Climate change and rapid urbanisation lead to the reduction of green spaces due to infrastructure development to meet the growing population's demands. As a result, the increase in impervious surfaces and inadequate drainage systems leads to flooding problems. As one of the tropical countries with heavy annual precipitation, Malaysia has gained attention for global warming issues. The purpose of the study is to analyse stormwater management practices in several developed countries, such as the Netherlands and Japan, compared to Malaysian practices. Case studies were extracted from the literature findings, allowing the adoption and utilisation of practices from developed countries in Malaysia. The research revealed that both case studies, Tokyo's G-Cans Project and the Netherlands' Delta Works, implemented several techniques that offer significant potential for flood mitigation projects in Malaysia. However, the data reveal that previous pavements, swales, and detention ponds serve as stormwater infrastructure in all three nations. Both developed countries have encouraged the implementation of green roofs, but Malaysia continues to face resource limitations and new exposure issues. The Malaysian government should contemplate expanding the number of monitoring stations to enhance data accuracy and emulate Japan's innovative use of artificial intelligence (AI) for future flood prediction. Current issues in Malaysia, such as sinkhole incidents and flooding, require the government to act efficiently and regularly monitor. In summary, Malaysia still needs to catch up in stormwater management and flood mitigation, necessitating the adoption of practices from advanced countries for improved future development.

Keywords: climate change, G-Cans Project, Japan, Malaysia, Netherlands, SMART Tunnel, stormwater management

1.0 INTRODUCTION

The United Nations estimates that more than 55% of the world's population currently resides in urban areas, with a projected increase to 68% by 2050 (Kumar et al., 2021). People have repurposed the abundance of urban green spaces for the construction of housing, industrial facilities, transportation networks, and various other urban infrastructure projects. Cities face mounting demands to adjust to swiftly evolving environmental circumstances and keep pace with socio-economic progress (Zhang et al., 2022). The shifting growth trend has led to an extraordinary rise in developed land due to population and economic growth. Urban expansion in Malaysia has increased by nearly 30–40% over the last three decades (Hasan et al., 2019). The result has been an increase in non-porous land surfaces and insufficient drainage infrastructure, impeding the proper functioning of hydrological systems, ecological processes, and community well-being (Fang et al., 2021; Wu et al., 2021; Yang et al., 2021).

Cities are susceptible to water-related risks like droughts, water pollution, and flooding (Zhang et al., 2022). Urbanisation further alters the global water cycle due to climate change, leading to many water-related issues, including water scarcity and flood damage (Song, 2022). (Starzec et al., 2020) support this, stating that local urban flooding is an increasingly common phenomenon in densely populated areas. They are caused by heavy precipitation, whose intensity exceeds the capacity of municipal drainage systems to convey them hydraulically. Besides, increasing the composition and weight of urban litter are the primary environmental issues that demand attention. The blockage of drains and waterways results from unrestricted human activity, including the development of buildings near rivers and the unregulated disposal of debris (Mohamad Yusoff et al., 2018). Environmental awareness and societal views play a crucial role in this.

Over the past two decades, Malaysia has received considerable attention in environmental research, and its repercussions are due to its substantial rainfall patterns and warming (Tang, 2019). Flash floods are particularly worrisome for residents and workers in metropolitan cities such as Kuala Lumpur. In an urban area with a high population density where land adequate for holding water is limited, a flash flood is defined by poor drainage management during heavy rainfall (Misni & Shahfuddin, 2017). Moreover, the threat of flooding has caused more revenue losses than any other hazard affecting cities (Assaf & Assaad, 2023). Therefore, it is crucial to implement effective flood mitigation measures and stormwater management techniques in the country, as they not only enhance the ecosystem but also lessen the negative impacts on communities.

This study aims to identify Malaysian stormwater management practices and compare them to those of other countries, such as Japan and the Netherlands, with significantly better stormwater management practices. Due to its geographical location, which is prone to natural disasters, Japan is recognised for its use of advanced technology and better prevention. At the same time, the Netherlands is known for its flood management. The findings can be used as a reference to adopt or adapt best practices that suit the local context of Malaysian cities.

