# Investigation of Flood Inundation under Climate Change and Landuse Change for the Small Urban Catchment

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# Investigation of Flood Inundation under Climate Change and Landuse Change for the Small Urban Catchment

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**Abstract:** *Climate change and land use change are two significant factors that impact flood inundation. The effects of these changes can be seen in various regions worldwide, with some areas experiencing an increase in flood frequency and severity while others may see a decrease. Thus, the main objective of this study is to investigate the impact of climate change and land use change on the occurrence of floods. The hydrological data and land use, soil types, and hydraulic data were used as input data to simulate the flood scenarios. Two different land use types, current and future, were used to compare the impact of these changes coupled with the Climate Change Factor (C.C.F.). The result shows that flood depth is not significantly different between current and future land use; the flood depth varies from 0.1 – 2.217 meters and 0.3 – 2.247 meters for current and future land use, respectively.*

**Keywords:** Masai River, Flood Mapping, Hydrodynamic Modeling, Climate Change, Urbanization

## 1. INTRODUCTION

The increasing frequency and intensity of extreme precipitation events due to climate change, coupled with the impacts of land use changes, have exacerbated the risk of flood inundation in many regions around the world [1, 2, 3]. The hydrological cycle is expected to intensify with global warming, leading to more extreme rainfall and an elevated risk of flooding, particularly in areas with limited water availability.

Studies have shown that climate change has the potential to alter human exposure to flood hazards substantially. For example, under specific climate model projections, by the year 2050, approximately 450 million flood-prone individuals could be exposed to a doubling of flood frequency, along with around 430,000 square kilometers of flood-prone cropland [4]. Globally, the total flood risk could increase by as much as 187% compared to the scenario without climate change [4]. However, these impacts are highly uncertain and can vary regionally, with some areas potentially experiencing reduced flood frequency for millions of people and thousands of square kilometers of cropland [4 & 5].

The effects of climate change on flood risk are particularly pronounced in developed urban watersheds, where the combination of more intense rainfall events and highly modified landscapes can lead to significant increases in flood potential [6]. Additionally, land use changes, such as increased urbanization and deforestation, can exacerbate flood risk by altering the landscape's hydrological characteristics and reducing the natural capacity to absorb and retain water [6 & 7].

Addressing the challenges of climate change-induced flooding will require a multifaceted approach, including improving flood risk assessment, implementing adaptive measures, and carefully considering land use planning and management strategies. By understanding the complex interactions between climate change, land use, and flood risk, policymakers and communities can work to mitigate the impacts and build resilience to these increasingly pressing environmental challenges.

Malaysia, a diverse and vibrant Southeast Asian nation, has long grappled with the persistent challenge of flooding. This natural disaster has had far-reaching consequences for its people, economy, and infrastructure. The country's vulnerable geographic location, coupled with the recurrent patterns of heavy monsoon rainfall, has contributed to the severity of this environmental crisis[8]. The primary culprit behind these floods is the Northeast Monsoon season, which commences in early November and extends until March, bringing an onslaught of heavy precipitation, particularly in the east coast states of Peninsular Malaysia and western Sarawak [8]. The resulting flood waters often inundate vast swathes of inhabited areas, disrupting the lives of millions and causing significant damage to property, agriculture, livestock, and critical infrastructure [9].

Notably, the catastrophic floods of December 2014 stand out as one of the most devastating in recent memory, affecting several states and leaving a trail of destruction in its wake. More than 200,000 people were affected, with 21 reported casualties, underscoring these natural disasters' immense human toll [8]. In the face of these challenges, Malaysia has undertaken concerted efforts to mitigate the impact of flooding and enhance its preparedness for such events. One of the key strategies has been the development of advanced flood forecasting and early warning systems, leveraging statistical methods, machine learning, and chaos theory-based approaches to improve the accuracy of streamflow predictions. [9].

Additionally, the country has recognized the importance of accurate elevation data and high-resolution digital elevation models (D.E.M.s) in flood management and floodplain mapping. LiDAR (Light Detection and Ranging) technology has emerged as a valuable tool, providing detailed information on the extent and depth of flood inundation, enabling more effective disaster response and recovery efforts.

However, despite these efforts, the recurring nature of floods in Malaysia continues to pose a significant challenge, and further improvements are necessary to mitigate the impact of these natural disasters. The need for comprehensive land management, improved drainage infrastructure, and enhanced community resilience remains paramount as Malaysia strives to address the complex and ever-evolving flood problem.

