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Flow Assessment of Brunei River due to the Impact of Climate Change

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Abstract. Though Brunei Darussalam is a small country, it has the highest percentage of energy usage per capita as well as the largest carbon footprints of 22.9 metric tons per capita in the world. High emission followed by extreme rainfall resulting from climate change is likely to create challenges to manage increased river flow causing floods. The number of wet days has increased by 0.16 days per year based on the analysis of last 45 years precipitation data. Over 115 cases of flooding and 105 landslides were reported in the year 2014 alone. The watershed of Brunei River is low-lying and swampy; consist of mangrove areas extending 10 km downstream to the mouth of the Brunei River. The effects of varying water depth and tides create a complex zone, an excellent habitat for various fish species particularly cat fish and tilapia. Thus, recognizing the potential threat from flooding altering the flow pattern, the present research focuses to assess the impacts of climate change of Brunei River's flow for the next 20 years. A computer-based modeling tool, WEAP is used to simulate the river flow based on the climatic data, land use change and potential growth of industries.

Keywords: brunei river, climate change, flood, WEAP.

1. Introduction

Climate change or its variability is likely to intensify the global water cycle, alter the timing and magnitudes of runoff and affect the livelihood of people, economies and ecosystems [1]-[3]. Many stakeholders and water experts perceive water related risks (e.g., floods, droughts) as the most serious impact of climate change [4]. Flood disasters are the most frequent and devastating natural disaster in the Asian region, and its impacts have grown despite improved ability to monitor [5]. The availability and use of water is constrained by its spatial quantity and quality [6]. Population growth, economic development and climate change are the driving forces for temporal and spatial variability of availability of water [7] aggravating water crisis and leading to water scarcity. Improve living standards, urbanization, and industrialization lead to a greater competition for water resources. Quantitative estimates of river flow resulting from climate change are required to identify the potential vulnerability to flooding. This vulnerability to flooding occurs to Brunei Darussalam due to intensive rainfall coupled with backwater flow resulting from tidal fluctuation, which is beyond the capacity of the existing drainage facilities. Brunei Darussalam has experienced a number of floods in last two decades. Over 115 cases of flooding and 105 landslides were reported in the year 2014 alone.

Although Brunei Darussalam is a small country, it has the highest percentage of per capita usage of energy. It is one of the largest carbon footprint contributors in the world at 22.9 metric tons of CO_2 per capita [8]. There are four major rivers in Brunei Darussalam and Brunei River comprises of pristine tropical jungles and valuable freshwater sources at its upstream catchment. The watershed of Brunei River is low-lying and swampy; consist of mangrove areas extending 10 km downstream to the mouth of the Brunei Bay. The effects of varying water depth and tides create a complex zone, an excellent habitat for various fish species particularly cat fish and tilapia. A high proportion of urban development also borders the Brunei River. Thus, recognizing the potential threat from flooding altering the flow pattern the present research is focused to

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assess the impacts of the climate change of Brunei River's flow for the next 20 years. Planning the adaptation to climate change requires the use of information on present and future climate conditions [9]. The uncertainty of future climate can be one of the most important barriers for climate change adaptation [10]. A computer-based modeling tool, Water Evaluation and Planning (WEAP) is used to simulate the river flow based on the climatic data, land use change and potential growth of industries. Through WEAP we can analyze the future water situation of a particular basin under different scenarios of socio-economic development and climate change [11], [12]. WEAP results offer a solid basis to assist planners in developing recommendations for future water resource management by revealing hot spots of action [13].

2. Methodology

WEAP has been used to model the Brunei River catchment area. In this modelling, both natural variations in climate data (temperature, rainfall etc.) resulting from land use changes and extraction of water due to growth of industries have been considered for scenario analyses. Water Year Method, which is integrated into WEAP, has been used to analyse a number of scenarios. The Water Year Method is a simple means to represent variation in climate data such as streamflow, rainfall, and groundwater recharge. According to this method, different climate regimes (e.g., very dry, dry, wet, very wet) have been compared relative to a normal year, which has been given a value of 1. Dry years had been assigned to a value less than 1, wet years have been assigned to a value larger than 1. Thus, a water year sequence is created by assigning each year of the period as one of the climate categories (e.g. wet, very wet, normal, dry and very dry). The climate sequence in current account has been set as wet for the climate data to compare it with the accounts like land use change, growth of industries and climate change scenario.