2.0 LITERATURE REVIEW

To prevent urban flooding, adequate drainage systems for collecting and transporting stormwater are required. The SWM concepts emerged as early as the 1960s, examining the quantity and quality of urban stormwater in response to land use and climate change (Bibi et al., 2023; Song, 2022). In 1977, the United States proposed best management practices (BMP) as the first preventive plan to describe a systematic strategy or practice intended to prevent pollution (Fletcher et al., 2015), and this progressively transformed other developed nations to utilise other stormwater management concepts such as Low-Impact Development (LID), Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage System (SUDS), Best Management Practices (BMPs), Sponge City and Blue-Green Infrastructure (BGI). Nonetheless, all these concepts aid in managing stormwater to reduce surface water runoff sustainably. As previously mentioned, the study aims to compare the stormwater management practices implemented in Malaysia and other regions, and the sub-section below will further explain the case studies.

2.1 Malaysia Urban Stormwater Management

Malaysia is a tropical country that experiences significant rainfall throughout the year. Inundations are the most prevalent natural disaster in Malaysia. Malaysia has encountered a variety of climatic and weather occurrences, such as El Nino 1997 and La Nina in 2011 and 2012, which resulted in severe droughts and floods, respectively. About 9%, or 29,800 km2, of Malaysia's landmass, is susceptible to flooding (Diya et al., 2018; Mohamad Yusoff et al., 2018; Saleh Dutsenwai et al., 2015).

Conventional stormwater management in Malaysia has been comprised of the rapid conveyance of runoff via the sewage system to prevent inundation (Abdul Khadir et al., 2023). The Malaysian government has published the Urban Stormwater Management Manual for Malaysia, or MSMA (DID, 2000), to acknowledge the necessity for a change in stormwater handling. This manual includes a particularly present innovation in stormwater management, the control-at-source strategy. According to MSMA 2nd Edition, control at source refers to the runoff quantity control requirements for construction or redevelopment projects of any size. "The post-development peak flow of any ARI at the project outflow must be below or equal to the before-development peak flow of the associated ARI". Effective in 2001, every new project in Malaysia must adhere to an amendment that mandates the use of sewage treatment devices or infrastructure to regulate the amount and the quality of stormwater runoff (Zakari, 2016). A new MSMA 2nd Edition manual was published by DID, which enforced the execution of Best Management Practices (BMPs). The manual offers a comprehensive guide to suggested procedures for resolving current obstacles and issues.

According to (Wan et al. et al., 2017), the Integrated Flood and Rainfall Management (IFFRM) is a fully automated system that operates by a combination of life, telemetered gauged data from the Department of Irrigation and Drainage's (DID) personal InfoBanjir database, spatial rainfall radar data, and Numerical Weather Prediction (NWP) rainfall forecasts from the Malaysian Meteorological Department. This system aims to aid in emergency response. About 335 telemetric rain gauges and 208 telemetric water level stations are installed throughout Malaysia (Muhd Zain et al., 2020). Additionally, the government, in collaboration with numerous agencies, has initiated the "River of Life" project, which concentrates on the Klang River, which spans the most intensely populated region (Yeo et al., 2023). The river encountered intensified inundation during storm seasons and became highly polluted due to accelerated development.

Furthermore, to control and remove stormwater in urban areas, Malaysia offers a diverse selection of gross pollutant traps (GPTs) specifically designed to catch litter during irrigation conveyance (DID, 2012; Malik et al., 2019). Detention ponds, on-site detention (OSD), perforated pipe systems, porous pavements, and infiltration utilities such as swales and trenches are among the Low Impact Development (LID) techniques that Malaysia has implemented (Misni & Shahfuddin, 2017; Sidek et al., 2006). Kuala Lumpur's Stormwater Management Road Tunnel (SMART) is an additional captivating stormwater infrastructure that effectively addresses flash flood issues. The city's most susceptible areas are protected from floodwater from the Upper Klang Ampang catchment by the 9.7km tunnel, which consists of 30 hydrological stations, floodgates, a flood warning system, a retention pond, and a mitigation pond. The tunnel begins just before the meeting point of the Klang and Ampang Rivers (Azhar et al., 2021; DID, 2008; Ramly et al., 2020).

