Chapter 8
Floods in Tutong District, Brunei Darussalam and the Role of Tutong River: Approaches for Mitigation Measures

Shafi Noor Islam, Sandra Reinstädtler, and Khairunnisa Haji Ibrahim

Abstract Brunei Darussalam is a small country located in Southeast Asia, divided into four administrative regions, the districts of Brunei-Muara, Tutong, Kuala Belait, and Temburong. The country has enormous natural and water resources. Rainfall is an essential phenomenon in Brunei Darussalam. Brunei's saline seawater and significant rivers play an important role in protecting the natural landscapes and developing and fertilizing the apartment lands. Tutong District is located in the country's middle and shows proximity to the South China Sea to the west. The Tutong River basin carries water from the Rambai region to the South China Sea, with a tidal distance upstream covering the Tutong catchment area. The monsoon rains and extreme rainfall resulting from climate change will likely cause challenges in managing increased river flow, causing flooding in the Tutong District floodplain. Floods or flash floods are the most common natural disasters that frequently affect Brunei Darussalam and the low-lying flood-prone areas of Tutong District. The trend of wet days in Brunei is increasing, which can be seen from rainfall data and flooding conditions in four districts in Brunei. Tutong District has experienced several floods over the past two decades. In 2014 alone, over 115 cases of flooding and 105 landslides were reported. This study examines the trends and patterns of flooding and flash floods in Tutong District. The impact of climate change in the affected areas in Tutong District is mapped. The study will seek alternative environmental solutions to develop sustainable flood mitigation strategies for sustainable natural hazards measures and management in Brunei Darussalam.

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1 Introduction

The Nation of Brunei is located in Southeast Asia on the North side of the island of Borneo and has Bandar Seri Begawan (BSB – 100.3 km^2 extent) as the main city and capital of the country of Negara Brunei Darussalam. General hazard risk is high being impacted by global climate change as well as by the country's local geography and Brunei's relative location in the Asia–Pacific Region (Gupta, 2010; Saxena et al., 2012; NIDM, 2014; Ndah & Odihi, 2017). Floods and landslides are the most prevalent hazards (NIDM, 2014; Irlapati, 2017). Thereby the types of monsoon floods or flash floods are predominant. With especially 97% of the Bruneian population living in the western lowland region (NIDM, 2014) and, in general, low-lying areas being more flood-prone, this research is most important for the country and one of four districts of Brunei Darussalam, Tutong District. Also, next to district perspectives, similar worldwide situations are given, for which this regional case study is comparable to many other countries and regions with similar initial situations (NIDM, 2014; Gupta, 2010).

So the main observation and case study area of this research, Tutong District, has an area extent of 1116 km^2 (NIDM, 2014) while the entire area extent of the country is 5765 km^2 (2226 sq. mi) (land: 5265 km^2 (2033 sq. mi); water: 500 km^2) (Hassan, 1988; CDD, 1993, 2008; Ibrahim, 2005; Khatib & Sirat, 2005; Omar, 2005; Osman & Lim, 2018). Tutong District grew from 19,151 people in 2021 (World Population Review, 2021), while Brunei Darussalam's total population was 423,200 in 2014 (NIDM, 2014). The Tutong River system's catchment area is about 1300 km^2 with a multi-layered estuarine structure that has formed two sandpits over time. Tutongs' height above water (sea) level accounts for 7 m, and elevation is up to 13 m (FloodMaps, 2020). Although Brunei Darussalam is consecrated with minimal occurrence of natural phenomena, Brunei is still vulnerable to flooding activity because of the country's geographical location or climate conditions, for instance. Moreover, the natural hazard of flooding increases the risk of further environmental catastrophes (Islam, 2020, 2021), such as landslides, which frequently happen in Brunei. On top of that, climate change and environmental degradation are increasingly discussed and recognized topics in today's society (Islam & Gnauck, 2007, 2009, 2011). In addition, the Tutong area, especially the rural areas of Tutong, is highly vulnerable to flood hazards compared to the other three districts: Flooding has subsided most areas of Tutong District, and these low-lying areas are especially prone to flooding during the monsoon season (Islam et al., 2019). Therefore, authorities and residents remain on high alert: For example, heavy rains on December 7th, 2020 caused a rise in water level and affected 47 families, with at least evacuations being unnecessary (Bakar, 2019). The heavy rains also triggered two landslides in kampongs (Kg) of Kg Ukong and Kg Lamunin. As heavy thunderstorms were afterward expected and may have caused flash floods in low-lying areas, the Brunei

Darussalam Meteorological Department continued to issue weather warnings (Islam et al., 2018, 2019). These weather warnings are some of the important measures for further crisis prevention and risk reduction.

Therefore, approaches for mitigation measures have to be further developed next to an early warning system and other initiatives that have been or still must be considered to reduce the risk of flooding in vulnerable areas (Islam, 2010a, b; Reinstädtler, 2022a, b, c). So this chapter highlights the involvement of mitigation measures against flooding at the Tutong River in the affected area. In general, this research emphasizes the function of rivers in flooding by focusing on the Tutong River case in Negara Brunei Darussalam. As it is essential to know the main driving forces and pressures within natural hazards such as (monsoon) floods or flash floods in order to develop adequate risk preparations in the form of mitigation approaches, the following research requests were set up for a further structured assessment:

(a) Is Tutong River playing a potential role in creating a flood in Tutong District, or which other sources of floods are important?
(b) And/or are natural or other phenomena the most important drivers for flooding in Tutong besides the general human influences as well as climate change impacts functioning as a driving force in flooding Tutong District (Islam et al., 2014a, b, 2018)?
(c) Which impacts of floods on the socio-economy of the flood-prone areas exist?
(d) How will the mitigation approach(es) be developed in correlation to these results so that better risk reduction and prevention for Tutong District result in chances?

This research examined the trends and patterns of flooding and flash floods in Tutong District in Brunei Darussalam. An analysis of the conceptual model will be investigated to understand the people's perception of the flood-prone concept.

Based on the aim of this study, the specific objectives have been considered that will meet up the aim of this study in Tutong District:

(a) To investigate the flooding and the impacts of floods in the affected areas in Tutong District.
(b) Mapping the flood-prone areas in Tutong District and examining the impacts on human livelihoods and socio-economy.
(c) To seek alternative environmental solutions to develop a sustainable flood mitigation policy for sustainable management of natural hazards in Tutong District as well as for the entire Brunei Darussalam.
(d) To prepare potential recommendations for floods and natural disasters mitigation measures for Tutong District and Tutong River Basin (TRB).

In this way, the chapter on floods in Tutong District in Brunei Darussalam and the role of Tutong River with its approaches to mitigation measures are structured by first describing data and methodology, followed by the description of the geographical location, physical setting and cultural characteristics of the case area. This description of natural and cultural characteristics is essential for a further assessment of flooding drivers, impacts, or solution findings. The results are such as following with highlighting the sources of floods in Tutong District in Brunei Darussalam, the flood

disaster risk in Tutong District, the role of the Tutong River for flooding in the catchment area, impacts of floods on the socio-economy in the flood-prone areas, and a closing up approach for flood mitigation measures and solutions. The discussion part, conclusions, recommendations, and a summary complete the chapter outcome.

2 Data and Methodology

This research utilizes various materials and methods to study the effects of the annual flooding in Tutong District in Brunei Darussalam. The study has been designed based on the primary and secondary data sources. Data collection for this study is a combination and collection of quantitative and qualitative research methods. Qualitative methods were used to develop and collect new ideas and perceptions about the involvement of Tutong River Basin (TRB) in the hazardous occurrence of flooding. Quantitative research data, such as analytical observations and some primary data, have been collected from field observation and field-level interviews with the senior citizens and the victim or flood-affected people in Tutong District. Partially, several field visits were processed, where observations on the flood-affected areas took place, especially within the almost every year flood-affected kampongs such as Tanjong Maya, Sungai Damit, Penapar, Keriam, Telisai, Kiudang, Lamunin, Rambai, and Ukong (flood-prone areas have been indicated in Figs. 8.2 and 8.3) (also comp. DI, 1992). The primary data and information concerning yearly flood-affected areas, affected people, and houses were collected in a database on field level in Tutong District. It includes statistical data and interpretation of the data collected. Google Earth (2020), FloodMaps (2020; with further data sources of Leaflet, Esri, OpenStreetMap, Mapzen, TNM, SRTM, GMTED, ETOPO1), and GlobalFloodMaps (2020) (in comparative form) are three of the applications used to show and display flood-prone areas.

Nevertheless, it has to be stated that flood mapping applications, in general, do not show historical or current flood levels. It depicts, for instance – and depending on the input – an area below the set elevation (Islam, 2016). The collected data have been rearranged and developed for analysis. The excel program has been used for graphs or tables, and some further software has been used for analysis and displayed. ArcGIS 10.5 has been used for flood mapping of the case area. The satellite images of the affected areas have been used to map and interpret flood impacts. The primary data sources from field investigation and data collection were from the years 2019, 2020, and 2021, often just after the floods.

Moreover, secondary data have been used to make the participatory flood mapping on the flood-prone areas in Tutong District. These areas are evaluated and monitored for the events that could trigger such a disaster in the affected areas. The Tutong flood-prone area maps have been prepared based on primary and secondary data. Especially field observation (primary data) as well as partially newspaper information (a smaller part of the secondary data partially using Borneo Bulletin daily News Paper and MOH) have been considered for data arrangement or even rearrangement.

