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Climate Change Adaptation for Urban Drainage System Design

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Abstract: This project aims to develop a climate change adaptation for urban drainage system design. The study area selected for the research is Penampang, Sabah. Penampang in the West Coast Division of Sabah, Malaysia, which is the capital of the Penampang District. Climate change factor have been involved in generating of flood flows along Panampang area. Flooding is one of the main natural disasters in Sabah, Malaysia. Substantial downpour has triggered floods and caused extreme loss in Penampang area. The 2014 floods have affected 40,000 people from 70 villages. The first objective of this study is to simulate the flood inundation mapping using GIS software. A city-wide pluvial flood hazard assessment is carried out in order to identify crucial places that will be investigated further. In this step, a flood inundation mapping is simulated by using ArcMap and ArcScene. This stage is vital because it allows resources to be focused and detailed studies to be conducted solely on critical drainage network portions. The flood risk map is also produced to show the most floodable area to represent the flood risk area. The second objective is to analyse climate change impact on rainfall in Return Period. In this project, detailed climate change impact assessment is carried out. It is to analyse the climate change impact on Return Period using the historical rainfall data and projection climate data under emission scenarios; RCP2.6, RCP4.5, RCP6.0 and RCP8.5. Climate Change Adaptation for Urban Drainage System is generated to fulfil the third objective of this project, which is to research climate Change Adaptation for Urban Drainage System according to the most floodable area and less floodable area. In this study, the most suitable climate change adaptation method is selected by Cost-benefit analysis and Net present value which is construction of levees and retention ponds.

Keywords: Climate Change, Flood Modelling, Rainfall Data

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1. Introduction

Urban drainage is a critical component of city infrastructure that is meant to transfer surplus water away from urban areas in order to keep floods to a manageable level. Climate change has the potential to affect not only surface floods, but also the planning and construction of drainage system. Long-term changes in hydrological regimes, particularly surface flooding routes and features, might, for example, lead to adjustments in city land use and drainage systems in order to minimize flood disruptions and damages. Meanwhile, better control of urban floods along the growth path, often by drainage system upgrades, can have a direct impact on flood hazard and vulnerability by influencing surface and underground routing and conveyance processes.

It is widely assumed that the volume of precipitation in severe events would rise as the climate changes. (IPCC2012; Interagency Climate Change Adaptation Task Force 2011) [4]. Increases in precipitation magnitude and intensity are projected, as are increases in runoff, storm water discharges, and flooding. Because of the considerable growth and large population concentrations that prevail in metropolitan areas, these problems are more significant. Thus, it is to be assumed that urban drainage networks constructed for previous or present climatic conditions would not perform as efficiently in the future as they do now. Municipalities and other stakeholders must have adequate strategies or processes in place to guarantee that these changes, or the adaptation process, do not negatively impact infrastructure services.

The aim of this research is to analyze the impact of climate change and climate change adaptation for the urban drainage system in Penampang, Sabah. The impact of the climate change is analysed by modelling flood inundation simulation and create flood risk map to determine the area with the most potential flood hazard. In this study, the flood inundation modelling is created by GIS software which are ArcGIS. Then the impact of climate change on Return Period using the historical rainfall data and projection climate data under emission scenarios; RCP2.6, RCP4.5, RCP6.0 and RCP8.5. Rainfall data of 10-year return period and 25-year return period under emission scenarios; RCP2.6 and RCP8.5 are analysed and compared to determine the impact of different RCP emission scenarios on the rainfall data of the return period. After the adaptation measures are proposed, the most suitable and economical adaptation measures is determined by cconomics analysis such as benefit/cost (B/C) ratio net present value (NPV) method. Figure 1 and 2 shows the study area and cases of flood in Penampang, Sabah.