Thus, in this study, the impact of climate change and land use was integrated into the hydrodynamic scenarios to simulate the flood inundation map for this area.

## 2. STUDY AREA

This study was conducted at the Taman Rinting, Mukim Plentong, Johor Bahru. The housing area is just slightly beside the Rinting River. Floods often occur in Taman Rinting, especially in Kg. Sg. Rinting C, Kg. Sg. Rinting D and Jalan Kota Puteri 1, during the collision of heavy rains and backflow water effect from Sg. Masai due to high tide from Johor Straits). Fig. 1 shows the location of the Sg. Rinting in Mukim Plentong, Johor Bahru.

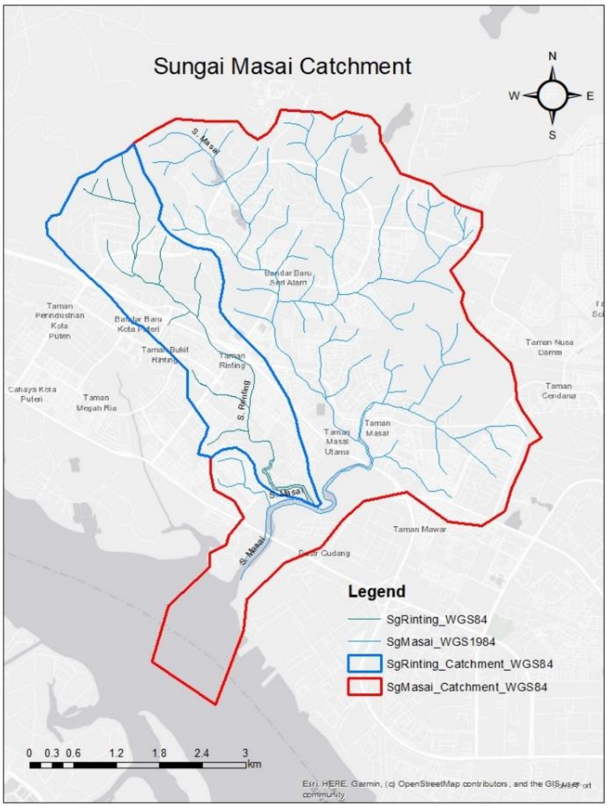


Fig. 1. Location of Study Area located in Johor State, Malaysia

## 3. RESEARCH METHODOLOGY

Several data sets are needed to perform this study, including hydrology, hydraulics, and maps. The data collection and analysis will be further elaborated in the following sections. The Department of Irrigation and Drainage Malaysia (D.I.D.) provided the primary data source for this study.

### 3.1 Hydrology Analysis

Three (3) rainfall stations near the study area were used for this study, as shown in Table 1. In 2021, D.I.D. published a report Reviewed and updated the Hydrological Procedure No.1 - Estimation of Design Rainstorm in Peninsular Malaysia (HP. 1). The report outlined the procedure to estimate design storms using the I.D.F. relationship and developed temporal patterns for various rainfall duration. The I.D.F. relationship is shown in Equation 1.

$$i = \frac{\lambda T^K}{(d+\theta)^\eta} \qquad (1)$$

Where;

T = design years,

D = return period,

$\lambda$,k,d,$\theta$,$\eta$ = Derived Intensity Duration Frequency (I.D.F.) parameters

To develop the IDF Curve and further hydrological analysis, the nearby IDF station will be identified from the listed IDF stations in HP1, 2021. Based on the HP1 (2021), the Stor JPS Johor Bharu station was selected and used in this study. The storm intensity parameter of this station is shown in Table 2. Table 3 shows the details of rainfall intensity for the Stor JPS Johor Bharu.

Table 1. Location of Rainfall Stations

| Station ID | Station Name | Latitude | Longitude |
|---|---|---|---|
| 0420041RF | Ladang Lim Lim Masai | 1.521 | 103.992 |
| 0420041RF | Ladang Sg. Plentong | 1.535 | 103.844 |
| 0430131RF | Ladang Sg.Tiram | 1.588 | 103.918 |

Table 2. Derived IDF Values for Stor JPS Johor Bharu

| Station ID | λ | K | θ | η |
|---|---|---|---|---|
| Stor JPS Johor Bharu | 61.169 | 0.191 | 0.222 | 0.774 |

Table 3. CCF Value based on NAHRIM (2013)

| | ARI | | | | | |
|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 |
| CCF | 1.02 | 1.09 | 1.12 | 1.15 | 1.19 | 1.21 |

