Impact of Climate Change on water resources in the Context of Brunei Darussalam: IWRM Perspectives

Shahriar Shams
{shams.shahriar@utb.edu.bn}

Civil Engineering Programme Area, Jalan Tungku Link, Gadong BE 1410, Brunei Darussalam

Abstract. Water is vital for all living creatures, and life without it is unthinkable. The demand for freshwater over the last few decades has increased significantly due to increased population, urbanization, and erratic precipitation resulting from climate change. Brunei Darussalam, situated on Borneo Island with a population of 450,000, has witnessed a change in precipitation with increased intensity. The aim of this study is to identify the impact of climate change on water resources in Brunei Darussalam and to assess the impact based on IWRM perspectives. Temperature and precipitation trends over the last 30 years show increased trends with frequent flash floods. Increased precipitation with high intensity has caused flash floods, which often lead to increased turbidity and impact water quality. The tidal surge in the form of backwater flow has increased salinity upstream by 2.6%, which has particularly affected freshwater aquaculture. The rich biodiversity, aquatic ecosystem, flora, and fauna are facing threats due to increased salinity. Potential coral breaching near Pelumpong Island and Brunei reefs having greater depth are also vulnerable to global warming. The rise in sea level along the coastal area of Brunei Darussalam has increased by 5.5 mm per year. Besides, limited access to freshwater has impacted farming. The increase in precipitation can affect the crop yield as rice fields are prone to flooding and require a sustainable and adaptive approach like Integrated Water Resources Management (IWRM). Coordination among the Department of Drainage and Sewerage (DDS) and the Department of Agriculture and Agrifood (DOAA) can further strengthen IWRM application in the water sector.

Keywords: Brunei Darussalam; Climate Change; IWRM; Water.

1. Introduction

Water is crucial for humans, animals, and plants to survive and for society to achieve sustainable development. Particularly, the demand for freshwater over the last few decades has increased significantly, driven by increased population, urbanisation and erratic rainfall patterns influenced by climate change. It is essential to have a sufficient amount of water to ensure food security and a healthy ecosystem, which is why emphasis has been given to Sustainable Development Goal 6 (SDG 6). One of the solutions is to introduce or develop sustainable ways to manage water resources and make good use of them. In other words, fundamental shifts in

SRICOENV 2022, October 05-06, Palembang, Indonesia

DOI 10.4108/eai.5-10-2022.2328343

implementing better technologies, integrated water resources planning and management are needed.

IWRM was defined by the Technical Committee of the Global Water Partnership (GWP) as a process that encourages the coordinated development and management of water, land, and related resources in order to make best use of economic and social welfare in an equitable way without putting vital ecosystems at risk. In Brunei Darussalam, the Department of Water Services is in charge of planning, designing, and managing the country's water resources to make sure they are sustainable and have enough water to meet future needs. This includes protecting and preserving the existing and potential future resources. Their long-term water supply development goals are (i) ensuring continuous water supply by increasing the resilience of water resources and managing water demand; (ii) improving overall network efficiency and reducing non-revenue water loss; (iii) providing clean and safe water for all to use; and (iv) strengthening good governance and improving service delivery.

Brunei Darussalam, located on Borneo Island with a population of 450,000, has witnessed a change in precipitation with increased intensity. Increased precipitation with high intensity has caused flash floods, which lead to increased turbidity and impact water quality. The aim of this study is to identify the impact of climate change on water resources in Brunei Darussalam and to assess the impact based on IWRM perspectives.

2. Climate change's impact on the hydrological cycle

Precipitation, evaporation, runoff, groundwater, and soil moisture are the key components of the hydrologic cycle, which is linked to variations in air temperature and radiation balance. The impact of climate change results in spatial and temporal trends in precipitation, variation in evaporation, changes in soil moisture, and river flows that affect flooding conditions. The situation is further aggravated by the rise in sea level resulting from tidal effects.