3 Geographical Location, Physical Setting, and Cultural Characteristics of the Case Area

Brunei Darussalam, officially Nation of Brunei, the Abode of Peace, is lying in the Southeast Asian Malay Archipelago and is situated on the equatorial line between the southern and northern hemispheres and is placed at latitudes and longitudes of approximately 4° 30′N and 114° 40′E, respectively. Brunei Darussalam is located on the northwest coast of Borneo Island, which also belongs to Indonesia and Malaysia (Fig. 8.1). Its capital city is Bandar Seri Begawan. Tutong Town, named in Malay Pekan Tutong, is as district city of Tutong District, the third largest district town in Brunei Darussalam. The country is divided into east and west areas throughout the Malaysian northern part and the state of Sarawak the Island. The western part of Brunei is predominantly hilly lowland, whereas the eastern part consists primarily of rugged mountain terrain. So, apart from the Brunei Darussalam coastline to the South China Sea, it is surrounded by the East Malaysian state of Sarawak. Brunei shares a 266 km (165 mi) (CFE-DM, 2018) border with Malaysia, and Sarawak has an enclave, the district of Limbang, along the Limbang River that splits Brunei Darussalam into that two separate parts (Fig. 8.1; GIS Lab UBD, 2020; comp. FloodMaps, 2020) (Brown, 1970, p. 132; Hassan, 1988; CDD, 1993, 2008; Ibrahim, 2005; Khatib and Sirat, 2005).

Brunei Darussalam is the one state located entirely on the island of Borneo (named in Indonesia Kalimantan Island). The summit ridge of Bukit Pagon, in the western part, contains the country's highest point, with an elevation of 1850 m above sea level. The lowest point is the South China Sea (0 m). The coast has a vast, tidal, and swampy plain.

Important for any to be developed recommendations or suggestions on approaches to mitigation measures is the appearance of the regional spatial organization of any geographical location in order to provide possible adaptability on the ground – and so for this case study location of Tutong District, together with its direct district surroundings: Brunei Darussalam consists of four districts (or daerah): (1) the extensive Belait District in the south-west, (2) the here assessed Tutong District in the middle, (3) the Brunei-Muara District that surrounds the capital Bandar Seri Begawan, and (4) the separate Temburong District in the East (Fig. 8.1, Table 8.1) (CDD, 1993, 2008; Ibrahim, 2005; Khatib & Sirat, 2005). The daerah of Temburong is physically separated from the rest of Brunei by the Malaysian state of Sarawak (Fig. 8.1).

The case study area of this research, Tutong District, is one of the four districts of Brunei Darussalam, making it the third-largest of the districts (comp. Fig. 8.1, Table 8.1). The District borders the South China Sea to the north, the Malaysian state of Sarawak to the East, and the Belait District to the west, which the Bruneian government owns. The District is located at latitude 4.801890, longitude 114.652090 (or GPS coordinates of 4° 48′ 6.804″ N, 114° 39′ 7.524″ E) (Fig. 8.1) (GIS Lab UBD, 2020; comp. FloodMaps, 2020). The countries – and partially Tutong Districts – land boundaries being covered together with the neighboring country of Malaysia is approximately 381 km (Hassan, 1988; CDD, 1993, 2008; Ibrahim, 2005; Khatib & Sirat, 2005; Omar, 2005).

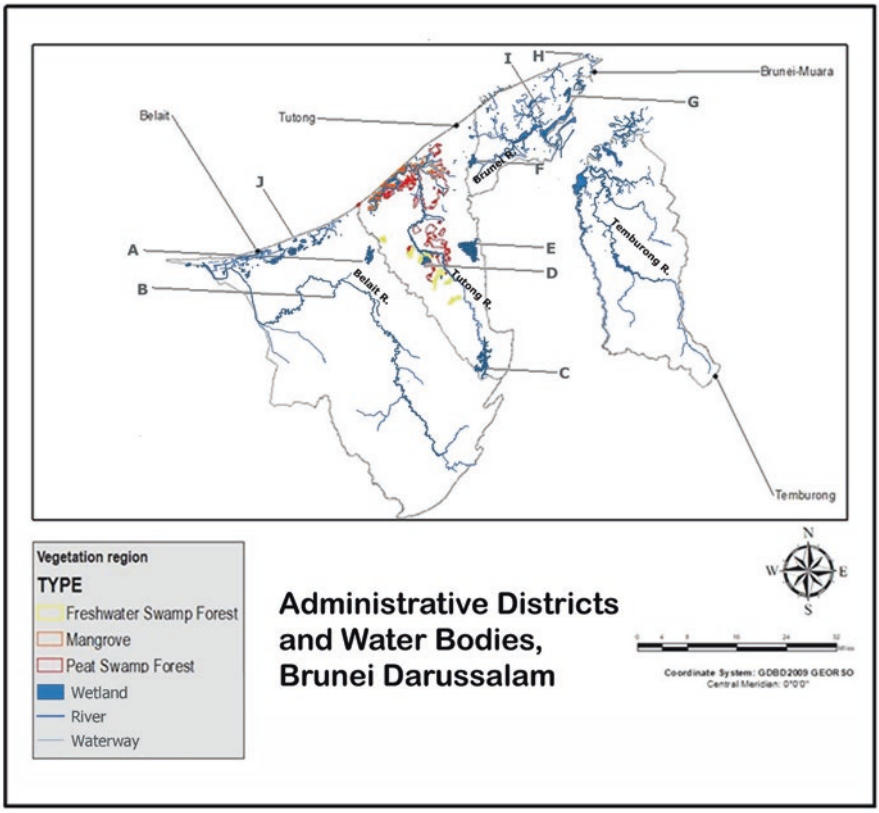

Fig. 8.1 The physiographic map and river system in Brunei Darussalam. (A – Andulau Reservoir, B – Lalak Lake, C – Belaban Ulu Tutong Golden Jubilee Reservoir, D – Tasek Merimbun, E – Benutan Reservoir, F – Imang Reservoir, G – Mengkubau Reservoir, H – Api-Api Wetlands, I – Tasek Lama Dam, J – Anduki Recreational Park. The Information for Tutong Golden Wetlands: A –Benutan Reservoir, B – Tasek Marimbun, C – Belaban Ulu Tutong Golden Jubilee Reservior) (Source: GIS Lab, Department of Geography & Environment, FASS, University of Brunei Darussalam (UBD) at 18.06.2020 (GIS Lab UBD, 2020)

Table 8.1 Four districts (daerahs) in Brunei Darussalam

No.	District – *Capital*	Population (2019 Census)		Area (km^2)
		Population	%	
1.	Belait –*Kuala Belait*	75,900	(16.5%)	2724
2.	Tutong – *Pekan Tutong*	52,700	(11.5%)	1166
3.	Brunei-Muara – *Bandar Seri Begawan*	319,500	(69.5%)	571
4.	Temburong – *Pekan Bangar*	11.400	(2.5%)	1304

NIDM (2014)

Fig. 8.2 The overview of the physical features and geomorphological pattern of Tutong Town in Tutong District (2020)

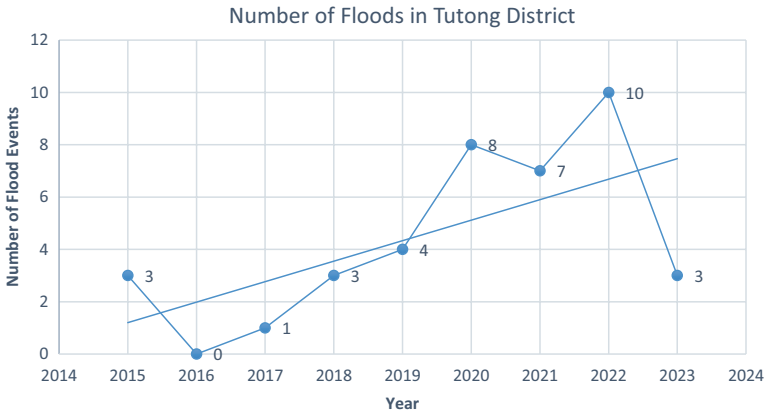

Fig. 8.3 Frequency of flood events in Tutong District (2015–2022). (Data source: Long, 2023)

Tutong Districts' main town is Pekan Tutong (Tutong Town) (Fig. 8.2 and later Fig. 8.3), one of the eight sub-districts called mukims. So each district consists of several sub-districts (mukims), which are 38 mukims in total. A mukim itself further consists of a group of kampongs or villages. The further Kampongs (Villages) are Tanjong Maya, Keriam, Telisai, Kiudang, Lamunin, Rambai, and Ukong (DI, 1992). They are administered by a district officer being responsible for all district affairs, such as general administration, welfare, development, and progress.

In addition, the country has a tropical equatorial climate characterized by uniformly high temperatures (Table 8.2), high humidity, and heavy rainfall within episodic monsoon rains with an average precipitation amount of about 2909 mm per

Table 8.2 Mean maximum and minimum monthly temperature and average monthly rainfall in Brunei Darussalam

Month/ Temperature/ Rainfall	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year average
Mean maximum (°C)	258	248	272	271	275	271	284	28.3	280	265	244	240	28.3
Mean minimum (°C)	221	220	225	239	239	247	241	24.3	253	231	222	236	26.2
Average rainfall (mm)	278	138	113	200	239	214	229	216	258	320	329	343	2877

NIDM (2014), Weather and Climate (2021)

year (NIDM, 2014; Weather and Climate, 2021). So annual rainfall varies from 2500 mm on the coast to 7500 mm in the country's interior (Gupta, 2010). The dominant influences on the climate are the northeast monsoon from November to March and the South-west monsoon between May and September.