Time of concentration ($t_c$) represents the time travel of excess rainfall from the most remote point in the catchment to the interest outlet. It depends on the length and slope of the catchment. $t_c$ for each sub-catchment is derived using The Kerby-Kirpich method. The total time of concentration was obtained by adding the overland flow time (Kerby) and the channel flow time (Kirpich) s shown in equation 2.

$$t_c = t_{ov} + t_{ch} \qquad (2)$$

Where:

$t_{ov}$ = overland flow time

$t_{ch}$ = channel flow time

The Kerby-Kirpich method for estimating $t_c$ applies to watersheds ranging from 0.25 square miles to 150 square miles, main channel lengths between 1 and 50 miles, and main channel slopes between 0.002 and 0.02 (ft/ft) (Roussel et al. 2005). The Kerby equation is

$$t_{ov} = K(L\ x\ N)^{0.467}\ S^{-0.235} \qquad (3)$$

Where:

$t_{ov}$ = overland flow time of concentration, in minutes
K = a unit conversion coefficient, in which
K = 0.828 for traditional units and K =1.44 for SI units
L = the overland flow length, in feet or meters, as dictated by K
N = a dimensionless retardance coefficient
S = the dimensionless slope of terrain conveying the overland flow

For a channel-flow component of runoff, the Kirpich equation is:

$$t_{ch} = KL^{0.770}S^{-0.385} \quad (4)$$

Where:

$t_{ch}$ = the time of concentration in minutes
K = a unit conversion coefficient, in which
K = 0.0078 for traditional units and K= 0.0195 for SI units
L = the channel flow length, in feet or meters, as dictated by K
S = the dimensionless main-channel slope

### 3.2 Geographical Information System (GIS)

Geographical Information System (GIS) is the primary process technique for spatial analysis. All the spatial data, such as the LiDAR, land use map, elevation, soil types, drainage network, and slope map, are processed using ArcGIS software.

### 3.3 Hydrodynamic Analysis

InfoWork ICM software was utilized for the hydrodynamic analysis, where the data were carefully processed to be used as input data to perform the hydrodynamic model. Before the flood plain modeling-2D (outbank), the 3D ground model must be developed from the flood plain information. Once the hydrological analysis and 2D hydraulic model incorporate the 3D ground model using the 2D hydrodynamic software has been calibrated, the hydraulic model is then verified for correctness. This study has limitations that need to be addressed when producing the flood plain and map. The study limitations are as follows:

i. The 3D ground model, IFSAR (Interferometric Synthetic Aperture Radar), is made available from IFSAR suppliers through the DID. The IFSAR data received by a consultant for this project supposedly has a 1m horizontal interval with an elevation accuracy of ±1.0m. Cross-references shall be carried out during the data processing, including survey information and site visits.
ii. Hydraulic structures constructed along the river network that could not be identified during the survey work shall be collected visually via site visits. These hydraulic structures will have a better effect on 2D hydraulic modeling.

The catchment and sub-catchment need to be prepared as the main input for the model setup. The information and characteristics for each sub-catchment must be defined based on the hydrological analysis. The engineering survey cross-sections were then imported into the model and matched with IFSAR to delineate the river system. The long section of the cross-section, together with the invert level. According to previous historical flood events, information on the cause of flood occurrences was clarified. There are two (2) possibilities of flood events that occurred due to (i) heavy storms and (ii) high tide. Based on these two factors, the model was set up to consider both scenarios. This approach is essential to understand which factor contributes the most to the flood occurrence in this study area.

## 4. RESULT AND DISCUSSIONS

The main results from this study will be discussed in this section, which covers the analysis of hydrology and hydraulics. For the flood modeling, scenarios will be compared to find the worst scenario due to climate change and land use changes in this study area.

### 4.1 Hydrologic Analysis

Referring to Eq.1, the IDF curve was generated by incorporating Table 2 and Table 3 values. Two IDF curves were developed for the Stor JPS Johor Bharu that consider CCF and without CCF, as shown in Fig. 2 and Fig. 3, respectively. Based on these graphs, the value of IDF has increased between 1.96 - 17.36 percent based on the ARIs. This finding indicates that the impact of climate change is significant on the rainfall pattern, which could lead to an increase in rainfall amount and intensity. The selection of rainfall with CCF should be considered to ensure that the proposed solution can be adopted and will be sustained for a long duration.