2.1 Changes in precipitation patterns, both spatial and temporal

Precipitation changes have significance for hydrology and water resources because they impact the water balance. Rainfall intensity may affect the volume of the catchment, contributing to seasonal, prolonged, or short-term flood and drought frequency. Rising temperatures intensify the influence of the hydrologic cycle through increased evaporation. Statistical downscaling techniques have been used by many researchers to look at changes in precipitation and temperatures in Brunei Darussalam's past and possible future climate change. [1-3].

2.2 Change in evaporation

The rate of evaporation is determined by vegetation and soil conditions, as well as the availability of water. The process of potential evaporation rises with temperature, owing to the increased water-holding capacity of air. The moisture retention capacity of the atmosphere

increases by 7% for every 1°C increase in global temperatures [4]. As a result, increased moisture in the atmosphere eventually causes changes in precipitation patterns.

2.3 Soil Moisture

The soil's water storage capacity is critical to agriculture because it influences the rates of evaporation, groundwater recharge, and runoff generation. The impacts of climate change have various effects on soil moisture depending on the extent of the change and the properties of the soil. Soil moisture storage is most vulnerable to climate change, especially when its water-holding capacity is at its lowest. This can further worsen with the change of soil characteristics as it goes through changes in waterlogging and cracking.

2.4 River Flows

The effects of climate change on river flow are linked to changes in precipitation and temperature rise. These patterns were recorded in various parts of Russia, Eastern Europe, central Canada, and California, indicating a significant change in river discharge between spring and winter since rainfall occurred instead of snow fall, allowing rivers to flow faster than before [5]. In general, where there has been an increase in precipitation, runoff tends to increase, and vice versa. When and for how long the rainy season lasts have a significant impact on runoff regimes in humid tropical locations. River flow is thus influenced not just by climate change through variations in rainfall magnitude but also by possible changes in rainy season duration.

2.5 Rise in sea level

The rise of the sea level is a major concern as it relates to climate change. The rapid warming and melting of ice caps in the Arctic has led to a concern that many countries, such as the Maldives, Bangladesh, Vietnam and the Philippines, are vulnerable to inundation, particularly in their coastal areas. The sea level rise can have a catastrophic impact on the livelihood of people living in coastal areas by causing salt water intrusion, damaging crops, loss of freshwater ecosystems, and impacting coastal habitats farther inland.

3. Study Area

Brunei Darussalam is a small country consisting of four districts that are located on the north coast of the island of Borneo in Southeast Asia. Brunei Darussalam comprises a total area of 5,765 km^2. It has a coastline of about 161 km stretched along the South China Sea. In the southwest direction along the South China Sea, the shoreline area consists of a sandy beach, whereas within Brunei Bay in the northeast, it mainly consists of an estuarine, mangrove, and mudflat zone. Two monsoonal trends affect the humid equatorial environment. The northeast monsoon, which occurs between mid-December and mid-March, and the southwest monsoon, which occurs between mid-

May and the end of October. The typical yearly rainfall ranges from roughly 2,500 mm in the northeast to more than 4,300 mm in the highlands.

Five dams in Brunei Darussalam have a combined storage capacity of a little over 172 million m^3 throughout the country. With a catchment area of 2.8 square kilometers and a total capacity of 13,000 m^3, the Tasek reservoir is utilized for water supply. 16.8 million m^3 can be stored at the Mengkubau dam in Mentri. The Benutan dam, an impounded reservoir, is used to control the Tutong River, with a catchment area of 28.6 square kilometers and a total storage capacity of 45 million m^3. Ulu Tutong Dam, located in Tutong District, is the largest reservoir in the country with a capacity of 100 million m^3 and a catchment area of 108 sq. km. Kargu Dam, located in Kuala Belait District, has a capacity of 10.7 million m^3 from a catchment area of 14.3 square kilometers. Brunei has four main river catchments, of which 75% cover the country's land. Almost 100% of the country's population is served by a safe potable-piped system. Under the four major water supply systems, the public water supply system is entirely dependent on surface water supplies, namely the Brunei Muara-Tutong system, the Kuala Belait-Seria-Sungai Liang system, the Labi Water Supply System, and the Temburong Water Supply System, as shown in Table 1. The consumption per capita is about 380 l/d [6].

Table 1. Projected water demand in the year 2025 by water supply system [6].