The rainfall regime contains a wet season from November to January (North East Monsoon) and a minor rainy season from May to October (South-West Monsoon) (comp. Weather and Climate, 2021). An occasional drought may occur between the monsoons between late January and April. Temperatures range from 23 to 32 °C (Gupta, 2010; NIDM, 2014) (comp. Table 8.2). The average annual temperature is 26.1 °C (79.0 °F), with the April–May average of 24.7 °C (76.5 °F) and the October–December average of 23.8 °C (74.8 °F) (NIDM, 2014) (Table 8.2). The regional climate, temperature, rainfall, and landscape change pattern are potential factors of a region to manage and conserve nature, culture, and heritage (Tyler, 2004).

The physical overview and geomorphology of Tutong District display an excellent overview. Tutong District is in its north territory one part of the Brunei coastline, which extends about 161 km (100 mi) from near the mouth of the Baram River in the south-west to the headland of Muara in the northeast and borders the South China Sea. Brunei Bay lies to the East of Muara and northeast of Tutong District (comp. Fig. 8.1), which is a large and protected shallow embayment. So especially the variety of sloping patterns, different landscapes, and their unique landscape beauty, vegetation, and rainforest availability are identity-building. Brunei is predominantly a hilly lowland in its western part, whereas the eastern part consists primarily of rugged mountain terrain. The summit ridge of Bukit Pagon, also lying in the western part, inhabits the country's highest point with an elevation of 1850 m above sea level, and the lowest point is the South China Sea (0 m) (Gupta, 2010). The coast consists of a tidal, vast, and swampy plain (Gupta, 2010).

The second-largest river in its catchment extent and length within the entire river system in Brunei is the Tutong River, with a length of 137 km and flowing through the district from southeast to northwest (comp. Fig. 8.1). Within the Bruneian river systems next to this for Tutong District mainly important Tutong River, the Belait, and Temburong Rivers are the further main rivers in Brunei. These rivers and their tributaries are part of two major drainage basins: the Bram drainage basin in the west and the Brunei bay drainage basin in the East. The Brunei River is the smallest

Table 8.3 Catchment details of the four major rivers in Brunei Darussalam

River	The catchment area (km^2)	Length Km
Belait River	4700	209
Tutong River	1300	137
Temburong River	1000	98
Brunei River	765	41

river, with a catchment area of about 765 km^2. The river's upper reaches are a major freshwater source, particularly for the western part of the country. The tidal Tutong River drains an area of around 1300 km^2 in the central part of the country directly into the South China Sea (Muhmud, 2017). Originating from the hilly catchment while carrying flash flows, the Tutong River flows uncontrolled, and saline water intrusion during high tides creates a saline river, historically damaging standing crops and lands by flooding and salinity (Shafiuddin, 2014). Some further details of the four major rivers in Brunei Darussalam are shown in Table 8.3:

Adversities of flood damages affect the TRB as a whole (Shafiuddin, 2014): drainage congestions, flash flows, inadequate irrigation application for lack of infrastructures and water sources, and thus failing in the agro-projects and especially in the rain-fed paddy schemes. So the most important natural resource in Tutong District is water, for which interdisciplinary mitigation approaches might be advantageous for Tutong Districts water resources, especially in the negative effect of saltwater intrusion from the Tutong River mouth. Drinking water for the district is supplied by the Sungai Layong Reservoir (SuLaRes) (later Fig. 8.3), which also supplies the areas of Brunei/Muara District closest to Tutong District. In addition, the recently completed Benutan Dam, with a catchment area of 23 km^2 and a storage capacity of 44 million cubic meters, serves as a backup supply when water levels in the SuLaRes are low. In 1991, the water consumption of the district and the adjacent areas in the Brunei/Muara District was about 22.09 million cubic meters (DI, 1992).

Also, Tutong District inhabits next to a higher biodiversity richness (SCBD, 2022) and a diverse ecosystem (GBD, 2014), a vast forest reserve, Bukit Ladan Forest Reserve, covering an area of 25,000 hectares, and an offshoot in Pekan Tutong. In general, Brunei – and partially Tutong – consists of mainly mountainous rainforests and lowlands, being among the countries with high forest cover (GBD, 2014; comp. GBD, 2018): Around 75% of the country's total land area is covered by the natural vegetation of tropical evergreen rain forests, which are composed primarily of old growth forests (GBD, 2014). Moreover, 41% of the country's total land area inhabits the national forest reserves, being protected by law (GBD, 2014). This fact might be of interest for preventing or mitigating parts of the adverse effects of floods in Tutong District due to better soil stability throughout forests and absorption capacity, especially of water through the vegetation cover. Here especially the sort of forest, primary or secondary, as well as the general sort of vegetation cover or intensity of land use (production forest, forest plantation areas, or protection, conservation, recreation forest, or national park) (comp. GBD, 2014) might be of interest. Also, the lowland character must be considered as creating a higher-risk exposition.

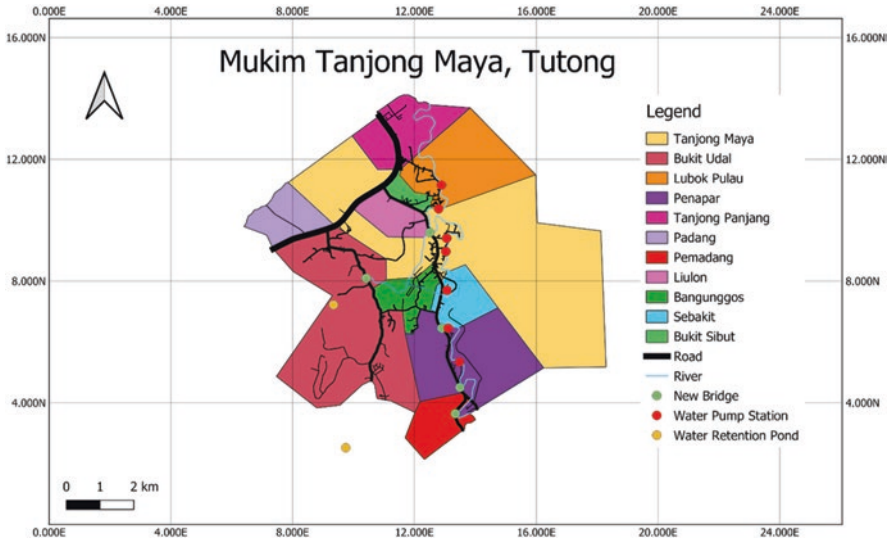

Fig. 8.4 The flood affected areas in Mukim Tanjong Maya, Tutong District. (Map source: Long, 2023)

Figure 8.3 demonstrates the flood events in Tutong District; the pattern of flooding in Tutong District is gradually increasing. The graph (Fig. 8.3) also shows that the flood trend line is very clearly displaying the floods increasing trends from low to high. In general, the trend was one or two flash floods were occurring in Tutong, but recently the number of flood events is getting high like in 2020 the floods event occurred 8 times and in 2022 the flood events occurred 6 times, the duration of floods are also getting longer time and the range is 4 days to 25 days (Long, 2023). The longer time is creating hardship moment for the affected people especially children and women of Tutong flood-prone areas. Figure 8.4 shows the flood-prone areas in Muking Tanjong Maya in Tutong District. This area was one of the most flood vulnerable areas in Tutong District. The drainage system and the geomorphological pattern is not flood-protective character, moreover the natural landscape displays the lowland and wetlands characters which ensure more vulnerability in the Tanjong Maya flood-prone areas (Long, 2023; NDMC, 2021).

Figure 8.4 shows the Mukim Tanjong Maya flood-prone areas in Tutong District where the geomorphological character and Tutong River catchment area and drainage pattern was not suitable for dispersing the rainwater or floods water through the drainage or river basin. The drainage system from Bangunggos to Pemadang in Mukim Tanjong Maya has been reconstructed which was very poor drainage character before and recently through Government initiative engineering construction has made in Tanjong Maya floodplain area, as a result there was no food in Tanjong Maya areas in Tutong District although the people of Tutong District has faced 10 floods and the duration of the floods was minimum 25 days in December 2022. The

data and Fig. 8.3 show that almost every month the citizen of Tutong town are facing flood problems in every month of the year.

Tutong District is further considered a cultural district in Brunei Darussalam due to its commitment to preserving its traditional customs and culture. It enables Tutong District to have its selling point to the international market, especially in the tourism industry. Historically, Borneo Island, while inhabiting Tutong District, is the place of case research for geomorphic, anthropogenic, cultural, and language diversity. It makes the whole Borneo region a unique island in the South East Asian region. Tutong District is also influenced by Brunei being a diverse country, being derived from the country's diverse historical links with the Hindu empire in the neighboring regions and modern-day Indonesia and Malaysia (BBY, 2014, 2015). From the point of cultural heritage further, an interesting fact is that Tutong District includes five major ethnic communities, the Tutong, Dusan, Kedayan, Iban, and Chinese: In mid-1990, an estimated 28,800 people were living in the District, of whom 23,700 were Malays, 2100 were other indigenous people, 2100 were Chinese, and 900 other ethnic groups. Of the total population, 15,000 were male and 13,800 female (DI, 1992). Indigenous groups such as the Tutong and Kedayan live in the urban and suburban areas, while the Dusan and Iban are mainly found in the rural and remote parts of the District. The majority of the population is Muslim. The rest, like the Chinese, Dusan, and Iban, practice their faith through their respective customs and traditions (DI, 1992). The herefrom evolving cultural and indigenous habits, traditions, and heritage are the same important for understanding, on the one hand, the role of Tutong River and its basin also in correlation to the implementations of cultural traditions and, on the other hand creating and developing approaches to mitigation measures, which are consent to exactly these cultural habits and traditions.

