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SITE SUITABILITY ASSESSMENT FOR SELECTED NATURE-BASED SOLUTION (NBS) IN FLOOD-PRONE AREA

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Abstract

In recent decades, Malaysia has experienced an increase in both the frequency and severity of flood events, making the country particularly susceptible to flooding. Therefore, is a growing recognition of the importance of nature-based solution (NbS) as a viable approach to enhance flood resilience. This study utilized Geographic Information System (GIS) technologies to address this challenge by identifying optimal locations for implementing selected NbS in Kota Tinggi district, Johor. The research involved selecting suitable NbS measures using Multi-Criteria Decision Analysis (MCDA). A two-phased approach was employed. Firstly, RECONECT's Measure Selector tool, a web-based tool was used to generate a preliminary list of NbS aligned with local conditions in Kota Tinggi. Following the initial screening, MCDA, a decision-making approach that considers multiple criteria was then used to evaluate the shortlisted NbS options. A site suitability analysis was then performed based on slope, distance to rivers, land use and distance to roads. Two NbS options, floodplain restoration and retention ponds, were chosen for further analysis with a more specific requirement. The results identified a total area of 126,798 hectares suitable for NbS implementation based on the general criteria. Floodplain restoration emerged as the more suitable option, with 107,929 hectares (89.67%) meeting the criteria compared to 12,419 hectar (10.33%) for retention ponds. Understanding the potential of NbS for flood mitigation in Kota Tinggi can assist with the selection and implementation of NbS in flood-prone areas to enhance flood resilience and create a more sustainable future.

Keywords: Flood management, Geospatial analysis, Nature-based solutions (NbS)

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INTRODUCTION

Nowadays, floods caused by the changing climate impacts a substantial population globally, resulting in human fatalities and significant damage. The phenomenon of climate change has been observed to have detrimental effects on the hydrological cycle, thereby influencing the precipitation patterns and potentially developing a lot of extreme weather events (Tarmizi et al., 2021; Anuar et al., 2022, Ata et al., 2023). Extreme events such as flooding are expecting to become more common in the 21st century (Tabari, 2020). Moreover, the severity of tropical storms in the South-East Asian (SEA) region is also anticipated to intensify due to climate change (Asian Development Bank, 2021). The majority of Malaysia's losses are due to flooding, even though it is also susceptible to drought, landslides, earthquakes and storm surges (World Bank Group, 2021). The changing climatic conditions, including increased rainfall intensity and frequency, pose a threat to the country's urban areas (Yassin et. al, 2023), particularly in low-lying regions. Research done by C40 Cities (2023) highlights that although cities across the globe will experience the impact of climate change, populations residing in the global south are at a significantly higher risk of experiencing the adverse effects of flooding and drought, as compared to their counterparts residing in the global north, with a tenfold difference in likelihood. Therefore, it is anticipated that Malaysia will experience increased occurrences of rainfall extremes, characterized by intensified precipitation during the wet season and reduced precipitation during the dry season. This phenomenon would result in increased high flows, which would consequently lead to more severe floods (Rahman, 2018).

According to the report by World Bank (2021), in recent decades, Malaysia has experienced an increase in both the frequency and severity of flood events, making the country particularly susceptible to flooding. This resulted in an increase in the median of the population impacted by an extreme river flood (90th percentile) due to climate change is estimated to be around 102,290 individuals by the year 2035-2044. This showed a rise of 140% from the population that was subjected to it during the period of 1971-2004. Local communities in flood-prone areas may be adversely affected by future land use changes, which will intensify the frequency and severity of flooding (Yassin et al., 2022). Flooding is a significant environmental challenge in Kota Tinggi district, Johor (Anuar & Rahmat, 2022) causing damage to infrastructure, property and livelihoods (Tam et al., 2014). In response to the flood risk associated with climate change, it is recommended that a suitable combination of measures be implemented to address this issue (Ferreira et al., 2021; Hamid et al., 2022). There is a growing recognition of the importance of nature-based solution (NbS) as a viable approach to enhance flood resilience. The implementation of NbS as a means of achieving sustainable mitigation and adaptation to floods has garnered increasing attention. This is due to the insufficiency of conventional solutions to overcome the problem. Conventional flood mitigation strategies often rely on grey infrastructure solutions, which can be expensive and have limited ecological benefits (Sowińska-Świerkosz & García, 2022). NbS leverages natural processes and features such as wetlands, green spaces and natural drainage systems to mitigate the impacts of floods (Castelo et al., 2023). This research aims to address this challenge by exploring the potential of NbS for flood mitigation in Kota Tinggi district. Implementing NbS effectively requires identifying suitable locations that maximize their flood control benefits. By understanding the specific challenges and opportunities, the study could contribute to the knowledge base and provides valuable insights for policymakers and stakeholders working on flood management strategies in the region.