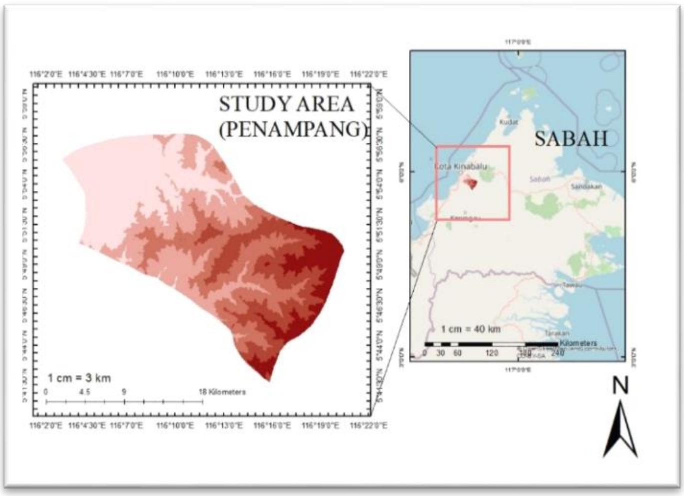

Figure 1: Study Area created in ArcGIS

Figure 2: Some cases of flash floods in Penampang, Sabah [5]

2. Methodology

2.1 Flood inundation modelling

The study involves simulating the flood inundation modelling, analyzing the climate change impact and adaptation decision-making framework for urban drainage systems. The flood inundation modelling is created by using ArcGIS which is a geographic information system (GIS) software which it can be shown in 2D and 3D. Therefore, the flood inundation modeling can be simulated in 2D and 3D mode in order to show the flood flow. The following is the procedure of flood inundation modelling using ArcGIS software:

1. The digital elevation model (DEM) data which download from the USGS website is imported into the ArcMap and the study area, which is Penampang, Sabah is extracted.
2. New shapefile is created for the water level. The feature type is chosen to be polygon and the geographic coordinate system used is WGS 1984.

3. The water level is set at the attributed data is same as the lowest of the land at the DEM. The water level raster is created by converting polygon to raster.

4. The file is imported to ArcScene. The elevation for surface is changed to floating on a custom surface at layer properties so the elevation of the ground can be seen at 3D view.

5. The vertical exaggeration is set to calculate from extent at scene layer to make it 3D. Colour ramp of the DEM is changed so that can differentiate the height of the land easily and colour of water level is changed to blue.

6. To simulate the flood inundation mapping, animation key frame of the water level is created. In this case, 19-layer keyframe are created and 20 per keyframe is set at the translation Z to show the flow rate of the water level. After the flood simulation, a total of 200 height of the land is flooded.

7. The animation control is opened to start the flood inundation simulation.

2.2 Flood risk map

Flood risk map is created by using ArcMap software. It prepared by highlighting the most floodable area and less floodable area in order to show those area clearly in the map for people to understand easily. In the flood risk map, different area of the map and the streamline are stated on the map.

2.3 Climate change impact on rainfall data in return period

The historical and projection rainfall data were accessed from The Climate Change Knowledge Portal (CCKP) [2]. The historical rainfall data shown is the highest monthly rainfall data in year 1991 to 2020. The projections were conducted under four emission scenarios; RCP2.6, RCP4.5, RCP6.0 and RCP8.5. The period is 2020-2039, 2040-2059, 2060-2079 and 2080-2099. The projections show Maximum Daily Rainfall (10-yr RL) of Malaysia and Maximum Daily Rainfall (25-yr RL) of Malaysia. In this study, the rainfall data under different emission scenarios is compared to show the impact of the climate change toward the rainfall in different return period.

The study involves simulating the flood inundation modelling, analyzing the climate change impact and adaptation decision-making framework for urban drainage systems. The critical procedures in assessing performance, hazard, and risk are highlighted, as is the economic analysis of adaption possibilities.

2.4 Climate change adaptation for urban drainage system and economic analysis of adaptation probabilities

The climate change adaptation of the urban drainage system is proposed. The most suitable and economic climate change adaptation method is selected by using cost benefit analysis.

