INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

IJIE

Vol. 16 No. 5 (2024) 476-488
https://publisher.uthm.edu.my/ojs/index.php/ijie

# Investigation the Impact of the Climate Change on Intensity Duration Frequency (IDF) Curve Development: Case Study at Hulu Terengganu, Malaysia

**Wan Amirul Syahmi Wan Mazlan[1], Nurul Nadrah Aqilah Tukimat[1]*, Siti Nazahiyah Rahmat[2], Hartini Kasmin[2], Samera Samsuddin Sah[3]**

[1] *Universiti Malaysia Pahang Al-Sultan Abdullah, Faculty of Civil Engineering Technology, Kuantan, Pahang, 26300, MALAYSIA*

[2] *Universiti Tun Hussein Onn Malaysia, Faculty of Civil Engineering and Built Environment, Batu Pahat, Johor, 86400, MALAYSIA*

[3] *Universiti Malaysia Perlis, Faculty of Civil Engineering & Technology Arau, Perlis, 02600, MALAYSIA*

*Corresponding Author: nadrah@umpsa.edu.my
DOI: https://doi.org/10.30880/ijie.2024.16.05.036

**Article Info**

Received: 29 February 2024
Accepted: 30 June 2024
Available online: 29 August 2024

**Keywords**

Intensity duration frequency, climate changes, MSMA2, statistical downscaling, future rainfall, AR6

**Abstract**

The intensity-duration-frequency (IDF) curves are the most common form of design rainfall data used for peak discharge estimation. Thus, the IDF curve needs to be improved with the expectation that rainfall intensity and frequency have increased as a result of climate change. The main purpose of this study was to investigate the changes of IDF curves considering the climate change impacts on Hulu Terengganu. The climate projection from MRI-ESM2-0, CMCC-CM2-SR5, and GFDL-ESM4 under 3 different scenarios (SSP1-2.6, SSP2-4.5, and SSP5-8.5) were used to provide the climate changes pattern in the future year (Δ2050). In order to downscale the climate projection, the statistical downscaling method (SD-LS) was employed to correct the biases of these three GCMs. The IDF curves for the return periods of 2, 5, 10, 20, 50, 100, and 200 year were then developed based on the maximum rainfall intensity that were projected by the SD-LS model. The results clearly indicated that there are possibilities for increasing patterns in the projected annual and monthly rainfall for both time periods compared to historical data. Thus, the future extreme rainfall events for various durations with different return periods are all likely to increase over time. The largest potential increase is predicted at Sg. Gawi (+2.0% to +86.0%) based on the different return periods and rainfall durations. It could change the pattern of IDF curve that been developed based on projected rainfall by various SSPs. The developed IDF curves shows higher rainfall intensities in a shorter duration under the same return periods. Therefore, comprehensive action must be taken immediately to regulate and manage the effects of climate change.

## 1. Introduction

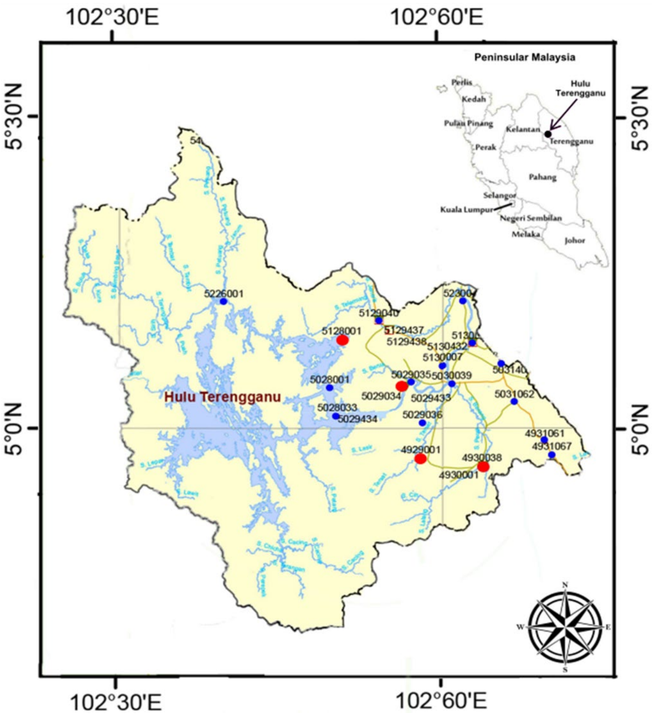
Over the last century, climate change has been exacerbated by increasing industrial activities, development-related deforestation, and agricultural practices [1]. Climate change has significant impacts on the hydrological cycle by altering rainfall patterns both in intensity and frequency [2], [3]. According to the Intergovernmental Panel on Climate Change [4], each degree of global warming is likely to increase global mean precipitation by 1% to 3%. Warmer temperatures increase the amount of moisture in the atmosphere, which feeds into weather systems and makes wet events wetter, potentially leading to floods. Flooding is an overflow of water that submerges land, cities, and low-lying villages, resulting in loss of life, livelihood, and infrastructure damage [5]. Besides, extreme rainfall events caused by climate change can cause unexpected flooding in some areas. Since 2008, weather-related extreme events such as flooding have resulted in the displacement of over 20 million people worldwide [6].