RESEARCH METHODOLOGY

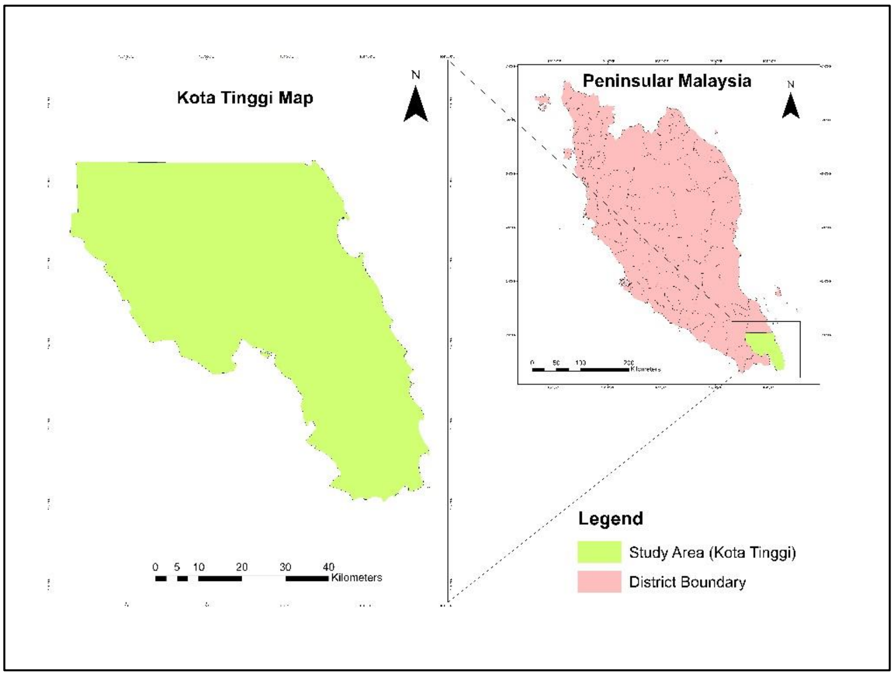

Figure 1: Geographical location of Kota Tinggi district in Malaysia

Located in the eastern portion of the state of Johor with the sea encircling 65% of its border, Kota Tinggi is among the districts that are severely impacted by floods nearly every year (Anuar & Rahmat, 2022). Kota Tinggi, located in 1°44′N 103°54′E, consists of a large watershed area and receives an annual average of 2,470 mm of precipitation. With a population of over 200,000 people, urbanization in this area is rapidly increasing with a focus on agricultural activities and housing development. This district's administrative town is also called Kota Tinggi. However, there is lack of comprehensive understanding of suitable locations for deploying specific NbS types within the area. This study hence is intended to identify optimal locations for implementing selected NbS in Kota Tinggi district, Johor. Due to its risk of having extreme rainfalls and floods in many future projection studies (Tarmizi et al., 2021; Hamid et al., 2022; Anuar & Rahmat, 2022), Kota Tinggi was chosen for this research.

Data Processing & Analysis
The methodology that was used to map out the site suitability analysis of selected NbS consists of two steps, which are the selection of NbS measures and site suitability analysis of selected NbS measures.

Selection of NbS measures
The initial screening for suitable NbS utilized the Measure Selector tool. This application is a web-based application that enables decision makers to choose preliminary measures for NbS depending on local considerations. The tool was created using a database including a comprehensive list of strategies for reducing hydrometeorological concerns. To narrow down the list of NbS measures, six filters (types of measures, hazard type, affected area, potential location for measures, project type, land surface relevant for application) are utilised to select appropriate solutions for a particular scenario. Each potential NbS option is evaluated against pre-defined criteria such as its effectiveness, feasibility, environmental impact and social benefits. Based on the filter, five NbS were listed out which includes floodplain restoration, re-meandering, retention ponds, wetland restoration and riparian buffers. These NbS options were prioritized for further analysis.