River system	Projected demand
Brunei Muara – Tutong System	563 Mld
Kuala Belait-Seria-Sungai Liang System	87 Mld
Labi Water Supply System	1.7 Mld
Temburong Water Supply System	8.7 Mld

4. Impact of climate change on water resources

4.1 Agriculture

Agricultural and fishing activities are highly dependent on the climate. Crop growth can be affected by extreme temperatures and precipitation. The impacts of droughts and floods can distress the crops with declining yields. In Brunei, the main agricultural activity is rice production, which is the staple food of Bruneians. The government has been focusing on increasing local rice production and is targeting self-sufficiency. However, Brunei Darussalam is experiencing an increase in precipitation of 26.16 mm annually and an increase in temperature of 0.031°C annually from 1979 to 2013 [7]. The increase in precipitation will impact crop yield as rice (paddy) fields are prone to flooding, and eventually it will damage the crop [8]. The climate change may also affect the irrigation systems that supply water to these paddy fields. With intense or prolonged rainfall or a period of prolonged drought, there is a need for better management of the allocation of water for irrigation systems, or it will affect the crop yield. As Brunei Darussalam still heavily imports rice for local consumption, adapting to climate change in farming practices and good water management are necessary to achieve high crop yields for its local rice production, thus

leading to national food security by reaching self-sufficiency, as shown in Fig. 2.Building climate change resilience in farming practices will benefit Brunei Darussalam in the long run.

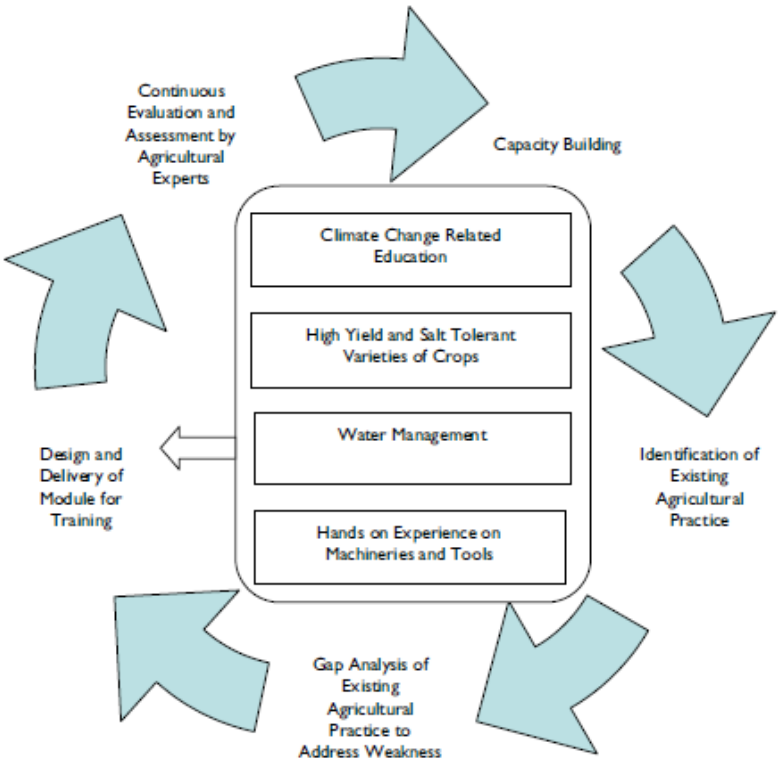

Figure 1. Developing Capability in Brunei Darussalam for Farming Adaptation [7].

4.2 Fisheries

Since the 1960s, anthropogenic activities have caused warmer temperatures in the upper ocean [9], and this could disrupt the ecosystems by causing disturbance to the habitat, which comprises a variety of species such as fish and shellfish. This may cause inconvenience to the fishing industry as fishermen have to go fishing in deeper water regions as many aquatic species move into deeper regions for colder water temperatures. In the case of Brunei Darussalam, diversification of the economy has always been actively pursued by the government, and fisheries have been recognised as one of the potential economic sectors. For the people of Brunei, the primary source of protein is the seafood. Brunei has a population of less than half a million but has one of the highest per capita fish consumption rates (47 kg/person) [10]. Aquaculture is also a booming sector in the fisheries industry, and it has experienced the fastest increase over the last five years, rising by 14%. [11]. However, aquaculture is at risk from the impact of climate change. Short-term climate

change impacts on aquaculture include a decline in production due to toxic algae, parasites, or deteriorating farming affected by red tides.