Fig. 1: SMART Tunnel in Kuala Lumpur City Centre
(Source: https://themalaysianreserve.com/2022/12/10/smart-tunnel-closed-in-preparation-for-flood-operations/)

According to the Economic Transformation Plan, DBKL intends to increase its tree planting initiatives to 100,000 trees, with a special focus on trees that provide broad coverage to give an appearance of green corridors (Kuala et al.– City Planning Department, 2024). Furthermore, the Malaysia Budget 2023 allocates RM15 billion for the Flood Mitigation Plan until 2030, which includes the construction of Sabo Dam, the establishment of a dual-function retention reservoir, and the National Disaster Management Agency's (NADMA) obligation to ensure preparedness in the event of flooding.

2.2 Japan Urban Stormwater Management

According to the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan is prone to natural disasters, including typhoons, earthquakes, and volcanic eruptions. As mentioned by (Uchiyama et al., 2023), Japan is bounded by oceans and has the world's sixth-longest coastline and twice as much precipitation as the global average. Approximately 70% of the land area is mountainous, and rivers are short and steep. Several studies have been carried out to investigate the impact of the subsequent flood events related to Northern Kyushu Heavy Rain in 2017, Western Japan Heavy Rain in 2018, and Typhoon Hagibis in 2019, which destroyed broad regions in Japan. This event has raised awareness about avoiding or reducing flooding losses.

The measurement of rainfall serves as the primary foundation for urban flood risk management, guiding the design of runoff management infrastructure, the preparation of evacuation plans, and the execution of numerical simulations. In 1974, the Japan Meteorological Agency initiated the Automated Meteorological Data Acquisition System (AMeDAS), an automated meteorological observation system, to observe regional meteorology and utilise the data for meteorological disaster preparedness (Shibuo & Furumai, 2021). The Tropical Rainfall Measuring Mission (TRMM) (Kummerow et al., 1998)and the Global Satellite Mapping of Precipitation (GSMaP) (Kubota et al., 2006) are examples of satellite-borne observations of rainfall. The possibilities for handling risks, especially flood prevention or identifying elevated water bodies, including floodplains, arise when satellite products are combined with rain gauges (Acierto et al., 2018).

Real-time prediction of the commencement and location of sinking areas is a significant challenge in urban stormwater management. Hence, in collaboration with the Tokyo Metropolitan Sewerage Service Corporation and Hinode, Ltd., Meidensha Corporation has created the "smart manhole cover" to address the ground-level area. Using the real-time water level information from a smart manhole cover results in early signs of pluvial flooding, ensuring the safe evacuation of the main underground area (Shibuo & Furumai, 2021).

Lastly, the G-Cans project (Fig. 2), the Tokyo metropolitan area's outer underground discharge channel, is the world's largest underground floodwater diverting facility and a well-known example of stormwater management in Japan. The project contains a storage tank with 78 pumps and five gigantic silos, as well as a 6.5 km-long connected tunnel (Bobylev, 2007; Chang et al., 2018). Modern remedies for comprehensive flood control are recognised, including rainwater retention such as swales, green roofs and infiltration as critical components (Saraswat et al., 2016).

Fig. 2: The G-Cans project's water storage tank is supported by 59 pillars and stands at a height of 25.4 meters.

(Source: https://www.water-technology.net/projects/g-cans-project-tokyo-japan/)

The engineering and scientific process of creating intelligent machines is known as artificial intelligence (AI). In recent years, there has been a significant increase in attention given to the potential of AI technologies for combating climate change (Jones et al., 2023). Japan is always one step ahead in flood mitigation. According to (UNESCO, 2021), the primary objective of Japan's Artificial Intelligence Technology Strategy is to "implement resilience-oriented urban planning through AI" in order to enhance the emergency response by decreasing the burden on disaster management agencies' staff in regards to gathering and analysing information and by offering early warning of a forthcoming catastrophe. AI systems can track flooding conditions and trace storms, preparing the public for these imminent catastrophes days or hours in advance.