Following the initial screening, a method of decision-making that takes into account several criteria called multi-criteria decision analysis, or MCDA was then used to evaluate the shortlisted NbS options. Three key criteria were identified for evaluating NbS options based on their relevance to flood mitigation in Kota Tinggi which are effectiveness in flood mitigation, environmental impact and social benefits (Table 1). Specifically, a simple weighted linear was used to determine the score for each of the criterion. This method draws inspiration from the Weighted Average Linear Model (WALM). It provides a straightforward way to consider the relative importance of various factors when evaluating potential locations for NbS (Bhole, 2018). The weights assigned to each criterion were determined through a comprehensive literature review of scientific studies on NbS implementation in similar riverine floodplains. Based on Table 2, the analysis shows that floodplain restoration emerges as the most favourable option with the highest total score (5). This reflects its strong performance in all three criteria, particularly its high effectiveness in flood mitigation and its positive environmental and social benefits. Retention ponds follow closely behind with total scores of 4.4. Wetland restoration also offers similar effectiveness to floodplain restoration but with slightly lower social benefits.

Table 1: Criteria and Weighting for NbS Options in Flood Mitigation

Criteria	Description	Weight
Effectiveness in Flood Mitigation	Ability to reduce flood risk through storing/slowing runoff, reducing peak flow, and minimizing erosion.	0.4
Environmental Impact	Positive or negative consequences for the environment. Measures considered include soil improvement, pollution reduction, habitat or biodiversity enhancement and climate benefits.	0.3
Social Benefits	Social and economic benefits for the community. Measures considered include creation of recreational opportunities and new job opportunities.	0.3

Table 2: MCDA Analysis of NbS Options for Flood Mitigation in Kota Tinggi, Malaysia (Weighting Scheme: WLAM)

Criteria (Weight)	Floodplain Restoration	Re-meandering	Wetland Restoration	Retention Ponds	Riparian Buffers
Effectiveness in Flood Mitigation (0.4)	High (5)	Medium (3)	High (5)	High (5)	Medium (3)
Environmental Impact (0.3)	High (5)	High (5)	High (3)	Medium (3)	High (5)
Social Benefits (0.3)	High (5)	Medium (3)	Medium (3)	High (5)	Medium (3)
Total Score	5	3.6	3.8	4.4	3.6

Site suitability analysis of selected NbS measures

A site suitability analysis was performed to identify the areas where selected NbS can be implemented. An extensive study found that slope, soil type, distance from the river, land use type, and urban land use are the most common criteria for selecting NbS sites (Mubeen et al., 2021). A derived map was produced using the base map by processing all of the key considerations required for spatial allocation to construct the suitability map (Figure 2). The acquired derived maps were then be used to perform a site suitability analysis using ArcGIS. Base maps utilize buffer tool and Euclidean distance calculation to calculate slope rate, distance from rivers, and road buffers. They are then transformed into Boolean maps that indicate places that match the following conditions as proposed by Mubeen et al. (2021): (1) slope rate ≤ 5%, (2) distance from river ≤ 1 km and (3) distance from road ≥ 50m. For each criteria, raster maps were created and then transformed into Boolean maps that illustrate the areas that meet that criterion. A general suitability map for allocating NbS in Kota Tinggi results from the combination of these maps. Justification on the above conditions are as follows:

Slope rate ≤ 5%: Gentle slopes (≤ 5%) allow for better infiltration of rainwater into the ground, reducing surface runoff and potential flooding (Morbidelli et al., 2018). Gentle slopes are generally easier and less expensive to work with for constructing and maintaining NbS features compared to steeper terrain.

Distance from river ≤ 1 km: Locating NbS near rivers allows them to directly intercept and filter runoff before it reaches the waterway. This can help reduce the peak flow of water quality entering the river. Being close to rivers can also enhance the ecological value of NbS by creating a buffer zone and potentially providing habitat for riparian plants and animals (Fletcher et al., 2014).

Distance from road ≥ 50 m: Areas close to roads are often already developed or have limited space for implementing NbS features hence a buffer zone ensures sufficient space for effective functioning (Longato et al., 2023).