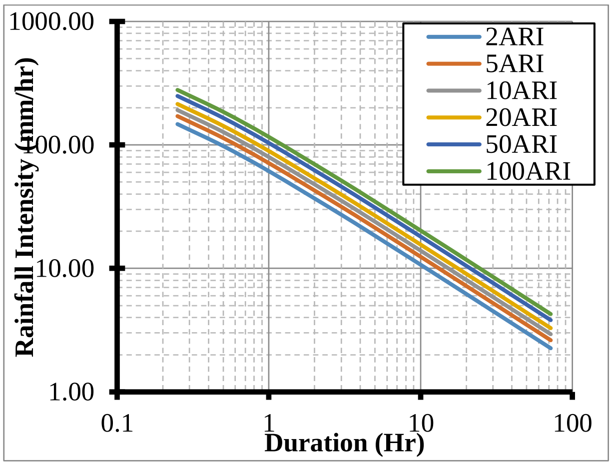


Fig. 2. IDF Curve without CCF for Stor JPS Johor Bharu, Johor (site 0410081RF, HP1 2021)

Recent analyses indicate that rainfall scaling may also increase as a function of duration. For example, shorter-duration, more extended return period events will likely see the most significant rainfall increases in a warmer climate. This has broad implications on the design and the use of rainfall intensity–duration–frequency (IDF) curves, for which both an overall increase in magnitude and a steepening can now be predicted. Based on a study by Tamm et al. [10] has mentioned that storm rainfall intensities used for stormwater infrastructure design have received considerably less attention despite their importance. This study quantified the effect of climate change on design storm intensity based on observations. A study by Xu [11] also mentioned that the increasing intensity and frequency of rainfall events, a critical aspect of climate change, pose significant challenges in constructing intensity–duration–frequency (IDF) curves for climate projection. These curves are crucial for infrastructure development, but the non-stationarity of extreme rainfall raises concerns about their adequacy under future climate conditions.

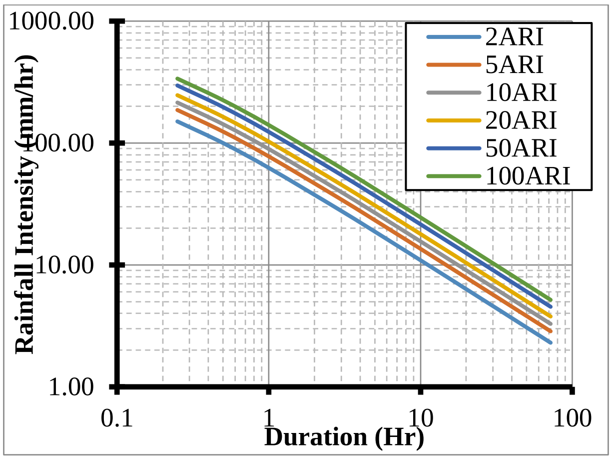


Fig. 3. IDF Cuve with CCF for Stor JPS Johor Bharu, Johor (site 0410081RF, HP1 2021)

A double mass curve is a simple, visual, and practical method, and it is widely used to study the consistency and long-term trend test of hydro-meteorological data. Generally, the curve is used to check the consistency of hydrologic data. The theory of the double mass curve is because a plot of the two cumulative quantities during the same period exhibits a straight line so long as the proportionality between the two remains unchanged and the slope of the line represents the proportionality. This method can smooth a time series and suppress random elements in the series, thus showing the main trends of the time series. Fig. 4 shows the double mass curves derived for all associated stations within the study area. It can be observed from these figures that the rainfall data collected from these hydrological stations are of high consistency and thus can be treated as homogeneous rainfall.

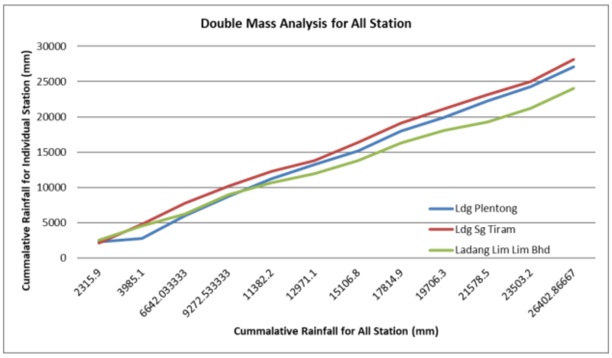


Fig. 4. The result of the Double Mass Curve for three Rainfall Stations used in this study.