A cost-benefit analysis is a useful tool for determining the relative economic advantages of various adaption options. There are two ways of carry out the cost-benefit analysis. One of them is the benefit cost ratio method which is the simplest way. The B/C ratio is calculated based on the equation below. If B/C ratio more than 1, the adaptation options is acceptable [3]. The formula is as follows:

$$\text{Benefit} - \text{cost ratio (B/C)} = \frac{(\text{Equivalent net Benefits})}{(\text{Equivalent net Costs})} \qquad \text{(Eq 1)}$$

Net present value (NPV) method is the computation of the difference between the current value of cash inflows and outflows, net present value (NPV) is employed as an analysis metric [1]. In this situation, the risk reduction caused by adaptation measures is weighed against the investment required to put the adaptation measures in place. An investment with a higher NPV is always favoured, and if the NPV is negative, the investment will result in a net loss. NPV is calculated as follows:

$$\text{NPV} = \sum_{t_o}^{t_e} \frac{E(L)\Delta R - C_{\text{adapt}}}{(1+r)^t} \qquad \text{(Eq 2)}$$

where

E(L) = the expected annual damage

ΔR = the risk reduction due to adaptation measures

Cadapt = the investment cost of adaptation measures

r = is the discount rate

to & te = the start and end time of the analysis period

3. Results and Discussion

3.1 Flood inundation modelling

Figures 3 show the flood inundation simulation of Penampang, Sabah in 3D view. This can used to simulate floodflows while during flood. Therefore, this is very much necessary for identification of possible inundated areas, so that a flood warning can be issued to the people in the affected areas. A suitable flood mitigation method of urban drainage system also can be carried out at the initial area of the floodflows to prevents the flood flowing to a higher level. Flood inundation models become important increasingly in both flood forecasting and damage estimation as it provides the basis for the decision making of flood risk management. In compared to conventional statistical models that are based on all numerical data observations of previous flood events, the most significant advantages of physically based inundation models are their ability to predict spatial and temporal variables such as discharge, water level, velocity, flow duration, and inundation extent on processive flood events. It is a flood predictive tools which are able to apply in different real and virtual scenarios for analysis. Moreover, a future flood at a higher area caused by climate change can be predicted by simulating the flood inundation and predicting the floodflows to know where flood is the most apt to occur at the higher area. Therefore, the climate change adaptation of the urban drainage system can be carried out to prevent future flooding earlier

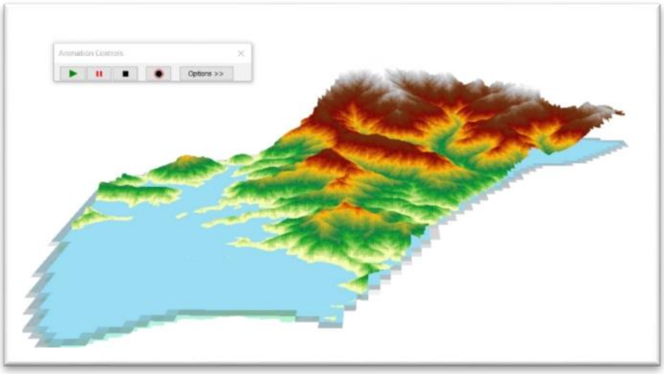

Figure 3: Flood inundation simulation created in ArcScene

3.2 Flood risk mapping

After flood inundation simulation of the area, a flood risk map must be created. It is very important as it can show the most floodable area and less floodable area in the map. It also provides information for other civil engineer when they need to propose a urban drainage system at certain area. At Figure 3.2, it shows that about 30% of the area in Penampang, Sabah is covered as most floodable area while only about 10% of the area is lees floodable area and the less is non floodable area. The most floodable area is due to the low ground elevation. Normally, this caused by the main channel quickly accumulates water from the lateral channels during storms and eventually the water level in the main channel rises to the extent that lateral channels are no longer conducive to water drainage because of the backwater effect. In the Figure 4, it shows that the most floodable area is at urban area which is about 80% because the elevation area is lower. Some area such as Friendship Garden Phase II, Delta Height, Taman Kasugui, Vista Minintod can be seen in Figure 4 is in the most floodable area while the less floodable area is at the boundary of urban area and some parts of the rural area. Flood Areas also appear near to the streamlines as shown in Figure 4 because the stream may overflow with water and cause flooding to the surrounding areas. Therefore, more climate change adaptation must be applied on the design of urban drainage system in the most floodable area and the areas near to streamlines while a normal flood mitigation method is applied for the less floodable area.