4.3 Floods

In the future, it is highly probable that Brunei will experience an increase in temperature and a decrease in the frequency of precipitation events, with the prospect of intensified and extremely heavy precipitation [1]. This may lead to an increase in surface water runoff and eventually cause flooding events. As shown in Fig. 2, the Shared Socioeconomic Pathways (SSPs) future climate scenarios (SSP245, SSP370, and SSP585) were evaluated based on their simulations of Brunei Darussalam's mean monthly and daily precipitation in Phase 6 of the Coupled Model Intercomparison Project (CMIP6). In the near future, the annual rainfall is expected to drop by at least 27% under the SD model and by 11% under the AM model. Long-term, the SD model predicts that annual rainfall will change less (17%). While the AM model predicted that the amount of rain would go down by at least 14% [3].

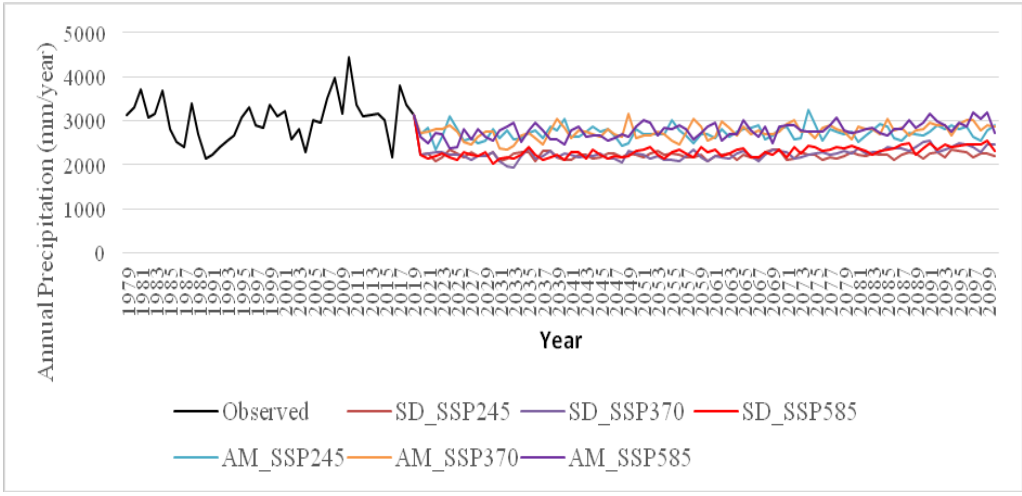

Figure 2. Annual Precipitation Generated by the SD and AM Models Compared to Observed Precipitation [3].

These events may lead to floods and flash flood occurrences, which are common in Brunei, especially during torrential rain events. Flash flooding occurs when there are fairly short, intense rainfall bursts, such as during a thunderstorm. As a consequence, there is insufficient capacity or time for the drainage system to handle the downpour. Due to intense rainfall and thundershowers, Brunei has recently witnessed flash floods, especially in lowland regions like Tutong District. [12]. In 2017, flash floods hit the Temburong district the worst during Tropical Storm Kai-Tak, as

the severe weather affected 317 houses due to floodwaters, and 88 residents were shifted to emergency shelters at Bangar Community Hall, as shown in Fig. 3 [13].

Figure 3. Flash flood in Temburong, December 2017 [13].

Flooding may pose health risks such as waterborne disease. To avoid flooding, there is a need for a better drainage system with provisions for detention basins, wetlands, and green spaces with sponge characteristics for delaying the flow of water. This can be constructed, especially in high-risk flooding areas in Tutong District.