Based on the conditions for the general suitability map, a simplified Boolean formula approach in ArcGIS was being used to identify potentially suitable areas for NbS:

(Suitable_Slope AND Near_River AND Buffer_From_Road) AND NOT Urban_Area

Vector layers are created and calculated using the transformed Boolean raster maps to yield discrete polygons that illustrate areas that satisfy every spatial allocation criterion. This generates the general suitability map which is used as the basis for spatial allocation. In order to identify areas where these measures can be employed, the general suitability map was further improved with additional particular criteria that differ based on the type of NbS. The flow length tool generates a raster of upstream and downstream distances in a catchment where the watershed is then separated into two sections: upstream and downstream. This helps identify places suitable for both the floodplain restoration and retention ponds (Mubeen et al., 2021). Vector layers containing polygons for retention ponds and floodplain restoration are the output of the suitability map for each NbS.

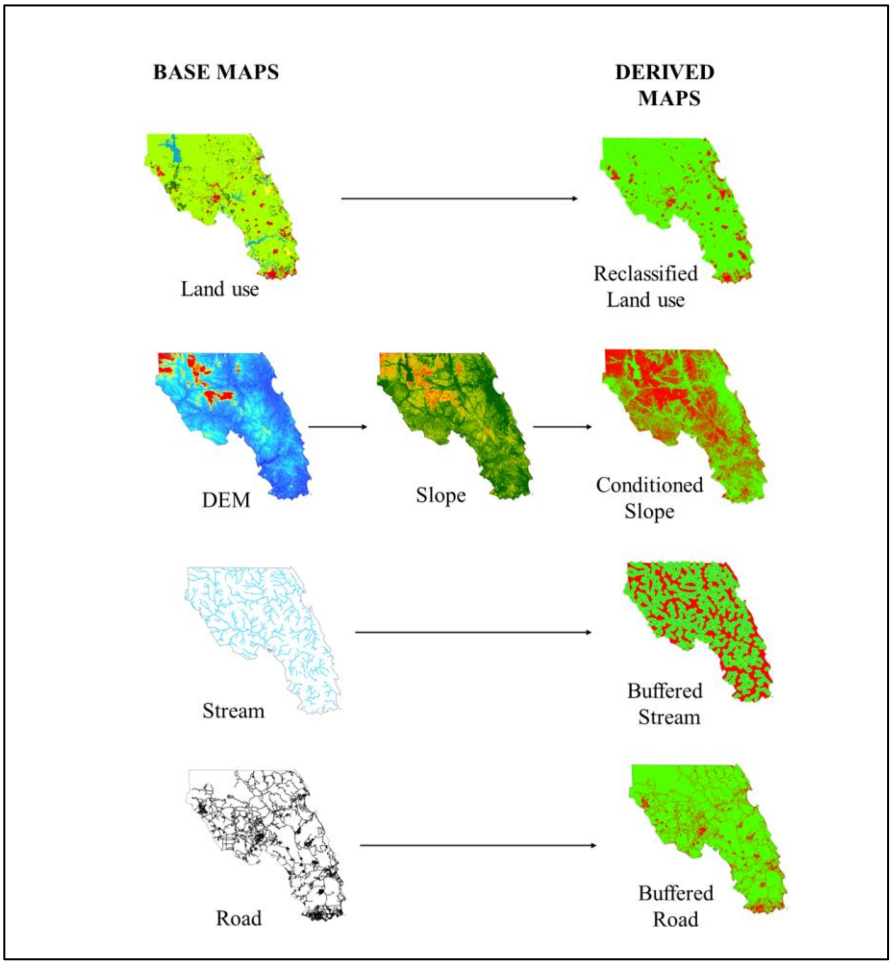

Figure 2: Derivation of NbS Suitability Maps from Base Maps in Kota Tinggi

RESULTS AND DISCUSSION

Result shows that a total area of 126,798 ha out of 342,259 ha is suitable to be allocated with NbS as it meets all criteria needed. NbS-specific criteria were then combined with general suitability maps (Figure 3) to develop the specific NbS suitability maps. Using NbS for upstream storage can help reduce the amount of runoff that flows downstream by establishing retention ponds. In flatter areas, floodplain restoration provides more conveyance area, which makes it more effective. Regions with an area of less than 10 ha were omitted from the suitability map due to their inability to provide adequate storage volume for effective flood attenuation (Mubeen et al., 2021)