2.3 The Netherlands Urban Stormwater Management

The Netherlands is located in the delta of the Rhine, Meuse, Scheldt, and Ems rivers, which run along the North Sea coast. The Dutch land lies approximately 26% below the normal sea level, and approximately 60% is vulnerable to flooding (Diakomopoulos et al., 2024). Since the 18th century, when the Dutch population began to expand swiftly, flood risk management has been a critical state concern for the Dutch people. The Royal Netherlands Meteorological Institute (KNMI) estimated that the sea level will rise by 0.35 m by 2035 and 0.65 m by 2070, which requires the city of Rotterdam to increase both the retention and detention capacity of its groundwater system (Francesch-Huidobro et al., 2017). A study from (Brouwer & Van Ek, 2004) highlighted that the critical situations in 1993 and 1995 in the Rhine and Meuse deltas, which threatened polders and required the relocation of tens of thousands of people, demonstrate the urgency of the inundation threat in the area.

In addition to raising dikes, the delta's future inundation necessitates implementing additional measures. The dikes mostly exceed the national standard (Xiong, 2021). The Room for the River program was designed to increase river capacity during high water levels (Mosselman, 2022; Verweij et al., 2021). Fig. 3 illustrates the Maestlantkering storm surge barrier to prevent flooding, which is managed by the Ministry of Infrastructure and Water Management (Rijkswatertaat).

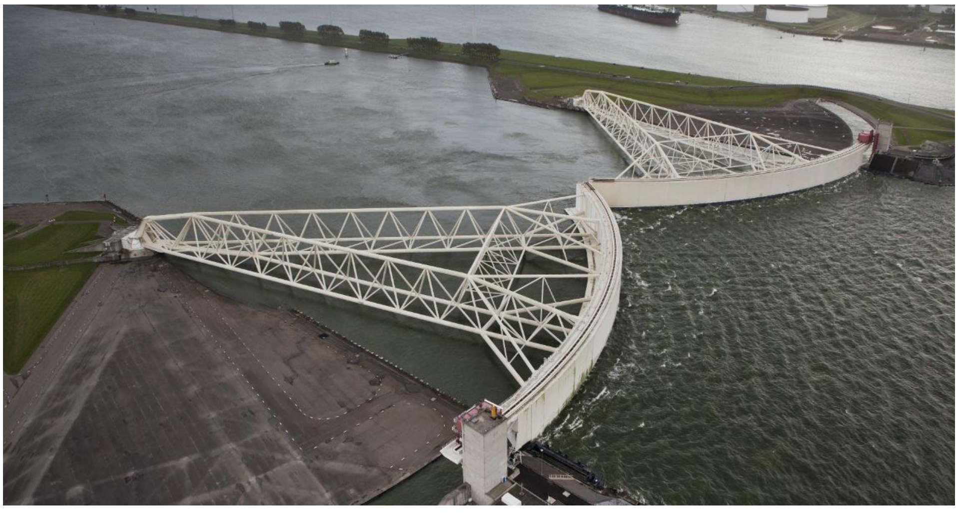

Fig. 3: The Maestlantkering is a storm surge barrier and a vital part of the Delta Works
(Source: https://www.rijkswaterstaat.nl/en/projects/iconic-structures/maeslant-barrier)

The utilisation of Sustainable Urban Drainage Systems (SUDS) has increased (F. Boogaard et al., 2014). As part of a planning strategy, the proposed land use change and floodplain restoration measures aim to prevent the occurrence of new cycles of dike reinforcement, promote the creation of ecological diversity, and encourage the multipurpose use of land whenever possible. The function of floodwater retention is of utmost importance due to the potential hazards to life and livelihood caused by flooding, as well as the ability of floodplain wetlands to mitigate this risk. Land used as an excess water retention area ensures that no further developments, such as the construction of freeways or residential housing, will compete for the limited available space (Brouwer & Van Ek, 2004).