2.1. Developing GIS map of case study area and its input for WEAP

A GIS map of the study area has been developed to use it as a background map in the WEAP model. WEAP allows to use both vector and raster layer. GIS layers are displayed as overlays or backgrounds on WEAP. Fig. 1 shows the vector layer of our study area which has been used in WEAP.

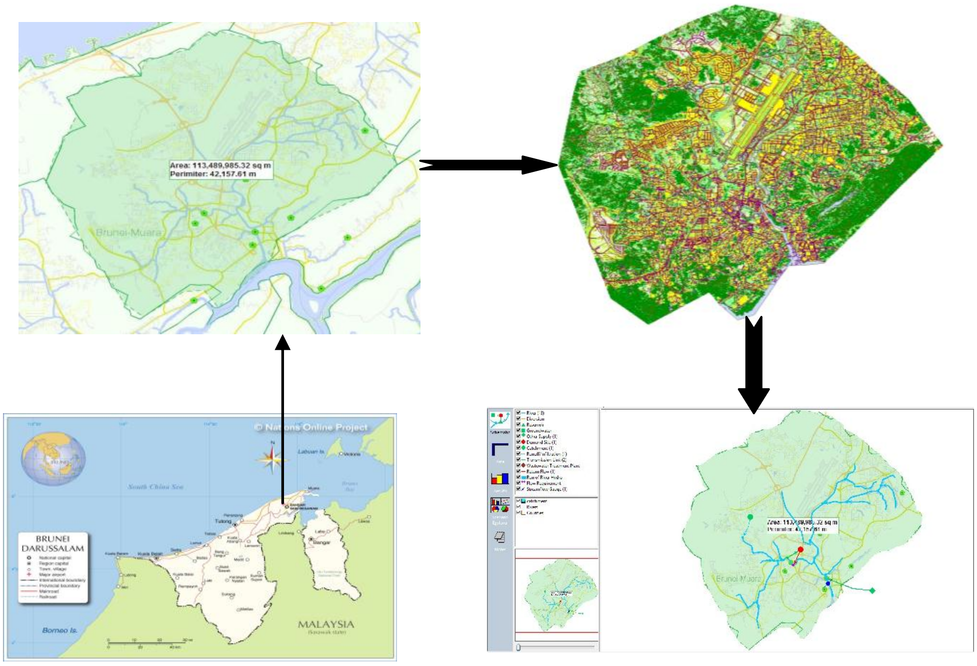

Fig. 1: Location of the catchment area, processed through GIS as input for WEAP

2.2. Creating scenarios

The year 2013 is defined as the current scenario in the WEAP model and the reference scenario is defined from the year of 2014-2033. Based on the reference scenario four other scenarios have been developed based on land use change, growth of industry and climate change based on extended wet climate sequence as shown in Table 1.

Table 1: Scenario analysis based on land use, climate change and industrial growth

Level of scenario analysis	Scenario	Remarks
0	Reference	No change with business as usual
1	Scenario 1 (Land use and climate change)	Land use changes and climate change triggered by global warming and increased trend of precipitation as compared to average existing precipitation
2	Scenario 2 (Industrial growth and land use change)	Steady growth of Food Processing and Pharmaceutical industries considered combined with land use change
3	Scenario 3 (Industrial growth and climate change)	Steady growth of Food Processing and Pharmaceutical industries considered combined with climate change
4	Scenario 4 (Industrial growth, land use and climate change)	Steady growth of Food Processing and Pharmaceutical industries considered combined with land use and climate change

2.3. Rainfall-runoff method

In this study, the rainfall runoff method was used to simulate river flows. The following types of data have been used to perform rainfall-runoff method:

(i) Land use

(ii) Climate (Temperature, Precipitation and Reference Evapotranspiration, ETo)

2.3.1. Land use

The total land use of the study area is 113.48 sq. km and the land use type is shown in Table 2 which indicate forest areas consists of 79.19%, urban area 15.11%, and water bodies 8.70%.