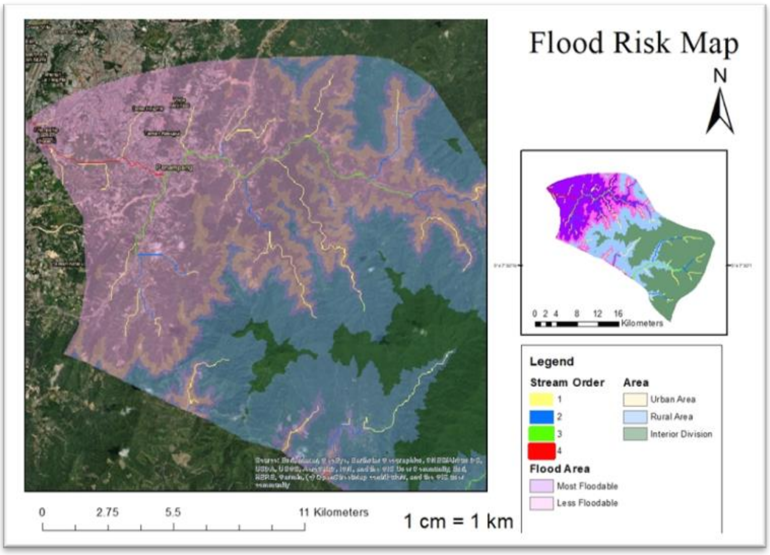

Figure 4: Flood risk mapping created by ArcMap

3.3 Climate change impact on rainfall data in return period

Based on the figure 5, figure 6 and figure 7, it shows that the historical annual maximum monthly rainfall is lower than that of the projected rainfall data, thus it increases every 20 years period continuously as in shown in the figure, despite the slight decreases. Therefore, it shows that the rainfall data increases in the future and pluvial flood hazard will increase in the future climate conditions.

Based on figure 8 and 9, it shows that climate change impact on return period. For example, annual maximum monthly rainfall under emission scenario RCP8.5 in 2080-2099 with 10-year return period is more than that of annual maximum monthly rainfall under emission scenario RCP2.6 which are 577.19 mm and 415.65 mm, respectively. Annual maximum monthly rainfall under emission scenario RCP8.5 in 2060-2079 with 25-year return period is more than that of annual maximum monthly rainfall under emission scenario RCP2.6 which are 638.79 mm and 533.91 mm, respectively. Therefore, it can conclude that the climate change can affect the rainfall data, thus affect the return period. The rainfall data under RCP8.5 emission scenarios is the most suitable data to be used in the design of the urban drainage system by the adaptation of climate change because it has the highest rainfall data among all the emission scenarios, and it affected the most by the climate change.