Moreover, the effect of climate change on rainfall intensity was investigated to estimate the potential changes in rainfall intensity due to the climate change factor. In this study, the impact of climate change was integrated due to the latest findings by various researchers that mentioned that increasing temperature will significantly impact the hydrological cycle in the near future. Based on a study by Haliza [12] has mentioned that the potential impacts of climate change in the Malaysian context would include sea level rise, reduced crop yields, greater diseases among forest species and biodiversity loss, erosion of shorelines, increased flood intensities, coral reef bleaching, increased incidences of disease, tidal inundation of coastal areas, decreased water availability, loss of biodiversity, and more droughts.

## 4.2 Critical Storm

As flood plains have very complex characteristics, critical storms are used to conduct simulations for various durations and compare them with flood extent. A simulation of 15 minutes, 30 minutes, 1 hour, 3 hours, 6 hours, 12 hours, 24 hours, and 48 hours of storm duration was conducted to generate the flood extent. The results of the simulations that produced the worst flood extent were selected as the critical storm for the study and to generate the flood hazard map. In this study, two scenarios, tide effect, and free flow, were used to compare the extent of the flood. Fig. 5 and Fig. 6 show the results of a critical storm of 50 years ARI for free flow tidal effect, respectively. Based on this figure, the critical storm for both scenarios is 1 hour, where the value flow discharge value for free flow is 109.10 $m^3/s$ and 104.234 $m^3/s$ for tidal effect.

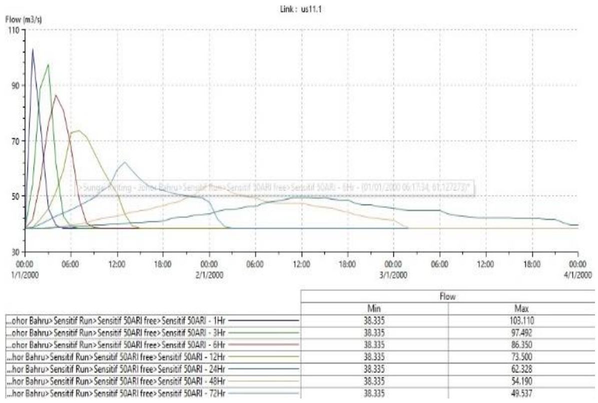


Fig. 5. Discharge for 50 years ARI for a Free Flow Scenario

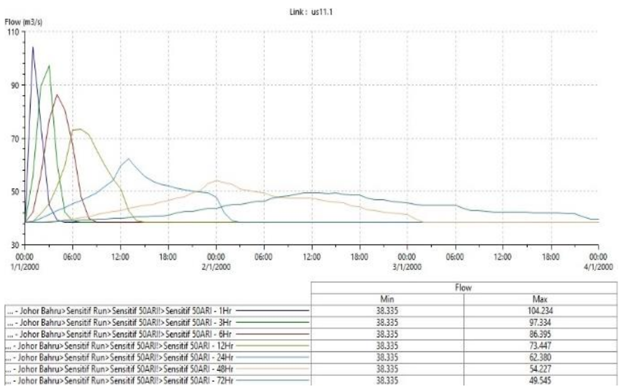


Fig. 6. Discharge for 50 years ARI with Tidal Effect Scenario

## 4.3 Model Calibration

Calibration processes must be carried out to ensure that the hydrological modeling result is acceptable. Due to the absence of streamflow data, the calibration process was conducted by comparing the flood depth from past flood events on November 21, 2021. Based on the past flood event, the flood depth at the Kg. Rinting is 0.5 m. This was used as a benchmark value to compare with the simulation result. The simulation result is more or less similar, about 0.56 m. This result is acceptable since the error is less than 30 percent (Fig. 7). According to Dasgupta et al. [12], using water level for calibration can generate an acceptable result, especially in calibrating hydraulic models in ungauged catchment.