Additionally, (Birch et al., 2008) discovered several case studies in the Netherlands where the Leidsche Rijn implemented a comprehensive confined canal system that maintains water velocity by pumping water from lower to higher ground. The system directs the collected stormwater from roofs through downpipes, spouts, and small streets paved with permeable pavement, culminating in a 40-meter-deep lake on the northwestern edge of Leidsche Rijn, after traversing a network of wadis, also known as swales and canals. Furthermore, Culemborg's EXA-Lanxmeer has implemented local infiltration, effluent treatment, rainwater harvesting, and reusing. This method is supported by (F. et al., 2023) who stated that the Netherlands has mapped more than 1500 swales using the ClimateScan instrument. KNMI has set up various types of meteorological and hydrological monitoring facilities with 45 automatic weather stations, 320 voluntary observers, and seismometers and infrasound sensors.

Additionally, maintaining and strengthening existing infrastructure (dykes, barriers, and sewers) is necessary (O'Donnell et al., 2021). Thousands of green infrastructure projects have been implemented with grey infrastructure (F. et al., 2023). In order to protect the city from urban floods, Rotterdam implements a variety of indicators for stormwater adaptation resilience. These assessments include conventional engineering, water pipes, drainage pipes, progressed public facilities such as the water square (Fig. 4), and measurement regulations. Underground parking water storage is an approach that addresses the issue of urban water retention by utilising multipurpose space rather than utilising the urban environment directly (Xiong, 2021). Rotterdam has implemented various measures, making the city one of the most effective in the world at mitigating urban floods and waterlogging. In summary, the Netherlands is leading the way in encouraging BGI approaches, such as redesigning the city to increase water storage space and collaborating with other city initiatives to connect adaptation and spatial planning.

The Dutch government established statutory standards for flood protection structures, including dikes, dams, and other civil engineering structures established by the Water Act (soon to be the Environment Act). Every 12 years, the regional water authorities must conduct inspections to verify that the flood defences meet the legal standards. If the requirements remain unmet, the responsible entity may apply for funding from the Dutch Flood Protection Programme (DFPP). However, concurrent challenges exist, including improving the production rate (effectiveness) of flood defence projects and enhancing efficiency through lowering expenses per kilometre (Tromp et al., 2022).

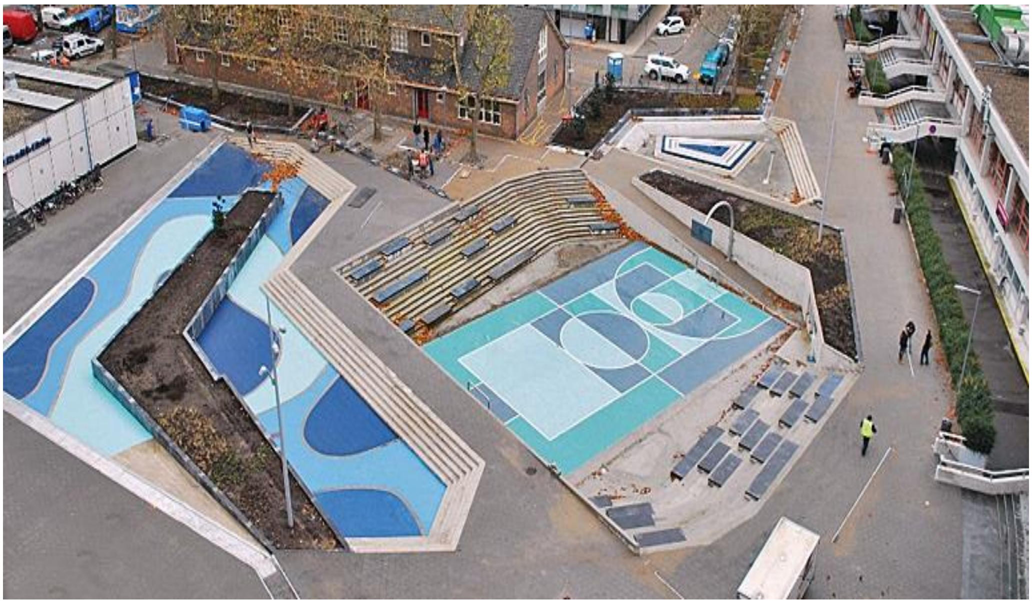

Fig. 4: Rotterdam’s first full-scale water square
(Source: https://www.dutchwatersector.com/news/new-innovative-water-square-combines-leisure-and-storm-water-storage-in-rotterdam-the)