General Suitability Map

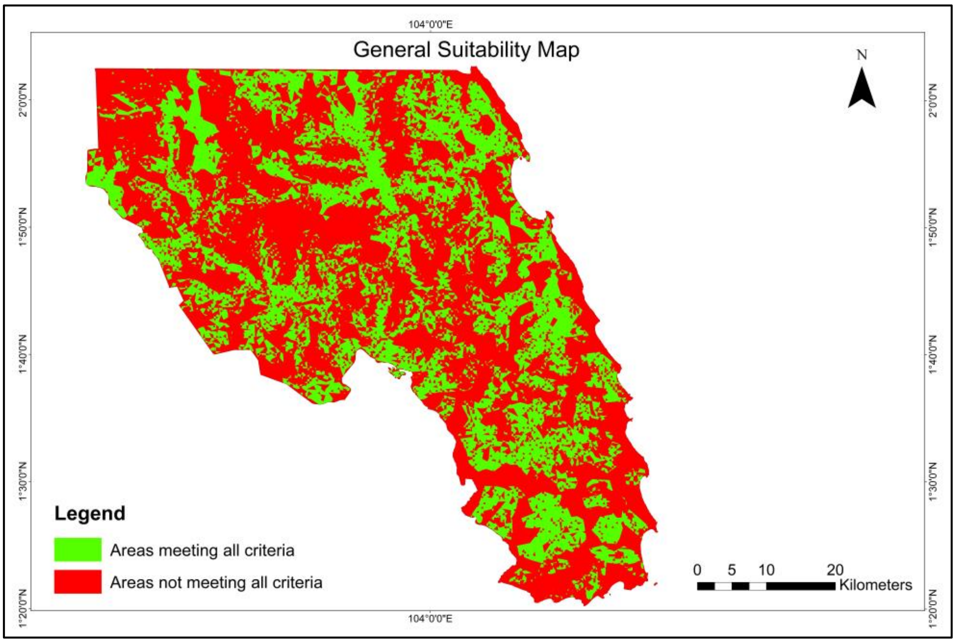

Figure 3: General Suitability Map for NbS allocation

Table 2: Total area for NbS implementation

	Total Area (ha)
Area meeting all criteria	126,798
Area not meeting all criteria	215,461

NbS Suitability Map

Figure 4 shows a combined area of 126,798 ha, where 107,929 ha or 89.67% of the total area that fulfilled all the criteria can be utilized for floodplain restoration and a total area of 12,419 ha, or 10.33% are considered suitable for the development of retention ponds as NbS.

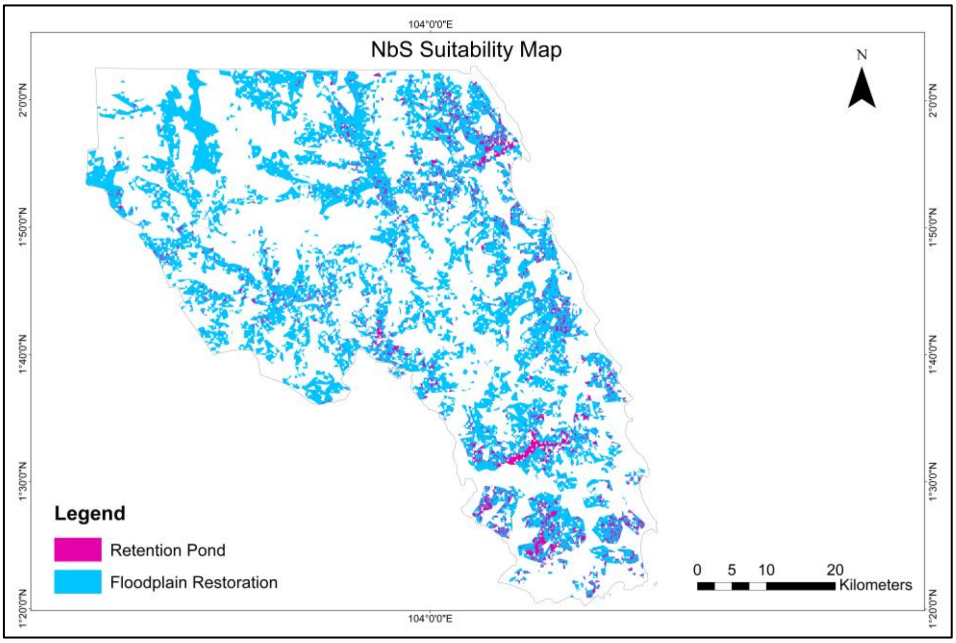

Figure 4: Suitability maps for floodplain restoration and retention ponds in Kota Tinggi