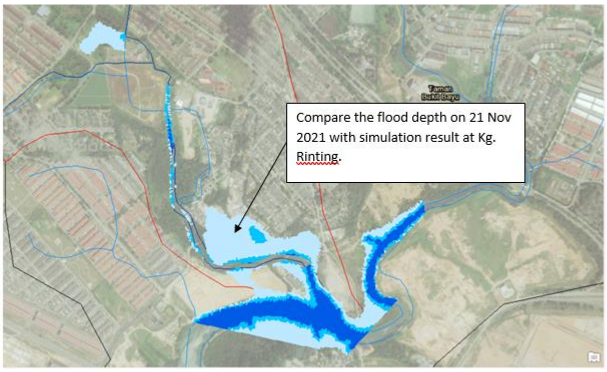


Fig. 7. The calibration of the simulation result

### 4.4 Flood Hazard Map

This study produced a flood hazard map based on two (2) scenarios: current (2022) and future (2030) landuse scenarios. These scenarios are selected based on the site condition, where the study area is projected to expand the percentage of urban and residential areas, and the percentage of green area is expected to be reduced. In addition, the effect of the Climate Change Factor (CCF) on flood occurrences is also considered during the simulation. The flood hazard map with CCF could be used to evaluate the impact of climate change on flood occurrences and flood extent. Fig. 8 shows the Flood Hazard Map for current land use scenarios. Based on Fig. 8, the flood depth is within the range of 0.1 to 2.217 meters depending on the location. The highest flood depth occurred in the area close to the sewerage pond and flat land area. This area has recorded a series of floods in a year due to inadequate drainage capacity and low elevation.

For the future land use scenario, the changes in land use from green areas to various land use types such as urban, industrial, and residential areas have increased the percentage of impervious areas. Based on Fig. 9, the flood depth is within the range of 0.3 to 2.247 meters, depending on the location. The impact of land use change does not significantly impact the flood depth but is evident in the increasing flow discharge. The flow discharge increases by around 10 – 25 % with the increase in impervious areas. This finding shows a good agreement with the study conducted by [12, 13, 14] which also mentioned that the change in land use and land cover in upstream watersheds would change the features of drainage systems such that they will impact surface overflow and affect the infiltration capacity of a land surface, which is one of the factors that contribute to flooding. In addition, cross-checks with flood record and site visit were conducted to validate the simulation result. Based on the site observation, the simulation results match the ground observation values.

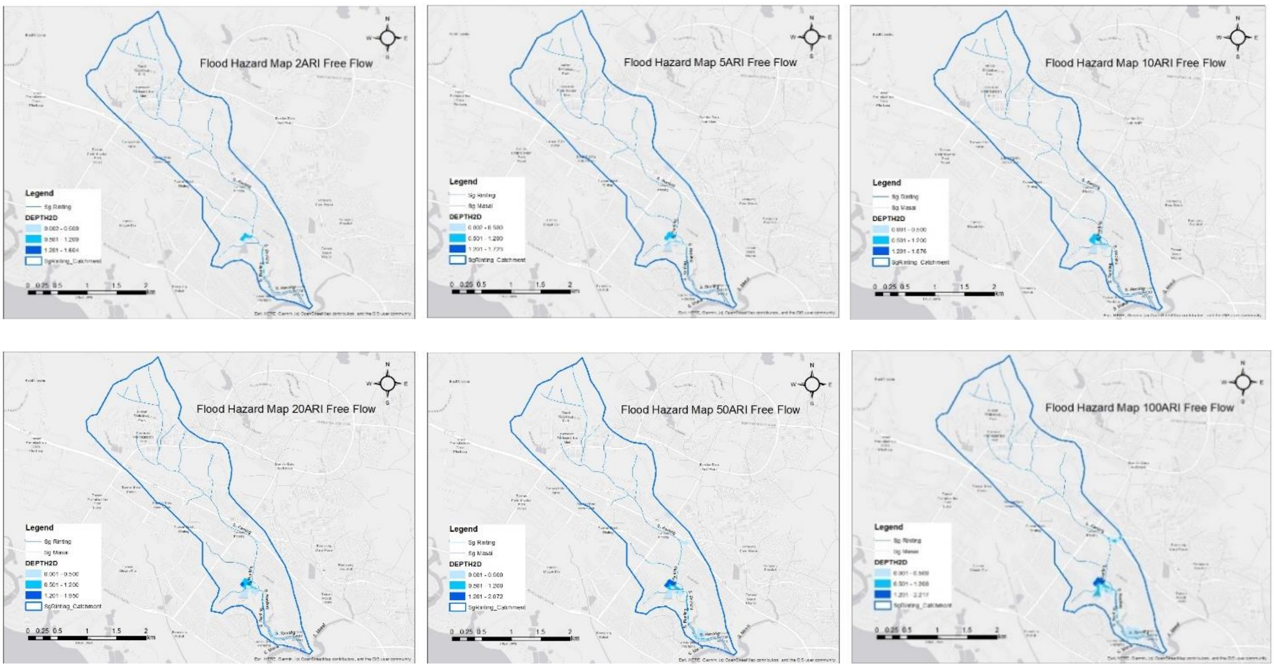


Fig. 8. Flood Inundation Map for curent landuse Scenarios of six different ARIs: 2 years, 5 years, 10 years, 20 years, 50 years and 100 years