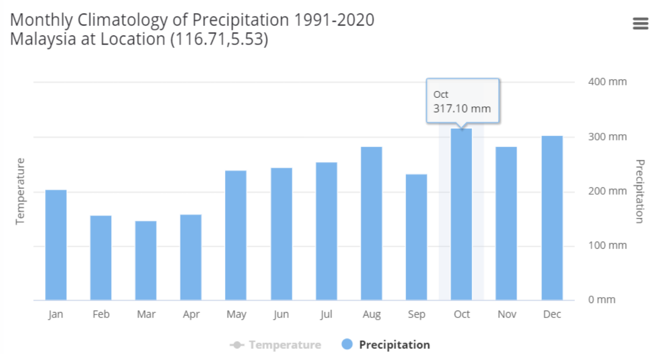

Figure 5: Historical Monthly Precipitation 1991-2020

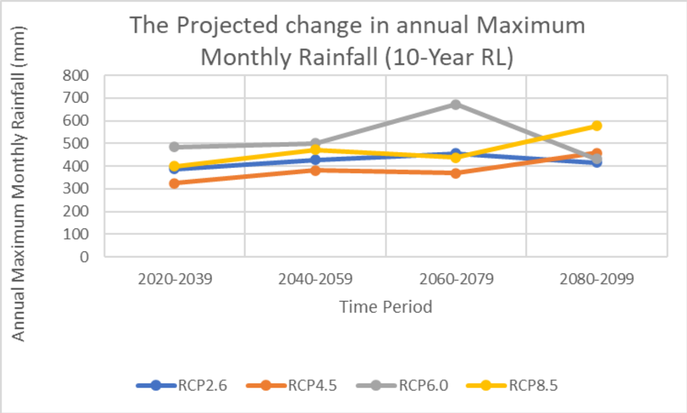

Figure 6: The Projected change in annual Maximum Monthly Rainfall (10-Year RL)

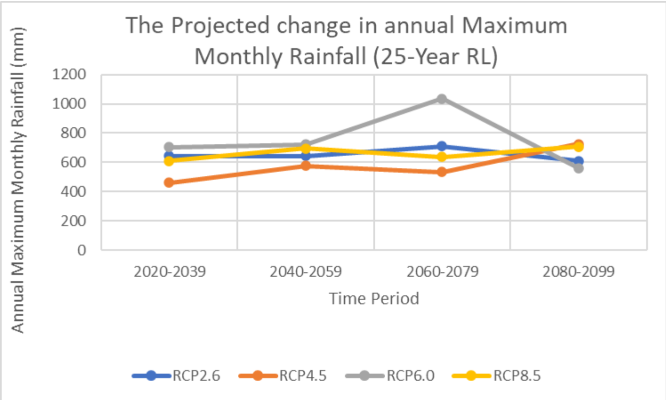

Figure 7: The Projected change in annual Maximum Monthly Rainfall (25-Year RL)

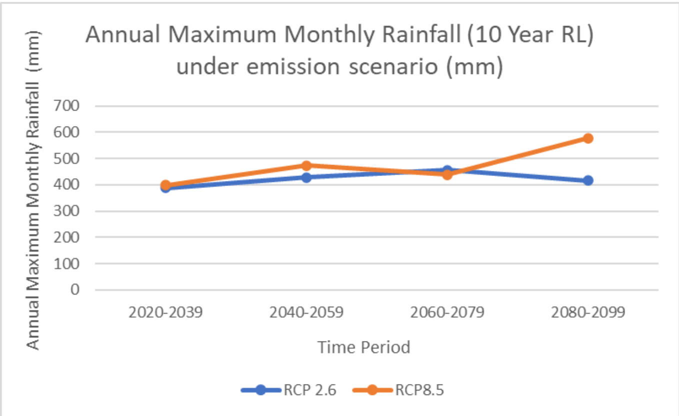

Figure 8: Annual Maximum Monthly Rainfall (10 Year RL) under emission scenario (mm)

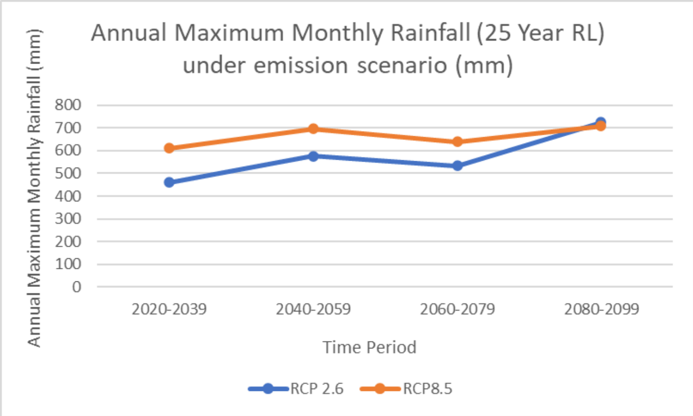

Figure 9: Annual Maximum Monthly Rainfall (25 Year RL) under emission scenario (mm)

3.4 Adaptation decision making

In this study, the climate change adaptation of urban drainage system design is proposed and some adaptation measure for urban drainage system especially the down-stream measures are proposed. The following flood mitigation method are for the climate change adaptation of urban drainage system:

<u>Drainage design</u>

1. Design the urban drainage system by considering the future IDFs under Representative Concentration Pathways (RCP) emission scenarios. It will be difficult to completely base the planning procedures on predicted future precipitation patterns due to the uncertainties in climate modelling. However, both historical and update IDF curves can be used together to make more robust decisions. In this case, IDFs under Representative Concentration Pathways (RCP) emission scenarios of RCP8.5 is considered for the design of the urban drainage system because RCP 8.5 corresponds to a high greenhouse gas emissions pathway and it is the most extreme climate change assumption in the future, and also the largest increases in temperature and rainfall are expected in the projection data.
2. The drainage system is designed with at least 10-year return-period at critical area such as the area that are potential hazard for flooding while the 10-year return-period is flood protection standard. In order to design the urban drainage system economically, the suitable return period for threshold is estimated by carrying out the flood hazard assessment. In flood hazard assessment is carried out by hydrological modelling (HEC-HMS), hydraulic modelling (HEC-RAS) and Flood mapping (ArcGIS) in different design period and the projection rainfall data under scenarios emission of RCP8.5 which is considered the most extreme rainfall data prediction due to climate change is used in all the flood hazard assessment.

<u>Other urban drainage system design</u>

1. Construction of pumping station or flood diversion works is a suitable adaptation method due to climate change. They can be installed at locations in the rainwater pipe network where the drainage capacity is insufficient or the area with lower elevation because it can be used to remove the water accumulation at lower ground and pumping stations play an important role in flood mitigation in metropolitan areas.
2. Construction of retention ponds to decrease peak water level and reduce inundation risk. Retention ponds can provide both stormwater attenuation and treatment. They are designed to support emergent and submerged aquatic vegetation along their shoreline.
3. Construction of levees is the most cost-effective method of mitigating flood hazards, also known as dikes and earth embankments. Levees are defined as raised earth embankments built along rivers, lakes, and seas to protect floodplains and low-lying areas from flooding. A

floodplain area protected by a levee system not only reduces the risk of flooding, but it will also subsequently attract development and thus increase the land value behind the levee.

The Table below shows the adaptation decision making for different areas.

Area	Adaptation decision making
Most floodable area	Climate change adaptation in drainage design and other urban drainage system design
Less Floodable area	Climate change adaptation in drainage design

Table 1: Adaptation decision making for different areas

3.5 Economics analysis of adaptation probabilities.

In this study, the most economical flood mitigation method is chosen among the other urban drainage system design by using benefit/cost (B/C) ratio net present value (NPV) method.

3.5.1 Benefit/cost (B/C) ratio

Based on the Table 2 below, it shows the comparison between the benefit and costs of the alternatives. As the B/C ratio in each case exceeded one, the alternative presented was financially valid as it is profitable while the B/C ratio less than 1 is financially not valid as the benefit obtained is less than the cost amount which causing the project to lose money or not profitable. Therefore, it shows that construction of retention ponds, levees and Rainfall-Storage-Drain (RSD) model are potential adaptation measures financially because the B/C ratio is more than 1 while the construction of pumping station is not a suitable adaptation measure in term of investment because the B/C ratio is less than 1.

Adaptation method	Amount	Flood damage (RM Million)	Cost (Rm Million)	Benefit (Rm Million)	B/C (RM Million)
Construction of pumping station	100 units	10	31	2	0.065
Construction of retention ponds	7000 cm^3	10	1.76	2	1.14
Construction of levees	12000 m	10	1.75	2	1.14
Construction of the Rainfall-Storage-Drain (RSD) model	100 Units	10	1.84	2	1.09

Table 2: Benefit/cost (B/C) ratio of the adaptation measures

3.5.2 Net Present Value (NPV) Method

Assuming it is 1 year period, the Table 3 shows the NPV for 4 adaptation measures. Option A shows a negative value of NPV which means the adaptation didn't bring any profit to the investment. Option B and C gives the most value of NPV compares to the other adaptation measures. Therefore, it shows that construction of levees and Rainfall-Storage-Drain (RSD) model are the most suitable adaptation measures financially compare to others because they are the most profitable investment.