Table 3: Total area of suitable NbS location

	Total Area (Ha)	%
Floodplain Restoration	107,929	89.67
Retention Pond	12,419	10.33

Floodplain restoration was found to be particularly effective in low-lying and flatter regions, which not only helps in reducing flood risk but also in providing habitat for native species, improving water quality, and enhancing ecosystem connectivity across the region. Integrating floodplain restoration across 107,929 hectares (89.67% of the total suitable area) can have extensive ecological benefits by creating green buffer zones along waterways, which can improve biodiversity and boost ecosystem resilience (Nilsson et al., 2018). This high suitability aligns with Kota Tinggi's geographical characteristics, especially its relatively flat areas and extensive low-lying zones (Yeganeh & Sabri, 2014) that naturally lend themselves to floodwater conveyance and storage. Floodplain restoration in these areas can absorb large quantities of runoff during heavy rainfall, slowing the flow rate and reducing peak discharge in downstream areas (Mubeen et al., 2021). This natural storage capacity not only aids in flood mitigation but also supports ecological health by creating habitats that can enhance local biodiversity. Given the increased urbanization and agricultural development in Kota Tinggi (Kang & Kanniah, 2022), this NbS approach helps retain critical floodplains that might be at risk of degradation or development.

Retention ponds, while covering a smaller area (10.33%), play a crucial role in upstream storage by capturing runoff and allowing gradual water release. The strategic placement of these ponds can intercept and store excess runoff from highland areas, thus mitigating downstream flood risks, especially in urban and agricultural zones prone to high runoff (Griffiths et al., 2024). In Kota Tinggi, this is particularly relevant as upstream runoff can intensify flooding downstream, impacting communities, agriculture and infrastructure in the district's central and coastal regions (Anuar et al., 2022). The retention ponds act as a buffer, capturing stormwater and gradually releasing it to reduce strain on downstream areas (Griffiths et al., 2024).

CONCLUSION

A suitability analysis was conducted in Kota Tinggi, Johor to map out suitability of the chosen NbS to be implemented in the area. The creation of the NbS suitability map provides spatial information to guide the selection of optimal locations for implementing NbS interventions of retention ponds and floodplain restoration. According to the findings, a significant area within Kota Tinggi (126,798 ha) was identified as generally suitable for NbS implementation based on slope, distance from rivers, land use, and distance from roads. Floodplain restoration emerged as the more preferable NbS option, with a potential application area of 107,929 ha (89.67% of the total suitable area). This is likely due to the prevalence of flatter areas in Kota Tinggi, which are more effective for floodplain restoration. Retention ponds were found to be suitable for a smaller area with 12,419 ha (10.33% of the total suitable area), potentially due to their requirement for upstream storage capacity. With over 120,000 hectares identified as suitable for NbS, Kota Tinggi has significant potential to utilize these natural infrastructure solutions to enhance flood resilience and manage flood risks that have been a problem for decades (Anuar et al., 2022).

However, involving stakeholders in choosing the specific NbS to be implemented as well as prioritizing specific areas for NbS implementation based on other additional factors such as flood risk, community needs, as well as cost-effectiveness would allow for more accurate details on the NbS choice and placement. Public engagement is also needed to ensure that chosen NbS solutions integrate well with the local environment and social context. These findings highlight the promise of NbS for mitigating flood risk in Kota Tinggi. Implementing NbS offers a more sustainable and potentially more cost-effective approach compared to traditional grey infrastructure solutions (Di Pirro et al., 2023). Additionally, NbS can provide ecological benefits such as improved water quality and habitat creation. By effectively utilizing NbS, Kota Tinggi can build a more resilient future in the face of increasing flood risk due to climate change.

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