4.4 Sea level rise

Due to two main factors—thermal expansion brought on by ocean warming and greater melting of land-based ice, such as glaciers and ice sheets—sea level is expected to rise with climate change. The sea level has risen by a mean of 0.19 m from 1901 to 2010, and it is predicted that it will reach up to 1.2 m by 2100 [14]. Further investigation has been conducted by using satellite altimetry data for the study of the sea level change in Brunei. Figure 4 shows the result of the satellite mission from 2002 to 2016. The sea level trend along the Brunei coastline has risen at

a rate of approximately 5.5 mm/year, with the expectation that it will continue to rise in the near future [15].

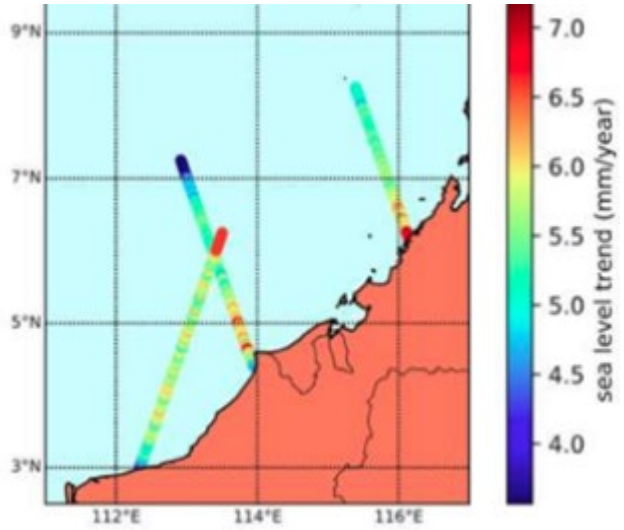

Figure 4. Sea level trend from 2002 until 2016 from three satellite tracks near Brunei coastline [15].

The sea level rise will increase tidal height and the water upstream of Brunei and the Tutong River will be affected by salinity, which may threaten freshwater vegetation and reduce the diversity of flora and fauna.

4.5 Ocean acidification and coral bleaching

Ocean acidification is a process where chemical reactions occur when seawater absorbs carbon dioxide (CO_2), thus reducing the pH of the seawater. The decreasing pH level of ocean water is expected to affect the various aquatic species and thus affect a reliable primary source of protein for billions of people. Increasing acidity of the ocean may affect the pteropods, which are the food source for many marine organisms such as krill, salmon, and whales. The reduction in pteropods may cause food competition among the primary consumers. It also may affect the shellfish because the low pH may be a factor in the failure of oyster reproduction, as observed in aquaculture facilities and natural ecosystems.

The increasing CO_2 levels and decreasing pH in seawater have proven to affect the ability of reef-building corals to produce their skeletons. When the water temperature rises too high, corals eject the algae (zooxanthellae) that live in their cells, causing the coral to turn entirely white. This event is recognised as coral bleaching. During coral bleaching, it may survive, but it is more susceptible to stress. Coral reefs are expected to erode at a faster rate than they can rebuild, and this may also affect other species that rely on coral reefs as their ecosystem. Coral reef fisheries in Brunei

Darussalam have a potential yield of about 750 metric tonnes per year with an economic value of BND $ 6 million, which would be under threat [16]. A study conducted by Tanaka (2016) stated that in July 2010, a major coral bleaching event occurred at Littledale Shoal, at one of Brunei Darussalam's major coral reefs [17]. The temperature of the seafloor at the site was observed to be above 30 °C, which is high for seawater. These findings revealed that the deeper Brunei reefs are locally vulnerable to the impacts of seawater warming. However, the majority of the coral reefs in Brunei are located greater than 4 kilometers off the shore, as shown in Fig. 5. Some corals also live adjacent to the coast near Brunei Bay on Pelumpong Island and Pulau Punyit. Terrigenous waters in Brunei Bay, which have high currents, nutrients, and turbidity as well as low salinity and pH, may have an impact on the corals near Pelumpong Island.