3.0 METHODOLOGY

This study utilised case studies within the qualitative method framework as the primary research approach. The authors developed in-depth studies for each country based on our understanding of the stormwater management techniques used in various countries to mitigate floods, aiming to offer more effective recommendations for implementation within Malaysia. Comparative analysis was used to identify the countries' differences in flood mitigation practices. Comparative analysis primarily clarifies and improves comprehension of the causes and effects that contribute to forming an event, feature, or relationship. This analysis combines differences in the explanatory factor or variables (Pickvance, 2005).

In this study, the method of conventional comparative analysis was employed. According to (Grandgirard et al., 2002), where conventional comparative analysis is a subtype of analysis that satisfies two criteria: (a) Data must be collected from two or more cases. The unit's subject matter is arbitrary; these instances may be countries, cities, firms, or families; and (b) Try to offer an explanation rather than just a description. This study has conducted case studies from Malaysia, Japan, and the Netherlands to evaluate their approaches to mitigating flooding.

4.0 RESULTS

This section provides findings for a comparative analysis of three (3) case studies identified based on the established criteria. Various characteristics were compared, such as climate, challenges, exceptional flood mitigation projects, stormwater infrastructures, and other aspects. The table below presents the findings from the case studies above.

Table 1: Comparative analysis of stormwater management in Malaysia, Japan and the Netherlands

Characteristics	Malaysia	Japan	The Netherlands
Climate	Tropical rainforest climate with high annual precipitation.	Seasonal typhoons and high rainfall.	Moderate rainfall, flood-prone from river and sea.
Major Challenges	Urbanisation, improper drainage system, lack of maintenance, flooding or flash floods.	Flooding due to typhoons and rapid urbanisation.	Coastal and riverine flooding and rising of sea level.
Remarkable Flood Mitigation Project	Kuala Lumpur’s Stormwater Management Road Tunnel (SMART) and River of Life.	Tokyo Metropolitan Area Outer Underground Discharge Channel (G-Cans project).	Delta Works, Maeslantkering, storm surge barrier.
Stormwater Infrastructure	Integration of BMP and LID techniques such as gross pollutant traps (GPTs), detention ponds, on-site detention, perforated pipe systems, porous pavement, retention ponds, swales, and Integrated Flood and Rainfall Management (IFFRM).	Smart manhole cover, retention pond, swales, green roof, infiltration and Automated Meteorological Data Acquisition System (AMeDAS).	Extensive use of SUDS and BGI practices, water squares, green roofs, swales, permeable pavements, downspout disconnection, underground parking storage and various types of meteorological and hydrological monitoring facilities.
Policies and Regulations	Urban Stormwater Management Manual for Malaysia (MSMA) and National Water Resources Policy.	Urban River Law, Disaster Countermeasures Basic Act, River Law.	Water Act, Delta Programme, “Room for the River” policies.
Responsible Agencies	Department of Irrigation and Drainage (DID), Local Authorities, National Water Services Commission (SPAN) and National Disaster Management Agency (NADMA).	Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan Meteorological Agency (JMA).	Ministry of Infrastructure and Water Management, Waterschappen (Water Board), Royal Netherlands Meteorological Institute.
Future Flood Mitigation Projects	Developing green corridor, construction of Sabo Dams and dual-function retention pond.	Expansion of underground detention, utilisation of AI in flood prediction.	Dutch Flood Protection Programme, Delta Programme 2024.