4 Results and Discussions

Brunei and Tutong District are located in the South China Sea, so it is prone to various disasters. Though Brunei Darussalam is free from major natural disasters such as earthquakes, volcanic eruptions, and typhoons, it experiences low-level hazards from earthquakes, cyclonic storms, thunderstorms, monsoon floods, anthropogenic-induced disasters, landslides, forest fires, seasonal smoke, hazes resulting for instance from forest fires in Indonesia (Gupta, 2010). Floods and landslides are the most prevalent hazards (NIDM, 2014; Irlapati, 2017), for which floods, especially monsoon and flash floods, are getting implemented in case of future mitigation approaches. The main importance is deriving since 97% of the population lives in the western lowland region of Brunei (comp. NIDM, 2014) and, therefore, partially within Tutong District. In order to find solutions to the floods in Tutong District within Brunei Darussalam, the possible sources of floods were observed for Tutong District in Brunei Darussalam. Also, the flood disaster risk in Tutong District played an active part in achieving solutions. The role of Tutong River for flooding at the

catchment scale was a further vital investigation in receiving results in sorts of approaches to mitigation measures. The viewpoint on the impacts of floods on the socio-economy in flood-prone areas helped to reach a higher community-based acceptance of the to-be-implemented mitigation measures. Moreover, an understanding and overview of the weather- and climate-related disaster form of floods in Brunei Darussalam could have been improved.

4.1 Sources of Floods in Tutong District in Brunei Darussalam

Floods or inundations are defined as the overflow of river water from the river banks surrounding the alluvial areas due to high runoff. Flooding is a natural phenomenon that occurs on the Earth's surface. However, human disturbances in the river floodplain cause the weakening of the river's geomorphological condition and, as a result, increase the risk and vulnerabilities of the alluvial plains against floods (Smith, 2013; comp. Ali et al., 2019). This phenomenon of flooding is difficult to control and sometimes inexorable. Regarding river systems, the human dimension and influence get clear: First, rivers are natural water resources for dwellings on the Earth's surface.

Nevertheless, channels cover about 75% of the Earth's crust and play a dynamic role in the hydrological cycle, serving as a drainage system for surface water. Thus, floods occur when the available water in the river exceeds the capacity to absorb it. Flood or inundation is a natural hazard that occurs on the surface of the Earth and are natural phenomena in tropical and sub-tropical regions. There are various reasons in any region of the world for these hazards, the risk, and the severity of flooding. "Regular" annual flooding is a desirable event for farmers and local inhabitants in the rural and urban areas of Brunei Darussalam. It commences at the right time for cultivation and lasts for an appropriate time to benefit paddy rice, other vegetation, and other major crops (Haque, 1997). The local landscapes, sloping patterns, drainage system, temperature, wind, and monsoon rainfalls are the most influential flooding factors in a particular region, such as Tutong District (Figs. 8.5 and 8.6).

Besides, the climate change impacts, drought, other natural and anthropogenic influences, and development activities are also responsible for arranging a flood in a particular area and region: rising sea levels (with saltwater intrusion), heavy rainfall, or increasing urbanization are some of the reasons for an increase of areas being flood-prone in Brunei (Saxena et al., 2012) and therefore in Tutong District in the future (Saxena et al., 2012).

However, excessive water in the rainy season often endangers human lives, livelihoods, agricultural crops, and other tangible assets. This negative aspect of floods is locally expressed by the term flood, meaning abnormal flooding (Haque, 1997). Therefore, the socioeconomic impact of such riverine hazards is more extensive and

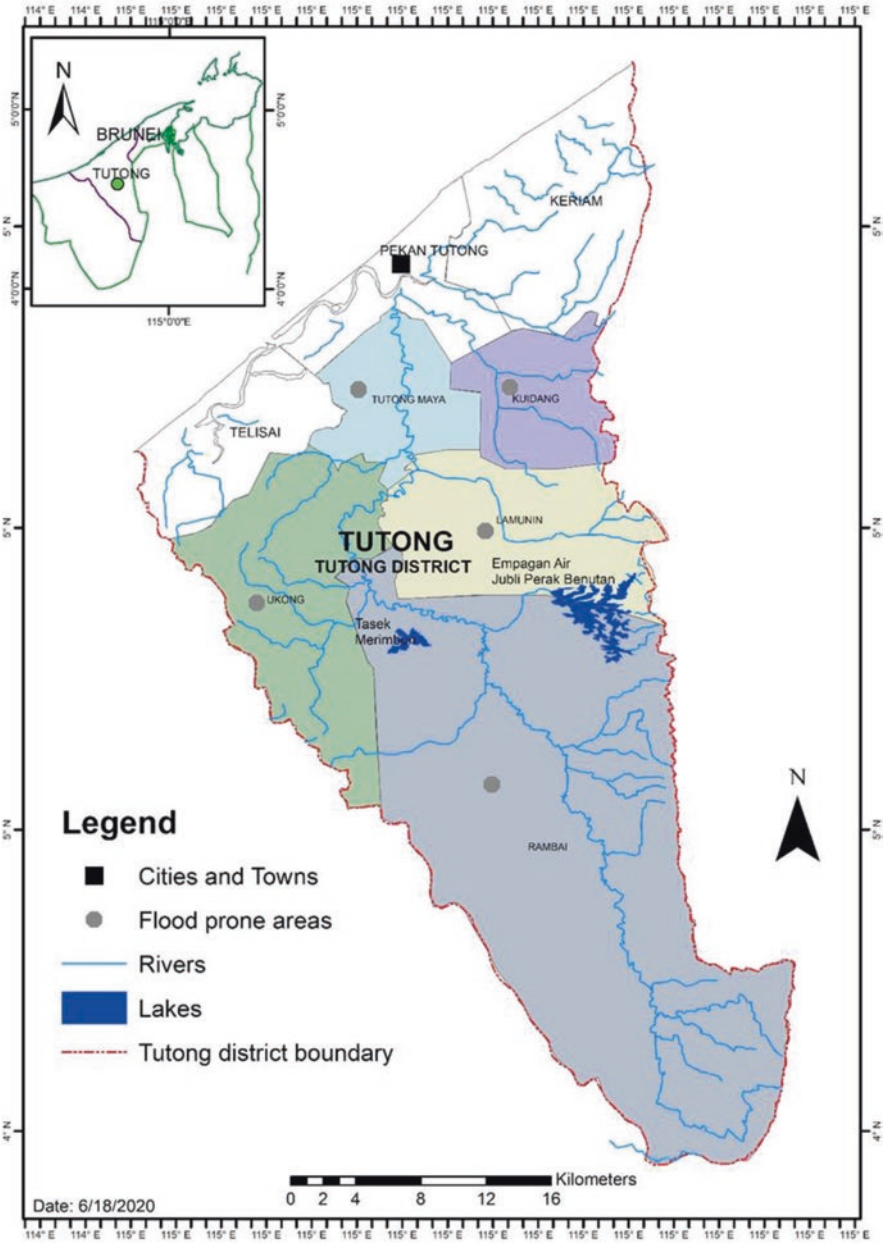

Fig. 8.5 Location of Tutong District and the flood-prone areas. (Source: GIS Lab, Department of Geography & Environment, FASS, UBD at 18.06.2020 (GIS Lab UBD, 2020))

Fig. 8.6 In the Pekan Tutong River Basin area in Pekan Tutong flooding scenario in 2020, the upper and lower scenario with flooding scenario in 2020. (Source: photographs made by Islam, 2020)

devastating than other types, such as droughts, tornadoes, cyclones, and massive riverbank erosion in the region (Haque, 1997).

The example of the Tutong flood in 2020 (Fig. 8.5) shows that several low-lying parts across the country were submerged in water following continuous heavy rainfall in many country areas. Especially low-lying areas are prone to floods, monsoon

floods, or flash floods, which might create fallen trees, causing massive traffic jams on roads and other more serious impacts. The Tutong River, with its channels, might also be one source of overflowing parts of the Tutong District, possibly flooding infrastructure, houses, streets, or several shops in Pekan Tutong (Figs. 8.5 and 8.6). Areas affected by that flood in Tutong included Mukim Keriam, Mukim Kiudang, Tanjong Maya, and Ukong. For example and fortunately, the water level at Hassanal Bolkiah Mosque in Pekan Tutong receded just before the mid-day prayer in 2020 (Fig. 8.5). The whole mosque and mosque complex was inundated, and two third the height of the Mosque building was inundated in the 2020 floods. The Fire and Rescue Department's Tutong branch received six reports of uprooted trees, four landslides, and five flash floods and urged motorists to use alternative routes.

So human intervention also impacts the severity of the unfolding disaster as such dam breaches cause severe and explosive downstream flows leading to flash floods or overflowing channels that might inundate such infrastructure, religious places, streets, and different places. Human influence needs to get balanced with natural space. In addition, human interventions lead to climate change, triggering back in a cumulative or synergistic way the further partially also human-induced natural hazards such as floods (Islam, 2014).