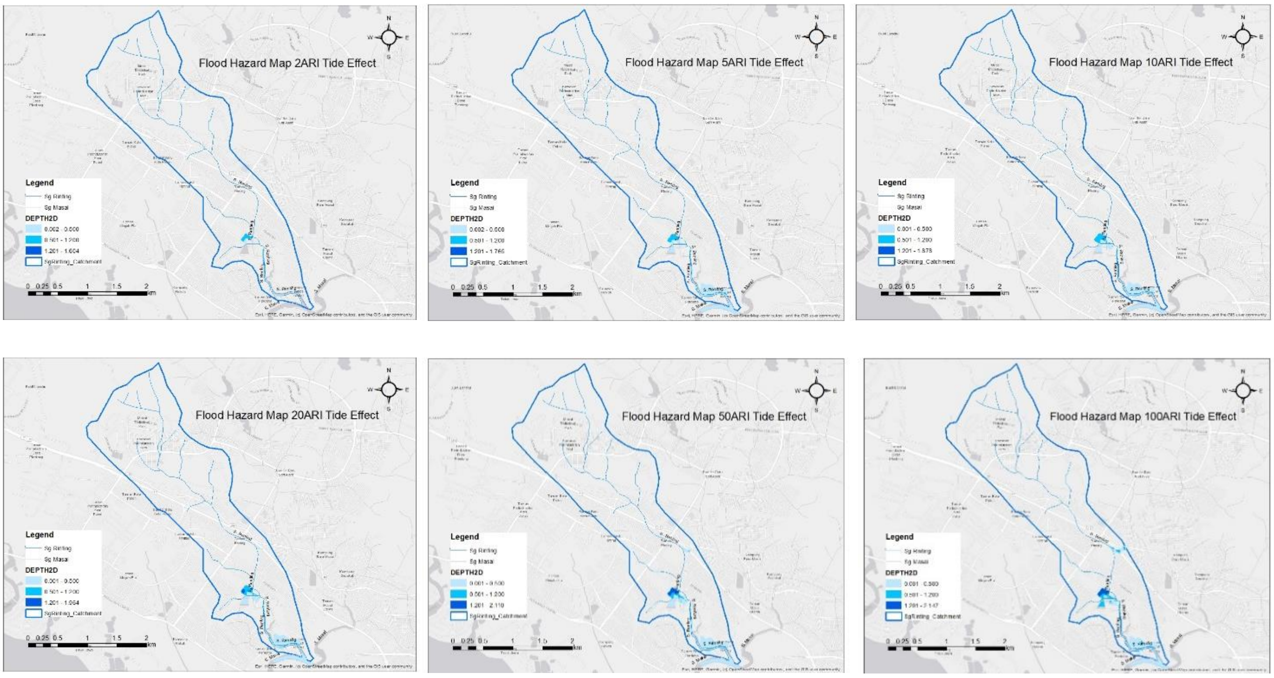

Fig. 9. Flood Inundation Map for Tidal Effect Scenarios of six different ARIs: 2 years, 5 years, 10 years, 20 years, 50 years and 100 years

## 5. CONCLUSION

In conclusion, the main objective of this study was to investigate the impact of climate change and land use change on flood occurrences in this study area, which was successful. The results clearly show that integrating the CCF and land use types of factors into the hydrodynamic simulation has significantly increased the potential of flood occurrence, depth, and discharge. The changes in land use also play an important role in impacting the surface runoff value, where the value of surface runoff increases with the decreasing previous area.

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## 6. REFERENCES

[1] Q. Huang, J. Wang, M. Li, M. Fei, J. Dong. Modeling the influence of urbanization on urban pluvial flooding: a scenario-based case study in Shanghai, China. J. Int. Society for the Prevention and Mitigation of Natural Hazards, 87(2), (2017) pages 1035-1055.