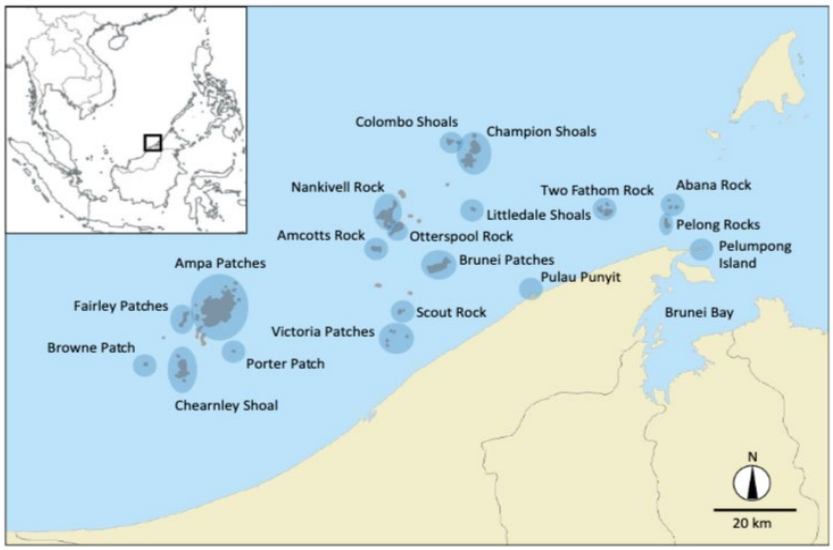

Figure 5. The location of major coral reefs in Brunei Darussalam. [18].

5. Adaptations and Interventions

Climate change is one of the pressures that water managers must continually adjust to, (either as a result of extreme occurrences or to meet greater demand). Over the years, numerous adaptive techniques have been developed for the adaptation to climate change on the basis of supply and demand for water resources and the requirements of water users. A range of adaptations from soft and hard measurements could be made to reduce the regional impacts, such as: building embankments, technological (creating buffer zones through the vulnerable coastline and avoiding settlements in the risk areas), policy-making (e.g., regulations), and planting mangrove trees to protect shores. Furthermore, the supply-side adaptive techniques take into account the altering

structures, rules of operation, and institutional arrangements, while the demand-side strategies consider the types of demand for water or protection against risk and include institutional changes as well. For instance, the adaptations on the supply side include improving irrigation source capacity, supplying water from non-conventional sources like treated wastewater, rainwater harvesting, drainage water collection, increasing flood defenses, and building or extending infrastructure to collect and distribute water to consumers. Demand-side strategies include water demand management (such as promoting water-efficient irrigation and introducing a water tariff), altering water allocations, and utilising land-use controls for flood management measures. Despite being in a high-risk area for catastrophe, Brunei has recorded to experience the least natural hazards in Southeast Asia. Brunei Darussalam is still susceptible to flooding, with a total annual loss of USD 31.31 million and 3.62% of annual social expenditure [19]. Hence, with regard to adapting to future natural hazards, integrated water resources management (IWRM) proves to be the best method for managing water resources in a situation where water demands are changing and conflicting [5]. IWRM primarily consists of three key components: a thorough evaluation of all possible supply-side and demand-side actions; participation of all relevant parties in the decision-making process; and ongoing tracking and review of the state of the water resources. These components are instrumental for integrated resource management and can be helpful in coping with climate variability.

6. Conclusion

It can be concluded that the manifestations of climate change can be foreseen to impact the water resources, and in Brunei, these impacts can be observed in several sectors. The vulnerability of the agriculture sector includes flooding, changes in temperature, and precipitation, which affect the production yield as well as the irrigation system. In the fisheries sector, alteration of marine ecology and warming of the ocean temperature place pressure on fishermen to go beyond their capability for livelihood as their main source is slowly deteriorating with changes in climate. The increase in rainfall intensity in Brunei has led to the occurrence of flash floods in low-lying areas and landslides during the monsoon season. The flood events pose health risks like water-borne diseases if specific actions are not taken with regards to the drainage system. Currently, Brunei is developing its fishing and aquaculture sectors, the threat of ocean acidification and coral bleaching may affect the potential yield of fish per year.

This study suggests that Brunei Darussalam should incorporate or improve its current water management system with the concept of integrated water resource management (IWRM). However, the adaptive capacity of countries' institutions may be an impediment to the degree to which the approach of IWRM is put into practice and enforced. It is important to develop strong coordination and commitment among various stakeholders, such as the Department of Drainage and Sewerage (DDS) and the Department of Agriculture and Agrifood (DoAA), for effective management of water.