4.2 Flood Disaster Risk in Tutong District

The number of flood-prone areas could increase in Brunei (Saxena et al., 2012) and, therefore, in Tutong District. After the exposure map of Brunei Darussalam with its districts and depicted hydrological exposure index, the hydrological exposure in Tutong District is high. After the vulnerability map, the integrated vulnerability index is moderate (Kumar et al., 2021). Tutong districts' proximity to the riverside is very less. Up to that, the district is facing the maximum number of rainfall days and maximum flood durations (Kumar et al., 2021). So flooding in Tutong District is getting a regular annual climatic phenomenon. Also, Tutong areas are well below sea level. Brunei's and, therefore, Tutong's flood-prone (Figs. 8.6, 8.7 and 8.8) or hilly areas are at further risk of landslides. In these redrawn flood risk maps of the case of 3 m (Fig. 8.7) and 6 m (Fig. 8.8) above sea level, higher rising overall water levels are simulated over FloodMaps (2020): The elevation unit layered on the map is in meters. It starts from a height of sea level, which is zero. A negative elevation means depth below sea level (Figs. 8.7 and 8.8). Data sources were Mazpzen, TNM, SRTM, GMTED, and ETOPO1, with additional data sources of Leaflet, Esri, and OpenStreetMap. Inland lilac areas are the concerned inland areas (next to blue colored ocean area), which are the water-inundating and, therefore, future potential flood-prone places in case of these heights of water rise with the need for stronger or most substantial protection (Source: FloodMaps, 2020; with additional data sources of Leaflet, Esri, OpenStreetMap, Mapzen, TNM, SRTM, GMTED, ETOPO1).

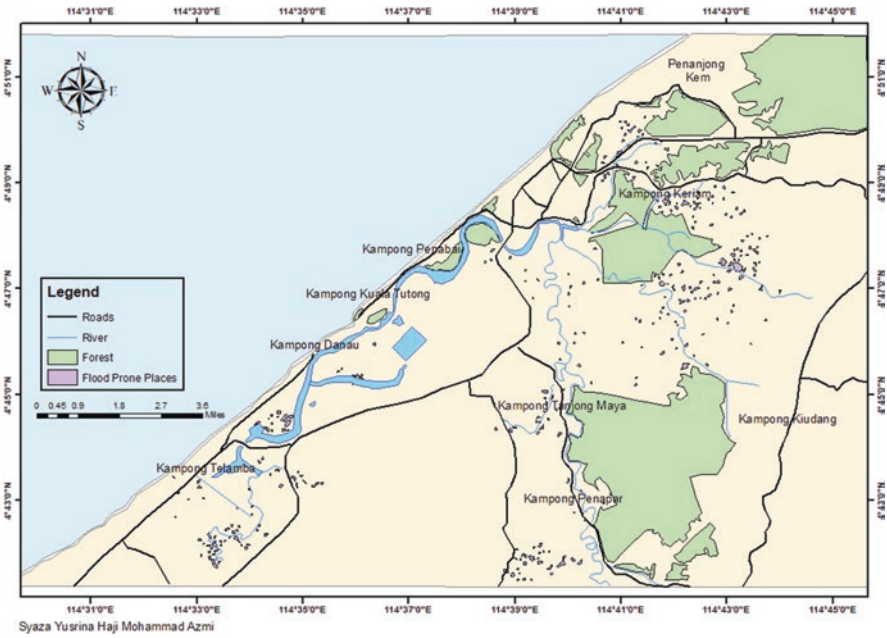

Fig. 8.7 Redrawn excerpt of the map for Tutong District with three meters above sea level higher overall water level: inland lilac areas are the concerned areas, which are the water-inundating and therefore flood-prone places with a need for stronger protection. (Source: FloodMaps, 2020; with further data sources of Leaflet, Esri, OpenStreetMap, Mapzen, TNM, SRTM, GMTED, ETOPO1)

It spatially verifies the high grade of exposure index for Tutong District by Kumar et al. (2021). In case of sea level rise, these simulations might also serve for partial answers on endangered low-lying areas being the same endangered throughout flash floods, thunderstorms, and monsoon floods. However, these elevation flood maps on their own might not be sufficient to analyze flood risk. Many other factors are involved, such as surface runoff, land type, soil type, flow diversion, etc. Those are the same responsible for the flood coverage in addition to elevation.

As seen in Fig.8.7, Tutong river and its catchment or Tutong River Basin (TRB) is another sensitive area and source of flooding, of which the Public Works Department (JKR) is aware. The nearby lying dam is another sensitive place in mitigation measures (NDMC, 2021). When a flood appears, the choice is to release the water or let it break and wash up as far as the Tanjong (TG) Maya-Lubok Pulau area. As the main transport way and access point to the district, the highway might have a high-to-be-observed infrastructure and security function. Also, severe damage to crops and property is caused due to uncontrolled flash flows in the TRB (Shafiuddin, 2014).

Further on, historical records of disasters in Brunei (Table 8.4) show the emergency for future mitigation measures and strategies. In its hazard profile, historically, Brunei is one of the least vulnerable countries to natural hazards (Gupta, 2010). Nevertheless, it faced a few disasters, such as in 2009, Brunei faced floods, a pandemic, landslides, a severe fire outbreak, and a haze (Gupta, 2010). Brunei was

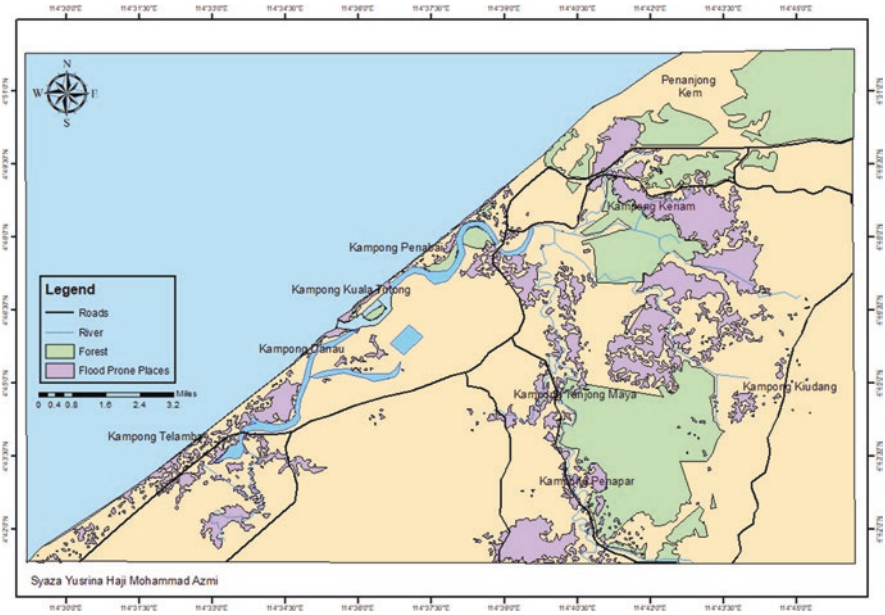

Fig. 8.8 Redrawn excerpt of the map for Tutong District with 6 m above sea level higher overall water level: inland lilac areas are water-inundating and therefore flood-prone places with a need for strong protection. (Source: FloodMaps, 2020; with further data sources of Leaflet, Esri, OpenStreetMap, Mapzen, TNM, SRTM, GMTED, ETOPO1)

partially disrupted in 2008 by landslides, floods, and strong winds, while in 2007, the country faced floods and strong winds (Gupta, 2010; NIDM, 2014; Saxena et al., 2012). The topographic area of the country of Brunei is not located in an earthquake hazard-prone area and therefore is a low seismic hazard region (GSHAP, 1998). Nevertheless, the region experiences reputedly high seismic hazards: The capital city Bandar Seri Begawan has experienced small earthquakes of a magnitude of 4–5. It caused the swaying of some high-rise buildings (5–6 stories) in 1992 (Waifong, 1993) and 2005. Further on, Brunei suffered from a forest fire disaster in 1998, which caused an economic loss of $two million with no reported casualties (Gupta, 2010).

So a general hazard-risk in Brunei is high with being impacted by global climate change as well as by the country's local geography and Brunei's relative location in the Asia–Pacific Region (in before Table 8.3) (comp. Gupta, 2010; NIDM, 2014; Saxena et al., 2012; Ndah & Odihi, 2017). Nevertheless, (1.) a limited reporting of localized disasters to international databases, however, prompts a misperception of low disaster risk in Brunei (Ndah & Odihi, 2017); (2.) limited knowledge, awareness, and motivation among the general population leads into high community vulnerability and disaster risk; to be activated knowledge, awareness, and motivation among the general population should be strengthened and would support effective mitigation and adaptation to lower magnitude but recurrent hazardous events (Ndah & Odihi, 2017); and (3.) only a partial, situated implementation of disaster risk reduction into development plans and governance structures contributes to

Table 8.4 The major disasters witnessed by Brunei Darussalam (since 1960) and flash floods were more consequently affecting, especially in Tutong District

S/N	Year	Name of Disasters	Impacts in society
1.	1962	Major floods	More than 2000 people were directly affected due to significant floods in Muara, Tutong, and Belait districts.
2.	1980s	Fire in Water Village	Over 200 incidents have occurred in Kampong Ayer (Water Village), and over 200 family and householders have lost their houses and properties due to a fire in Kampong Ayer.
3.	1987	Rasau Gas blow-out in Belait District	A gas blow-out in Belait District has severely damaged natural resources.
4.	1991	Poor air quality resulting from Mount Pinatubo eruption in the Philippines	The air quality of Brunei Darussalam was degraded during the mount Pinatubo eruption in the Philippines.
5.	1992	Small earthquakes in capital	The capital city Bandar Seri Begawan has experienced small earthquakes in a range of magnitude of 4–5, causing swaying of some high-rise buildings (5–6 stories) in 1992 and 2005.
6.	1998	Regional haze	Regional haze is a new threat for East Asian Countries as it is located in the southeast Asian region.
7.	1998	Forest fire disaster	The forest fire caused an economic loss of $ 2 million with no reported casualties.
8.	1998/1999	Flash flood during La Nina	Six flood-prone areas were affected by flash floods.
9.	2005	Small earthquakes in capital	The capital city Bandar Seri Begawan experienced small earthquakes (magnitude of 4–5) with swaying of some high-rise buildings (5–6 stories)
10	2007	Floods and strong winds	Bruneian people faced the impacts of strong floods and strong winds
11.	2008	Temburong flash floods, landslides, and strong winds	Community people are affected by flood damage and damage to agricultural crop fields.
12.	2009	Extensive flash flood in Brunei-Muara/Tutong and Belait Districts	Brunei faced floods, landslides, a pandemic, severe fire outbreaks, and haze.
13.	2010	Influenza A (H1N1)	Almost in every district (four districts), citizens were affected due to Influenza in Brunei Darussalam.
14.	2012	Heavy rainfall creates pluvial flash floods and thunderstorms in Tutong and Belait Districts.	Mukim Miudang and Mukim Lamunin of Tutang District are most affected by flashflood and thunderstorms during monsoon time.
15.	2019	Pluvial flash flood in Tutong Districts	Over 45 Tutong families were affected by floods during the monsoon season in early December 2019. (Source: The SCOOP, December 2019)