5.0 DISCUSSIONS

The findings above indicate a significant application of techniques or practices in those nations. While Malaysia is known for its tropical rainforest climate with high annual precipitation, Japan experiences seasonal typhoons and high rainfall, and the Netherlands experiences moderate rainfall but is prone to flooding from rivers and the sea. Despite the differences in climatic characteristics, Malaysia could potentially adopt or adapt other stormwater management practices. Observations from the countries reveal that flooding issues are the primary challenges, closely followed by urbanisation.

Based on the case studies, some practices can be adopted. For instance, Malaysian coastal areas, particularly flood-prone areas like Kelantan or Terengganu, may practice storm surge barriers known as Maestlantkering. Forecasts indicate that sea level rise will significantly contribute to flooding in the future; therefore, implementing storm surge barriers could mitigate the negative impacts of these global warming consequences. The storm surge barrier technique will protect the community's property, health, and well-being in these regions.

Furthermore, the SMART Tunnel in Malaysia, which functions as a double-decker motorway and a stormwater tunnel, is an intriguing project that aids flood mitigation (Bobylev, 2007). The SMART Tunnel shares nearly identical concepts with the G-Cans Project in Tokyo, Japan, which is designed to store rainwater during periods of heavy precipitation. However, Japan boasts the largest underground discharge channel capable of withstanding a flood that occurs once every 200 years. Detention ponds, swales, and pervious pavements were used as stormwater infrastructure practices in all three countries. However, due to the relatively new nature of green roofs in Malaysia and the scarcity of commercial materials, Japan and the Netherlands encouraged the implementation of green roofs more than in Malaysia (Ayub, 2020).

According to the Malaysian Meteorological Department (METMalaysia), Malaysia has 43 principal stations and 221 auxiliary stations throughout the country. This shows that our country has a low number of monitoring stations compared to other countries, such as the Netherlands. An increasing number of monitoring stations helps to provide accurate meteorological data and track weather changes. Advanced technology, such as automated systems, is used in weather monitoring to provide highly precise data and an up-to-date system.

For future mitigation projects, Malaysia plans to develop a green corridor, particularly in the city centre of Kuala Lumpur, to enhance the greenery index, reduce the urban heat island, and aid in flood mitigation. In addition, it is highly recommended that Malaysia increases the number of developments at Sabo Dam, adopted from Japan, to reduce flooding due to surface runoff and debris and to create a dual-function retention pond. Meanwhile, Japan is expanding underground detention and utilising artificial intelligence (AI) for flood prediction. The Malaysian government is also interested in using AI in stormwater management.

However, Malaysia must catch up and implement effective stormwater management strategies to mitigate flooding. Sinkholes and flooding continuously hit several areas of the Klang Valley, particularly during heavy rain. This event may be due to a lack of monitoring from the responsible agencies, which sparked curiosity and led to communities becoming more aware of their surroundings. Alternative stormwater mitigation strategies should be considered from various management, planning and development aspects, including government support in the form of tax incentives. With the incentives, developers or building owners may be encouraged to implement stormwater infrastructure, such as green roofs, downspout disconnection, and rainwater harvesting systems. Raising awareness about flooding problems is crucial, especially regarding inappropriate waste disposal methods, which are one of the factors contributing to flash floods. Therefore, the Malaysian government should tackle this issue rigorously, and countermeasures are necessary to ensure the communities' livelihood, property, and well-being.

6.0 CONCLUSION

This study compares stormwater management practices in developed countries such as Japan and the Netherlands with those in Malaysia. According to the research, both developed countries prioritise stormwater management by implementing new technology and enforcing stricter standards, as seen in the Netherlands, where barriers are built higher than the standards. Malaysia should investigate and implement the most appropriate techniques for the country, considering its unique geographical conditions. The development of expanded underground detention or retention ponds should be considered to address flooding issues, particularly in the Klang Valley area. The focus should be placed on urban areas and implementing storm surge barriers in coastal regions to prevent harmful environmental impacts. The use of AI in current technology also presents great potential for contributing to flood prediction and alleviating flooding issues.

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