Table 2: Types of landuse in the study area

Area Type	Area (in sq. km)	Percentage in Area
Forest area	86.47	76.19
Urban area	17.14	15.11
Water bodies	9.87	8.70
Total land area	113.48	100

2.3.2. Climate

Brunei Darussalam has an equatorial climate of high annual rainfall from the influences of the monsoon winds and temperature. Brunei generates high annual rainfall in two specific rainy seasons. The first rainy season is from September to January due to the influence of Northeast monsoon and November-December is the wettest period. The second rainy season is from May to July due to the influence of Southeast monsoon. The dry period is from February to April. Brunei's average maximum annual temperature is around 32.1^{o}C and average minimum annual temperature is 23.8^{o}C and an annual average rainfall of about 2770 mm per year [14]. Data collected for precipitation from Brunei Meteorological Department over the past 45 years from 1969 to 2014 shows an increase precipitation 10.18 mm/year as shown in Fig. 2. Compared to the present average rainfall this is an increase of 1.33% per year. Brunei experienced a heavy rainfall as well as high tide condition on 20th and 21st January of 2009 which has resulted into flash floods in the country. The number of wet days has increased by 0.16 days per year based on the analysis of last 45 years precipitation data. The temperature is increasing at a rate of 0.0375^{o}C per year based on the data for the last 45 years and tropical vegetation will be is exposed to a much higher level of thermal stress than temperate zone forests.

2.4. Stream flow analysis

The stream flow data was obtained in the form of gauge height readings and discharge was calculated using rating curve. Stream flow was measured for the year 2013. From these data the monthly average of stream flow from 2014 – 2033 has been simulated in WEAP for various scenarios as shown in Fig. 3. The highest peak is obtained from the period of April to May (16.93 m^3/s) and November to December (18.16 m^3/s) during the rainy season.

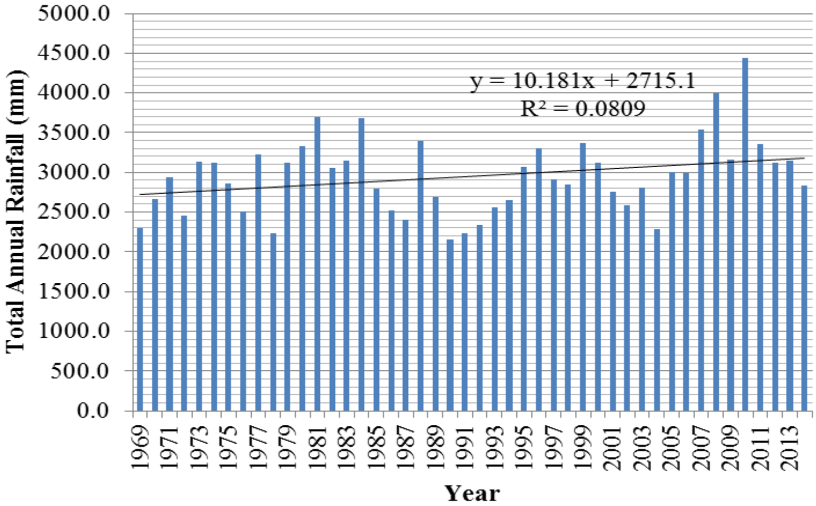

Fig. 2: Average annual rainfall from 1969 to 2014

2.5. Tidal flow analysis

Impacts of sea-level rise to coastal areas include increased coastal erosion, increased flooding risk, more extensive coastal inundation by higher storm, intrusion of seawater in estuaries. The global average rate of sea level rise is 1.7±0.5 mm/year for the 20th century [15]. The rising rates of sea level vary considerably from 1.5 to 4.4 mm/year along the coast of East Asia, due to regional variation in land surface movement [16]. The average rate of sea level rise of all the fifty-eight tide stations is 2.77 mm/year, 1.6 times higher than global average for the East Asia [17]. In this study, the sea level rise is estimated as 2.86 mm/year by taking the average of data cited by Mimura and Yokoki, and Doong et al. Considering the sea level rise of 2.86 mm/year, the tidal flow was simulated in WEAP for various scenarios and the highest peak flow is obtained from the period of April to May (25.76 m^3/s) and November to December (27.36 m^3/s) as shown Fig. 4.

3. Results and Discussions

In the context of the study area, five scenarios as documented in Table 1 have been analysed to identify the potential month for peak flow. Climate scenario has been modeled by "Water Year Method" based on extended wet climate sequences.

3.1. Reference scenario

Under this scenario, it is assumed that there is no change in land use and climate with business as usual. The climate and land use data for current year 2013 is considered as reference year. Stream flow and tidal flow for reference scenario are given as input in WEAP as shown in Fig. 5.