(continued)

Table 8.4 (continued)

S/N	Year	Name of Disasters	Impacts in society
16.	2020	COVID-19 Pandemic (1st wave)	141 were affected, and two died.
17.	2020	Pluvial flash flood in Tutong Districts	December 2020, January 2021, like Nr. 17 and flood cases 34 in Tutong District
18.	2021	COVID-19 Pandemic (2nd wave)	13,545 were affected, the number of deaths is 55, and 12,098 recovered from the case (until November 5th, 2021).
19.	2021/2022	Pluvial flash floods in Tutong and Belait Districts during the monsoon months of November until March 31st, 2022. COVID-19 Pandemic case until March 31st 2022	Severe floods occurred in Tutong and Belait Districts, and almost ten sub-districts were affected in Tutong and Belait Districts in 2021. Three floods have occurred in Tutong in 2023 A flash flood occurred in Tutong on the 22nd and 23rd of March, 2022. 73,919 affected – total number of cases 127,970 and total death is 94 until March 2022
20.	2022	Pluvial flash flood in Tutong District and the COVID-19 Pandemic until November 2022	Until December new cases has been seen in last 7 days affected 484 total deaths –225 and total cases – 241 K (Source: https://www.worldometers.info/coronavirus/country/brunei-darussalam/ retrieved: 27th September 2023)
21	2023 until September	COVID-19 Pandemic cases detected in September 2023	The total number of cases detected by September 2023 and the affected case is 310,522 and total death in Brunei is 225. Data Source: Borneo Bulletin,tenth June / and September 2023.

Gupta (2010), NIDM (2014), Saxena et al. (2012), Borneo Bulletin daily News Paper with next to others Osman and Lim (2018) as well as MOH, Government of Brunei Darussalam in (2019, 2020, 2021) and (2022), (2023)

heightened disaster risks (Ndah & Odihi, 2017; comp. AHA and JICA, 2015; NIDM, 2014; Saxena et al., 2012; Gupta, 2010).

4.3 The Role of Tutong River for Flooding in the Catchment Area

The Tutong River and the surrounding landscape features and sloping patterns are the potential factors of frequent flooding in the Tutong region. The flow assessment is essential for developing flood prevention measures (comp. Shams, 2015). Therefore the characteristics of Tutong River and its basin had to be described as follows: The Tutong basin area or catchment area is vast and measures about 1300 km^2 (Fig. 8.9), for which Fig. 8.10a, b, c identified the flood affected areas visually on parts of the Tutong River catchment. The upper section of the river

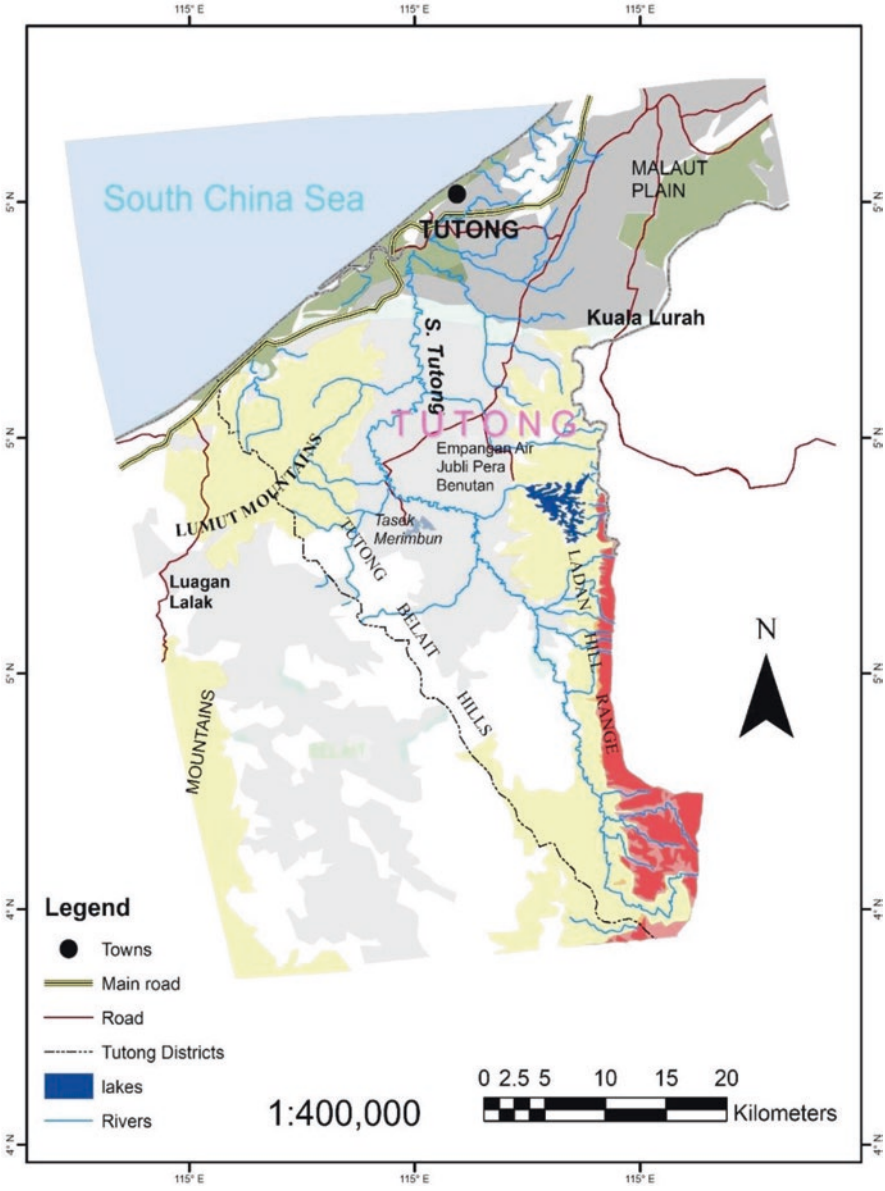

Fig. 8.9 The river system, landscapes, and flood-affected areas in Tutong. (Source: GIS Lab, Department of Geography & Environment, FASS, UBD at 18.06.2020 (GIS Lab UBD, 2020))

covers a mountainous and pristine forest. 70% of Brunei Darussalam's forest is pristine and untouched by humans. The settlements are located from the high-sloping to the low-sloping areas. Only the Pekan Tutong area is the high land area beside the Tutong Riverbank area as a shallow land area. The main roads are located in the

Fig. 8.10 (**a**–**h**) The eight different flood-prone areas are displayed (Locations Numbers **a**–**h**) (Locations of the flood-affected areas are **a** – Pekan Tutong, **b** – Lamunin, **c** – Kampong Rambai, **d**- Jalan Kuala Ungar, Tutong, **e** – Rambai area, Tutong, **f** – Rambai area, Tutong, **g**-Tutong River, Rambai, and **h** – Jalan Kuala Ungar, Rambai, Tutong)

lowland areas, but the highway is in higher altitude areas. The settlements in the lowland area have monsoonal floods every year, but some years the damage is more severe and crucial for the Tutong inhabitants.

Geographically, this river is also situated on alluvium, clay, and sand. The sampling area has a volume of approximately 500 m^3 with a maximum depth of about

3 m. The sampling points started from the Kelakas River tributary, surrounded by mangrove and Nipah swamps, straight into the Tutong District center, along the market and woodcutting industry areas. The sampling ended at the beach area, very close to the sea. The sampling locations can be seen in Fig. 8.10a–h. In the case of Tutong District, the river flows from the upper course, which is located in Ulu Tutong, then continue to flow toward the middle and lower course, where most of the settlement buildings and commercial sites, including all villages which are located in the flood-prone area (villages). The efforts and strategies put into both villages might have worked for a short time. However, during prolonged heavy rainfall, especially in the upper course of the river will reach its maximum capacity, which eventually will flow out of the river channel and flood the areas nearby (Muizz, 2021).

Figure 8.10b shows one of these rural areas in the Tutong District. This depicted place is part of the middle basin of the Tutong catchment (TRB). In theory, the meandering river, where erosion activities are dominant, would create erosion activities while initiating the river to meander deeper, and the surrounding floodplain, therefore, would change its appearance and river bed placement. Moreover, these areas are low-lying areas and prone to flooding. Houses and buildings are seen in Fig. 8.10b, c, showing that they are at risk. A more vulnerable environment can be predicted for the future in the surrounding areas. Humans populate the middle section of the river channels, which consist of rural areas such as Kampong Rambai, Kampong Lamunin, and Kampong Layong. The main income for these villagers is primarily through agriculture, living in the alluvial plain area, where the soil is fertile, rich in nutrients, and has a high chance for a successful crop outcome. As can be seen through Figs. 8.9 and 8.10b, c, in these areas population lived historically in a linear pattern along the river floodplain.