Adaptation method	Amount	The expected annual damage, E(L) (RM Million)	The risk reduction due to adaptation measures, ΔR	The investment cost of adaptation measures, C_{adapt} (RM Million)	Discount rate, r (%)	NPV
Option A: Construction of pumping station	100 units	10	0.5	31	10	-23.63
Option B: Construction of retention ponds	7000 cm^3	10	0.5	1.76	10	2.95
Option C: Construction of levees	12000 m	10	0.5	1.75	10	2.95
Option D: Construction of the Rainfall-Storage-Drain (RSD) model	100 Units	10	0.5	1.84	10	2.87

Table 3: NPV for Adaptation Measures

4. Conclusion

In conclusion, the flood inundation modelling shows the flood flow from a lower elevation area to higher elevation area. The flood risk map shows that there are about 30% of area of the Penampang area is considered as most floodable area while only 10% of the area is less floodable area which there is a total area of 40% of Penampang area stated as floodable area. Based on the the comparison made between the historical rainfall data and the projection rainfall data under emission scenarios of RCP2.6, RCP4.5, RCP6.0 and RCP8.5 in different return period, it shows that the rainfall data is increases while during climate change. There is consensus on the impact of climate change on precipitation patterns. Rainfall intensity under emission scenarios of RCP 8.5 in 25 return period is the most critical climate condition among all the other scenarios. The predicted rise in the intensity and frequency of precipitation events may exacerbate future urban flooding and sewer backlog. The first line of defense against pluvial floods is urban drainage systems. There are numerous adaptation techniques available to mitigate the predicted impact of climate change which lead to the third objective which is the climate change adaptation for urban drainage system design, the adaptation including design the urban drainage system by considering the future IDFs under Representative Concentration Pathways (RCP) emission scenarios which is RCP8.5and the drainage system is designed with at least 10-year return-period at critical area. Other structural adaption possibilities, such as the construction of pump station, retention ponds subterranean storage tanks or levees, are also potential solutions. The type of adaptation measure to be implemented should be decided based on an economic analysis of all available choices. After the economic analysis carried out, construction of levees and retention pond is the most suitable and economical adaptation measures. At the end of the study, the following are some of the recommendations that are encouraged to be carry out in the future work to get more accurate and precise results:

1. 1D-2D simulations are used to assess flood inundation for present conditions as well as three climate projection scenarios such as HEC-RAS or software package MIKE FLOOD to obtain a more accurate data.
2. The flood level of the flood risk map should determine from the actual flood level.
3. The historical and projection rainfall data should be obtained from multiple local GCMs and obtained the most accurate data.
4. The total cost of the adaptation measures must be surveyed based on Malaysia market.
5. The total damaged caused by the flood and total benefit gained by the adaptation measures must based on the actual data in order to perform the economic analysis of the adaptation measures

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References

[1] Abebe, Y., & Tesfamariam, S. (2019). Climate change impact and adaptation for urban drainage systems. In Climate Adaptation Engineering: Risks and Economics for Infrastructure Decision-Making. Elsevier Inc. Available: https://doi.org/10.1016/B978-0-12-816782-3.00003-6

[2] Historical and projection rainfall data, Penampang, Sabah, Malaysia, 2021. [Online]. Available: https://climateknowledgeportal.worldbank.org/.

[3] Kang, N., Kim, S., Kim, Y., Noh, H., Hong, S. J., & Kim, H. S. (n.d.). Urban Drainage System Improvement for Climate Change Adaptation. Available: https://doi.org/10.3390/w8070268

[4] Pachauri, R.K., Meyer, L., Van Ypersele, J.-P., Brinkman, S., Van Kesteren, L., Leprince Ringuet, N., Van Boxmeer, F., 2015. Climate Change 2014: Synthesis Report. In: Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change, IPCC.

[5] Roslee, R., Tongkul, F., Simon, N., & Norhisham, M. N. (2017). Flood Potential Analysis (FPAN) using Geo-Spatial Data in Penampang area, Sabah. Malaysian Journal of Geosciences, 1(1), 1–6. Available: https://doi.org/10.26480/mjg.01.2017.01.06