3.2. Scenario one: land use and climate change

This scenario is developed taking into consideration of land use and climate change for a projection period of next 20 years until 2035. The deforestation rate over the last four decades is 8.4%, i.e. 0.21 % per year [18] while during 1980-2000, it is calculated as 0.81% per year [19]. Therefore, taking the average of these two data we assumed forest cover change as 0.51% per year for the next 20 years. The amount of precipitation will increase by 10.18 mm per year based on the analysis of precipitation data from 1969 to 2014. The continuous wet climate sequence is considered taking into accounts the future climate change. This scenario emphasizes that future condition will be more prone to flooding. So, necessary steps should be taken to minimize flooding through adequate drainage system.

3.3. Scenario two: industrial growth and land use change

This scenario is developed taking into consideration of industrial growth and land use change for a projection period of next 20 years but the impact of climate change has been omitted. This scenario assumes that there will be steady increase in industries like food processing and pharmaceutical industries in the study area with expected number of food processing and pharmaceutical industries will be 10 and 2 respectively at the end of year 2035. One food processing industry will be established at every two year while one pharmaceutical industry will be established at every ten year. The average water extraction from the river by food processing and pharmaceutical company is 20906 m^3/day and 2720 m^3/day [20]. It is observed that there would be unmet demand because of industrial growth and land use change between the years 2029 to 2033 with highest annual water demand of 1,212,834 cusec for the year 2032 as shown in Fig. 6. In order to avoid this unmet demand, some effective steps for water management system in the study area like detention basin, rainwater harvesting, recycling of the industrial effluent should be implemented.

3.4. Scenario three: industrial growth and climate change

This scenario is developed taking into consideration of industrial growth and climate change for a projection period of next 20 years but the impact of land use change has been ignored. The average monthly stream and tidal flow will decrease due to extraction of water by the industries as compared to reference scenario while it will be higher than the scenario industrial growth and land use as shown in Figure 3 and 4 respectively.

3.5. Scenario four: industrial growth, land use and climate change

This scenario combines climate change with industrial growth and land use change as explained in scenario two. The average monthly stream and tidal flow will decrease due to extraction of water by the industries as compared to reference scenario while it will be higher than the scenario industrial growth and climate change as land use change contributes to increased runoff resulting increased stream flow as shown in Fig. 3 and 4 respectively.

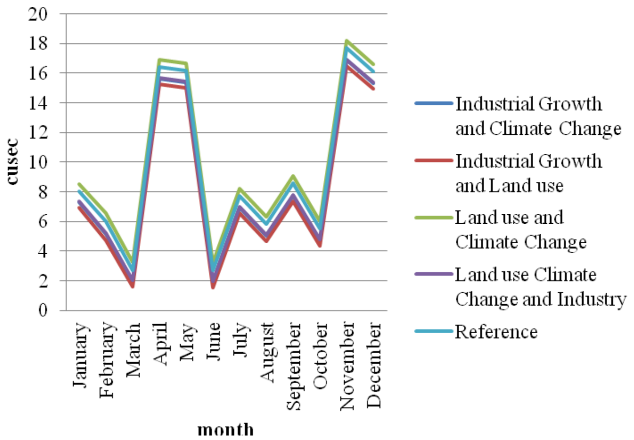

Fig. 3: Stream flow under various scenarios

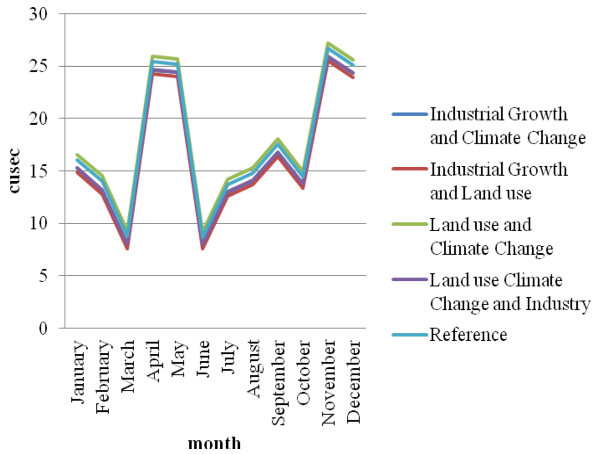

Fig. 4: Tidal flow under various scenarios

4. Conclusions

Modelling has become an essential tool in modern world of water management. It is used extensively and plays an important auxiliary role in fulfilling the core tasks of water management, in policy preparation, operational water management and research, and in the collection and monitoring of basic data. WEAP calculates water quantity for every node and link in the system on a monthly time step for various scenarios.