References

[1] Hasan D S N A B P A, Ratnayake U, Shams S, Nayan Z B H and Rahman E K A 2018 Prediction of climate change in Brunei Darussalam using statistical downscaling model Theor. Appl. Climatol. 133 343–360.
[2] Liang J, Tan, M L, Hawcroft, M, Catto, J L, Hodges, K I and Haywood, J M 2022 Monsoonal precipitation over Peninsular Malaysia in the CMIP6 HighResMIP experiments: The role of model resolution. Clim. Dyn. 2022, 58, 2783–2805.
[3] Rhymee H, Shams S, Ratnayake U and Rahman E K A 2022 Comparing Statistical Downscaling and Arithmetic Mean in Simulating CMIP6 Multi-Model Ensemble over Brunei Hydrology 9, 161.
[4] Trenberth K E 2011 Changes in precipitation with climate change Climate research, 47(1-2), 123-138.
[5] Arnell N and Chunzhen L 2018 Hydrology and Water Resources. African climate change research centre (n.d) Changes in the global climate system Available from https://accrec.org/ [Accessed on 23 February 2022].
[6] Department of Water Services (DWS) 2020 Ministry of Development, Brunei Darussalam.
[7] Hasan D S N A B P, Ratnayake U and Shams S 2016 Evaluation of rainfall and temperature trends in Brunei Darussalam AIP Conference Proceedings 1705, 020034 (2016).
[8] Shams S, Shafiuddin K B M, Sultan A M S B H M and Juani R B H M 2015 Agriculture Adaptation to Climate Change in Brunei Darussalam: A Step towards Food Security Environment and Urbanization Asia, 6, 1 (2015).
[9] Cheng L, Trenberth K E, Fasullo J, Boyer T, Abraham J. and Zhu J. 2017 Improved estimates of ocean heat content from 1960 to 2015 Science Advances, 3(3).
[10] FAO 2020 The State of World Fisheries and Aquaculture 2020. Sustainability in action Rome FAO Available from https://doi.org/10.4060/ca9229en [Accessed on 30 November 2021].
[11] Department of Economic Planning and Statistics Ministry of Finance and Economy 2020 Gross Domestic Product by Kind of Economic Activity at Constant Prices 2010-2019 Available from http:// www.deps.gov.bn/SitePages/eData%20library.aspx.
[12] Mahmud R 2018 Brunei experiences wet weather; floods hit several areas in Tutong District Borneo Bulletin Available from https://borneobulletin.com.bn/brunei-experiences-wet-weather-floods-hit-several-areas-in-tutong-district/ [Accessed on 23 May 2022].
[13] Bandial A and Bakar R A 2017 Flash floods inundate Brunei Temburong district worst-hit The Scoop Retrieved from https://thescoop.co/2017/12/21/flash-floods-inundate-brunei-temburong-district-worst-hit/ [Accessed on 21 December 2021].
[14] Kopp R, Horton R, Little C, Mitrovica J, Oppenheimer M, Rasmussen D, Strauss B. and Tebaldi C 2014 Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future 2(8) 383-406.
[15] Rahman H 2019 The Potential of Using Satellite Altimetry for Seal Level Study in Brunei. FIG Working Week: Geospatial Information for a Smarter Life and Environment Resilience, Hanoi: Vietnam.
[16] Department of Fisheries 2014 Coral Conservation Awareness Rehabilitation & Enrichment programme Ministry of Industry and Primary Resources Brunei Darussalam.
[17] Tanaka Y 2016 Coral diversity and coral reef environment in Brunei Darussalam Scientia Bruneiana 15.
[18]ReefBase: A global information system for coral reefs Available from http://www.reefbase.org/gis_maps/maps.aspx?#RGWReefGIS [Accessed on 25 July 2022].
[19]CRED 2015 Average annual loss (AAL) by hazard Available from http://www.preventionweb.net/countries/brn/data/ [Accessed on 9 December 2021].