[2] H.Eum, D. Sredojevic, and S. P. Simonovic. Engineering Procedure for the Climate Change Flood Risk Assessment in the Upper Thames River Basin. J. of Hydrologic Eng, 16(7), (2011) 608-612. https://doi.org/10.1061/(asce)he.1943-5584.0000346

[3] D. R. Judi, C. L. Rakowski, S. R. Waichler, Y. Feng, and M. S. Wigmosta. Integrated Modeling Approach for the Development of Climate-Informed, Actionable Information. Water, 10(6), (2018) 775-775. https://doi.org/10.3390/w10060775

[4] N. Arnell, and S. Gosling. The impacts of climate change on river flood risk at the global scale. Climate Change, 134(3), (2014) 387-401. https://doi.org/10.1007/s10584-014-1084-5

[5] A. E. Bocobo, S. P. Camatura, A. M. G. Forcadas, A. P. Sajonia, Impact Assessment of Land Use and Land Cover Change of Agusan River Basin to Climate Using Geospatial Techniques And Regression Analysis. Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 9, pp.214-220, 2023-10-19. 九州大学大学院総合理工学府

[6] J. G. Luzorata, A. E. Bocobo, L. M. Deteraet. Assessment of Land Use Land Cover Classification using Support Vector Machine and Random Forest Techniques in the Agusan River Basin through Geospatial Techniques. Publication info Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 9, pp. 240 - 246, 2023-10-19. 九州大学大学院総合理工学府

[6] S. Hettiarachchi, C. Wasko, and A. Sharma. Increase in flood risk resulting from climate change in a developed urban watershed – the role of storm temporal patterns. Hydrol. Earth Syst. Sci., 22, 2041–2056, (2018) https://doi.org/10.5194/hess-22-2041-2018

[7] H. Tabari. Climate change impact on flood and extreme precipitation increases with water availability. Scientific Reports, 10(1), (2020). https://doi.org/10.1038/s41598-020-70816-2

[8] F.S. Buslima, R.C. Omar, T.A. Jamaluddin, and H. Taha. Flood and Flash Flood Geo-Hazards in Malaysia. Int. J. of Eng. & Tech. 7(4.35), (2018) 760-760. https://doi.org/10.14419/ijet.v7i4.35.23103

[9] Majid, M A., Omar, M H., Noorani, M S M., & Razak, F A. (2021, October 1). River-flood forecasting methods: the context of the Kelantan River in Malaysia. IOP Publishing, 880(1), 012021-012021. https://doi.org/10.1088/1755-1315/880/1/01202

[10] O. Tamm, E. Saaremäe b, K. Rahkema, J. Jaagus, and T. Tamm. The intensification of short-duration rainfall extremes due to climate change – Need for a frequent update of intensity–duration–frequency

curves,. Climate Services, Vol. 30, (2023) https://doi.org/10.1016/j.cliser.2023.100349
[11] M. Xu, L. B. de Guenni, and J. R. Córdova. Climate change impacts on rainfall intensity–duration–frequency curves in local scale catchments. Environ. Monit. Assess. 196, 372 (2024). https://doi.org/10.1007/s10661-024-12532-2
[11] A. R. Haliza. Climate Change Scenarios in Malaysia: Engaging the Public. Int. J. of Malay-Nusantara Studies, Vol. 1, 2018.
[12] A. Dasgupta, S. Grimaldi, R.A.A.J Ramsankaran, V. R.N. Pauwels, and J. P. Walker. A simple framework for calibrating hydraulic flood inundation models using Crowd-sourced water levels. J. of Hydrology, Vol. 614 (2022).
[12] M.A.M. Razi, M.S. Adnan, M.S.H. Abustan, N. D. Anuar, M.H. Jamal, Flood modelling at Bandar Batu Pahat, Johor using HEC-RAS software, IOP Conf. Series: Earth and Environ. 1205(1), (2023) 012023
[13] A.F.M. Mohammed, M.S. Adnan, A. Muneer, S. Sadeq, Flood Estimation Studies Using Hydrologic Modelling System (HEC-HMS) for Batu Pahat River Malaysia. Third International Sustainability and Resilience Conference: Climate Change, Sakheer, Bahrain, (2021), pp. 225-230, doi: 10.1109/IEEECONF53624.2021.9667988.
[14] J. L. Martel, F. P. Brissette, P. L. Picher, M. Troin, and R. Arsenault. Climate Change and Rainfall Intensity–Duration–Frequen.cy Curves: Overview of Science and Guidelines for Adaptation. J. of Hydrologic Eng. Vol. 26, (2021) Issue 10 https://doi.org/10.1061/(ASCE)HE.1943-5584.0002122