These land patterns are due to their fertile soils and transportation purposes, as in the early days, transportation services were handled through waterways. However, due to the floodplain area combined with the low-lying area, the vulnerability of these individuals is fatal, especially in correlation to natural hazards, such as floods. These locations are severely flooded and affected by flooding in Tutong District (comp. in before Figs. 8.6, 8.7 and Figs. 8.8, 8.9).

The after the La Nina flooding from October 1998 to 1999, the Integrated Environmental Consultants (IEC) Brunei for Tutong River (Figs. 8.7 and 8.8) developed Sungai Tutong Early Flood Warning System gives a further spatial overview of necessary floodplain management and capital work to reduce flooding impact (IEC, n.d.; comp. Saxena et al., 2012): The historical floodings scenario displays that the majority of Tutong District's subdivisions are affected by annual monsoonal rainfalls and annual flooding (IEC, n.d.); the following areas are mostly the common areas where the annual floods destroy and damage house property construction, housing structure, road construction, and networking system; the areas are as follows: Keriam, Pekan Tutong (A), Tanjung Maya (D), Ukong, Kiudang, Lamnin, Kampong Panchong, Kampong Pangan, and Rambai areas being located in the downstream of the TRB areas (Fig. 8.10a–h) (IEC, n.d.).

Coordinating instances in case of Tutong River catchments' floods is the National Disaster Management Centre (NDMC), along with various other agencies such as the Operation Branch 'B' of the Fire and Rescue Department, the Third Battalion, the Belait District Branch of the Community Development Department (JAPEM) as well as the Belait and Tutong PWD are currently making efforts to control the situation and provide assistance to those affected in the flash floods (Ummu, 2021; Nurhamizah, 2021).

4.4 The Impact of Floods in Flood-Prone Areas on the Socio-economy

Brunei, as part of the Asia–Pacific Region (APR), is a natural hazard-prone area. The APR's socio-economy has a combined population of 622 million (UNISDR, 2016; Ndah & Odihi, 2017)—of which Brunei has a population size of 0.42 million and an urban population rate of 76.7% (NIDM, 2014)—with an average direct economic loss from disasters worth US$ 4.4 billion annually (UNISDR, 2016; Ndah & Odihi, 2017). Therefore, enormous socioeconomic costs threaten sustainable development and livelihood in the APR (UNISDR, 2016; Ndah & Odihi, 2017). As for Brunei, due to a lack of disaster data, the disaster risk analysis for economic loss potential has not been carried out (Gupta, 2010).

In Brunei, natural gas and crude oil production accounts for 60% of the gross domestic product (GDP) and more than 90% of exports (NIDM, 2014). Substantial income from overseas investment complements revenue from domestic production (NIDM, 2014). The Brunei Government has strong intentions to diversify the economy both within the oil and gas sector. However, new sectors should be introduced through policies and resource investments (NIDM, 2014). Brunei, particularly the inner parts of Tutong, has a small, prosperous economy that depends on revenue from natural resources. However, it comprises a mixture of domestic and foreign entrepreneurship, welfare measures, government regulation, and village traditions (NIDM, 2014).

Village traditions and other social activities and economies are predestined for negative impact due to floods. In December 2019, 47 Tutong families were affected by floods during the early monsoon season (Bakar, 2019). And since 97% of the population lives in the lowland western region of Brunei (NIDM, 2014), the prolonged risk of natural disaster is increasing.

In 2020, stronger and more severe floods have damaged and affected families and have continuously increased. The severity of the floods in Tutong in 2020 could be seen when citizens stayed at home for long durations as the main road was flooded and land vehicles could not move anywhere. The water taxi was the only possible vehicle used for transportation and mobility.

Throughout 2020, some 500 families faced problems with their homes during the massive floods in Tutong, and students also faced irreparable damages to books,

computers, and other educational materials. In 2021, the Brunei Darussalam Meteorological Department (BDMD) warned of the occurrence of wind speeds of up to 50 km/h (Ummu, 2021; Nurhamizah, 2021), and the public and motorists were urged to be on alert and to take necessary precautions to ensure their own safety (Ummu, 2021; Nurhamizah, 2021). However, 17 houses in Kg Sungai Liang, Kg Tunggulian, Kg Sungai Bakong, Kg Sungai Lalit, Kg Sungai Kuru, the Government Barrack Housing area located near Brunei LNG, as well as the Barrack Housing Area in Lorong Tiga Selatan, Seria were all affected by flash floods. It was so severe that the roof of one of the houses was blown away by heavy wind that accompanied the torrential downpour.

4.5 Flood Mitigation Measures and Solutions

In light of the aforementioned events, it is undeniable that the floods need to be mitigated. Measures are already being taken into account to lower the chance or risk of each occurrence. In the case of Brunei, the government has contributed with evaluative, coordinative, administrative, communicative, informative, and directive actions to help reduce the risks during these hazardous events. The National Disaster Management Centre (NDMC) plays a vital role in monitoring and allocating vulnerable areas, analyzing anthropogenic structures to lessen society's impact, building artificial levees, and widening the river channel (NDMC, 2021), while BDMD is responsible for providing meteorological and climate services, monitoring, and analyzing weather conditions. BDMC continues to issue weather warnings, for instance in the cases of heavy thunderstorms and flash floods in low-lying areas (Islam et al., 2018, 2019).

In the case of TRB floods, NDMC, along with agencies such as the Fire and Rescue Department, the Third Battalion of the Royal Brunei Land Force (RBLF), the Belait Branch of the Department of Community Development (JAPEM), as well as the Belait and Tutong Public Works Department (PWD) are responsible for controlling the situation and providing assistance to those affected, especially during flash floods (Ummu, 2021; Nurhamizah, 2021; Islam et al., 2014b, 2017). During the 2019 floods in Tutong, the Second Battalion of the RBLF was responsible for transporting residents from their affected homes in trucks (Bakar, 2019), while other uniformed officers were delegated to help and assist the vulnerable population. On a district level, the Tutong District Disaster Management Council (Tutong DDMC) provides fiberglass boats as transportation to affected residents (Islam et al., 2014b, 2017).

On a practical level, active flood prevention and planning are needed, such as administrative, coordinative, or communicative spheres and governance (Reinstädtler, 2022a, b, c, 2021a, b) and need to be communicated so that the relevant authorities can take responsibility. In Brunei, practical measures for active flood prevention have resulted in the development of the Early Warning System

(EWS), proposed by the Brunei Integrated Environmental Consultants (IEC) after the La Nina floods that occurred from October 1998 to 1999 (IEC, n.d.; Saxena et al., 2012); it should have been instigated for the country starting from the Tutong River. An overview of a flood study was undertaken using the Storm Water Management Modelling (XP-UDD), field investigations, and a history of the river from the residents' perspectives (IEC, n.d.). This overview on flood study provided the basis for hazard assessment and floodplain management while incorporating EWS, hazard control, and capital works improvements (Fig. 8.7).

EWS uses electronic sensors for upstream river levels, which telemetry conveys to control rooms at Bukit Barun and the Department of Drainage and Sewerage (DDS) at the PWD headquarter (IEC, n.d.). For downstream villages, the system provides lead times of 12–15 h, and up to 25 h for Tutong Town at the bottom of the catchment. DDS can produce daily reports predicting flood levels for 13 locations. The integrated flood hazard control provides a mapping of flood-sensitive areas, identifies danger levels for vehicles and pedestrians, and suggests flood response strategies (IEC, n.d.).

Further to the described advantageous flood forewarning system as a mode of emergency preparedness, reports such as NIDM (2014), AHA, and JICA (2015) provide further details on the roles, achievements, legislative and operational aspects of disaster management in Brunei (NIDM, 2014; AHA & JICA, 2015; Ndah & Odihi, 2017) and should be implemented in the approach for flood mitigation measures.

Meanwhile, some flood mitigation projects are also being implemented on a stand-alone basis (Shafiuddin, 2014). The relevant government departments had introduced projects that had been processed without considering and integrating the essential aspects of water issues, such as over-drainage, storage of residual flood flows on streams for agricultural irrigation requirements, and agro-land reclamation by leaching whole saline-damaged agri-fields (Shafiuddin, 2014). With follow-up projects, these parts have to be acknowledged for the countries' best interest in general and for TRB in particular. Therefore, an infrastructure for the development of irrigated agriculture is required which would utilize residual flood flows that have been stored in the streams (Shafiuddin, 2014).

Another essential approach for the development of flood mitigation measures and solutions is the availability of disaster data in order to analyses diverse coherences. However, due to the unavailability of any existing disaster data (except for one forest fire event), a disaster risk analysis economic loss potential (AAL) and economic losses for different probabilities of exceedance could not be carried out (Gupta, 2010). While these deficits have been bettered today, the consequences had been taken into account in 2006: the country established the NDMC to take on disaster risk reduction (DRR) initiatives. Furthermore, a National Progress Report on the Implementation of the Hyogo Framework for Action (2009–2011) was also developed (GBD, 2011).