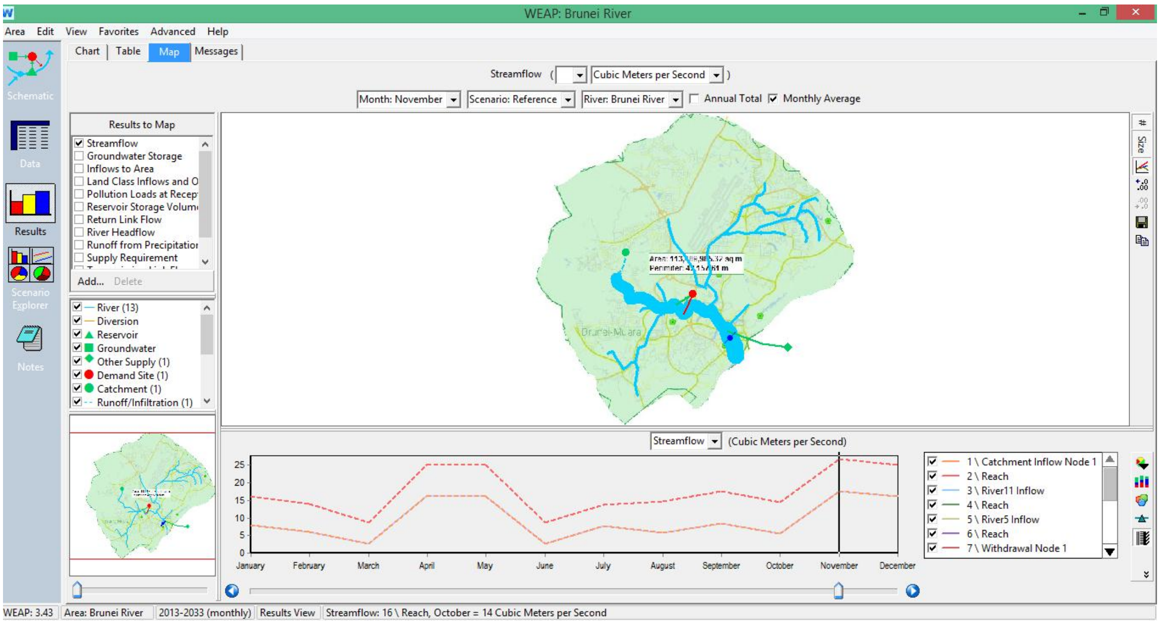

Fig. 5: Stream and Tidal flow under reference scenario

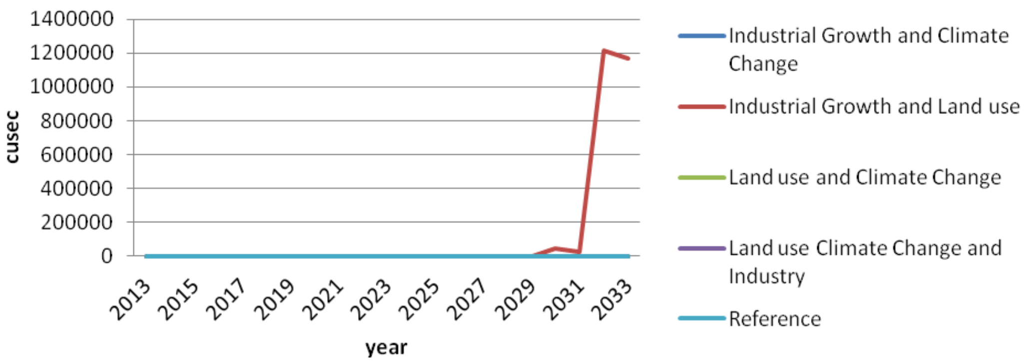

Fig. 6: Unmet demands for industry between the years 2029 to 2033 under industrial growth and land use scenario

The application of WEAP for water resources planning and management of Brunei River has been evaluated by comparing the stream flow with reference scenario. The highest peak is obtained between November to December 18.16 m^3/s for stream flow and 27.36 m^3/s for tidal flow. The scenarios displayed in this study could bring discussion among various stakeholders involved in water management in the catchment; this will enable understanding of the issues facing that catchment. The results show that the catchment is vulnerable to flooding under extended wet condition in the future year as shown in the model. Creating detention ponds near rivers allows for the uptake of excess water during high rainfall periods and supplement for shortage of water for unmet industries in future.

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