An elevation flood map such as the existing one (Figs. 8.5, 8.6, 8.7, 8.8, and 8.9) should always be carried out in all planning processes and to strengthen the

understanding and necessity for the implementation of mitigation measures on the ground. Elevation flood maps on their own are not sufficient for the analysis of flood risks. The awareness for preventive organization in spatially localized areas is a greater step forward. Many other factors are involved and have to be acknowledged in planning activities: surface run-off, flow diversion, land type, soil type, etc. For natural hazards, calamities, and flood mitigation in particular, measures and remediations should be taken into consideration:

- Lowering risk factors through.
  - Establishing a risk profile due to historical disaster data.
  - Minimizing urbanization and in general minimizing sealing against higher water run-off.
  - Accepting the floodplain area as retention space in case of floods.
  - Planning measures for new retention areas in the floodplain area of the Tutong River such as a renewed NBD Master Plan (NBD, 1987) and a renewed National Land Use Master Plan (NBD, 2008) for any national and up to local informal processing.
  - Sustainable floodplain management plan that could be implemented properly.
  - Protection of forests, natural resources, and environmentally sensitive areas through land-use zoning (MIPR, 2008), and strenthening rural livelihoods in line with nature.
  - Mitigation approach and nature-based solution development on the basis of the entire watershed perspective.
  - Engineering measures and involvement as well as non-engineering measures.
  - Structural measures and non-structural measures.
- Improving flood disaster data through databases on a regional and national level: Solving a lack of information on the intensity and duration of floods while bettering the identification of different classes of flood hazards.
- Enhancing, developing, and implementing the disaster risk reduction indicator in correlation to flash floods and monsoon floods on a national level.
- Enhancing, developing, and implementing the flood risk reduction modeling.
- Natural mitigation and indigenous engineering knowledge application.
- Improving flood disaster risk reduction in planning spheres (GBD, 2011).
  - A national development plan, and Sector Strategies and plans.
  - A climate change policy and strategy.
  - Poverty reduction strategy papers (the less financial resources that exist, the more prone to disasters in general).
  - Common Country Assessments (CCA)/United Nations Development Assistance Framework (UNDAF).
- Natural resource protection, throughly,
- Stabilizing vegetation cover near the riverine system (Huang & Nanson, 1997).

- River catchment management and drainage system development in consent with sustainable land use.
- Water storage, drainage, and supply system development.
- People's awareness on development, participation, and engagement and
- Infrastructure and security functions:

Specific flood mitigation and adaptation measures might be of highest interest, such as re-building the highway as a main transport way and access point to the district in the form of a combined highway and dam (German examples of railway dams) or by building the road(s) higher by topsoiling them.

5 Discussions

The natural disaster rate in Brunei is comparatively low, but the recent trend of flooding in Tutong is actually rated higher. However, natural disasters that Brunei has encountered so far are mainly floods and landslides. This is supported by the Brunei Disaster Management Reference Book (CFE-DMHA, 2022), which said that floods in Brunei are the highest natural threat to the country, brought on by disasters from neighboring countries, such as typhoons in the Philippines, although Brunei is not located along the typhoon path. In January 2009, flooding in Brunei caused significant damages to the infrastructure and economy, and has also caused the loss of many lives. More than 200 houses were damaged and some 420 residents in Brunei-Muara were flood victims, while power failures and disruption of phone services and traffic also occurred (Ndah & Odihi, 2017). Disasters or hazards that occurred in Brunei in the past compared to the current scenario have shown a significant increase and change in statistics. As a result, they have become a source of worry and anxiety within the Bruneian community (Ummu, 2021).

Human disturbances in the river floodplain might be minimized to better the river's geomorphological condition and decrease the risk and vulnerabilities of the alluvial plains against floods (Smith, 2013; Ali et al., 2019). The existence of the Tutong River basin is the first agent or the main factor that contributes to the hazard of flooding, next to aspects of land use activities by the river. Moreover, the importance of vegetation cover along the river channel should be acknowledged; the thickness of vegetation cover reduces erosion because the roots decrease lateral erosion, reduce the risk of flooding (Smith, 2013; Ali et al., 2019), and absorb parts of the water runoff. However, in the case of Tutong, drainage basins are pressured by human development, which explains the high vulnerability and risk of catastrophic flooding in several areas. The catchment area of the Tutong basin is distributed into canals, tributaries, and distributaries due to human interruption to the river's natural flow, which should be reassessed.

Human intervention on the Earth's ecosystem, such as the drainage basin, contributes to another overwhelming phenomenon: climate change. About 75% of the

Earth consists of water and this natural resource creates life, but it is also crucial for life and dwellings. Climate change and the excessive production of greenhouse gases into the atmosphere causes a change in the pattern of the Earth's ecosystem. Global warming is one of the inducing factors that increases the Earth's temperature, which causes sea levels to rise in the coastal regions and thus contributes to vigorous coastal erosion. The intrusion of coastal water in estuaries strains the river's capacity to hold water and eventually causes floods (Shams, 2015).

Development such as housing communities and business centers along the floodplains also creates strain on the geomorphology. Furthermore, human development on the floodplain surface creates impermeable surface rainwater that cannot penetrate the surface, which causes high surface run-off. As a result, vegetated land surrounding the floodplain could result in the slightest, though less chaotic, floods. However, this is due to little or no surface run-off as the canopy prevents 15–30% of rainwater from trickling into the ground, and the vegetation soaks up the existing moisture during photosynthesis.

The 1987–2005 NBD Master Plan (NBD, 1987) and the 2006–2025 National Land Use Master Plan (NBD, 2008) regulate and require the protection of forests, natural resources, and environmentally sensitive areas through land-use zoning (MIPR, 2008). In any national and local processing, these rules should be incrementally adapted.

6 Conclusions

In conclusion, the Tutong River is a natural ecosystem that is characterized by the event of flooding. Therefore, flooding events are regular, and it is a natural phenomenon that occurs along the drainage basin. However, the strain and pressure of human development has increased the severity of flooding in recent years. In the case of the Tutong basin, the flood-prone area is pressured by human development such as agricultural activities and heavy infrastructure. A report by NDMC, supported by the author's own evaluations, has verified that flood-prone areas include Kg Telanai and Kg Bebuloh in Brunei-Muara and Kg Kiudang in Tutong. They generally show the high flood rate of the Tutong River, as well as other areas in Brunei. Meanwhile, a higher rainfall rate that occurs from November to February during the monsoon months also results in a higher tendency of flood to occur in these areas.

In recent years, Brunei has faced disasters, as seen in Table 8.4. For instance, in 1998, Brunei faced a forest fire disaster, while in 2007, the country experienced floods and strong winds. In 2008, Brunei experienced landslides, floods, and strong winds, while in 2009, the country was inundated with floods, landslides, a pandemic, a severe fire outbreak, and a haze. Further floods occurred in 2019, 2020, and 2020/2021, while in 2020 and 2021, the COVID-19 pandemic affected the Sultanate

as well as the rest of the globe. Thus, the country is always at risk of natural hazards such as landslides, floods, forest fires, storms (winds), and haze. Based on evaluations in Table 8.4, the number of flood-prone areas in Brunei could increase in the future, through an increase in heavy monsoon rainfall, rising sea level, and devastating floods in Tutong, as well as in the rest of Brunei.

Therefore, the country has created DRR initiatives, such as the establishment of NDMC, to coordinate and communicate responsibilities to all governmental administrative levels, from the country level to the district level, and to eventually to the local level.

Flood prevention and mitigation can be better optimized by: (1) Creating a limited reporting of localized disasters to international databases to avoid misperceptions; (2) Activating and strengthening limited knowledge, awareness, and motivation among the general population, while supporting effective mitigation and adaptation; and (3) Implementing a partial DRR into development plans and governance structures contribute to heightened disaster risks.

Recommendations for Mitigation.

Brunei has hosted different initiatives related to flood mitigation that should be further fostered to create awareness on landslides and flood risks in Tutong. This would thus mitigate and prevent while at the same time increase public awareness. People within the community could also actively participate in sharing indigenous knowledge on the mitigation of natural hazards.

- The Tutong and Brunei Flood Map may help provide flood alerts/flood warnings, in the event that the floodwater level rises to a certain point. A flood map could help locate places at higher levels where people could escape from floods or where flood rescue/flood relief operations could be conducted as preventive measures.
- Global warming and rising sea levels are effects of climate change. Date related to these events could also be incorporated into a floodplain map and flood line map for streams and rivers; and, as a result, the effect of rises and changes in sea-levels could be seen. It could be helpful in coastal areas for the purpose of monitoring and management, and could help perform elevation analysis of an area for purposes such as city or town planning, new construction, etc.
- The Brunei Government, non-government organizations, and social organizations need to make an effort to develop methodologies and policies, validate tools, and create impact assessment indicators and instruments for flood and riverbank erosion protection and management on a micro level in Tutong (Islam, 2016).
- Geographical Information Systems (GIS) and remote sensing techniques should be introduced in the data analysis, visualization, mapping, planning, and modeling of flood-prone areas for future flood forecasting, erosion control, general floodplain control, and effective management measures.

- Flood monitoring, forecasting, and warning systems should be developed and communicated in a more transparent manner to the locals. Disaster risk and disaster behavior education with exercises for locals, as well as for the disaster management operators responsible, should also be prepared in a better way to create awareness.

Additionally, the community's participation, mitigation and adaptation strategy, awareness education, and applied research on floods, floodplain management, and agricultural cropping systems should be incorporated into the national development plan agenda. Local residents should be equal partners in decimating the knowledge about river systems and flooding pattern in the floodplains as well as in catchment development. Together, all relevant parties could create a safer and more sustainable settlement and livelihoods. Therefore, indigenous knowledge, skills, and capacities should be incorporated to the ecological management of the Tutong River floodplain and basin area. These mitigation approaches could then positively influence the riverine floodplains, and landscapes of Tutong District in Brunei Darussalam.

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