Flood events in Malaysia are getting more severe year after year, as the observed rainfall record for the past 40 years shows a significant increase in the annual total precipitation over Peninsular Malaysia [7]. As a result, in December 2020, the flood in Hulu Terengganu affected 572 people from 180 families [8]. According to the State Disaster Management Committee (JPBN) secretariat of Terengganu, the flood was caused by continuous heavy rains and high tidal phenomena [9]. The annual maximum daily rainfall recorded during that flooding event increased by 63% (510 mm/day) compared to the previous year (313 mm/day) [10]. Additionally, in February 2022, flood in Hulu Terengganu occurred in certain locations that had never experienced it before, such as the Jalan Sekayu area [11]. According to the Special Report on the Impact of Floods in Malaysia 2022 prepared by the Ministry of Economy, Hulu Terengganu district suffered the highest losses in Malaysia due to floods in 2022, with an amount of RM46.4 million [12]. This amount shows a very significant increase compared to the previous years, 2020 (RM16.5 million) and 2019 (RM2.3 million). As a consequence of that scenario, policymakers and institutions have recognised the need for a comprehensive approach to disaster management that considers directly the impact of climate change.

The issue of climate change has been discussed globally, particularly in terms of the best action and implementation for minimising the long-term impact. An increase of 0.84°C in the global average temperature (GAT) in 2021 as the 6$^{th}$ highest record (1880 - 2021) will have adverse effects on the environment as well as increase the frequency of unpredictable disasters in the future [13]. A warmer temperature increases the amount of water that evaporates from the land and oceans, which changes the patterns of rainfall and may result in more rainfall in localised areas. Besides, due to the uncertainties in climate change, the Coupled Model Intercomparison Project (CMIP) has been revised in CMIP Phase 6 (CMIP6) where the level of urbanisation, economic growth, and technological development are considered in identifying the climate change impact. For instance, the SSP5-8.5 predicts a rise in carbon dioxide ($CO_2$) to 1135 ppm (+13.5%). Meanwhile, the GAT is at 4.8°C anticipated to be 11.6% warmer than the RCP8.5. These findings show that the impacts of climate change have increased more severely over the past year and should be considered when making future planning decisions. Tukimat et al. [14] investigated the impact of climate changes to the irrigation water demand at paddy field area. The increment of 0.2°C in local temperature and 4% per decade of rainfall at the region causes the irrigation water demand reduced 0.9% per decade. Even it is good for water sustainability however it might affect the capability of the reservoir storage due to rises of rainfall intensity. The current IDF curves were developed based on historical rainfall data and are available for most geographical areas [15]. However, climate change is expected to increase rainfall intensity and frequency, which will directly alter the current IDF curve. Therefore, stormwater management relying on IDF curves developed from observed historical data may not be adequate to deal with an unexpected increase in total runoff [16]. Besides, it has been a well-accepted fact that IDFs developed from past climatic conditions cannot be valid for future climatic conditions unless they are updated to reflect future climate trends [17]. The use of updated IDF curves is important because, without the use of correct and up-to-date tools during the planning and design stages, the quality of the drainage and irrigation systems will be negatively impacted in the future.

### 1.1 Site Study

Hulu Terengganu, Terengganu located at 5°05′N and 102°45′E in Peninsular Malaysia. It covers nine townships and 387,462.60 hectares, which are surrounded by Kelantan and Pahang. Besides, Hulu Terengganu is in Malaysia's Central Forest Spine region. It designates the district as an environmentally sensitive area, with 99% of the land area undeveloped (Hulu Terengganu District Council). The location of the chosen rainfall station in Hulu Terengganu is depicted in Fig. 1. There were 14 active rainfall stations located throughout Hulu Terengganu. However, due to the availability of the existing or nearest IDF curve in MSMA2 and the quality of the historical data with less than 10% missing value, only four rainfall stations were selected. The 33 years (1988 to 2020) of observed historical daily and hourly rainfall data from four rainfall stations were acquired from the Department of Irrigation and Drainage, Malaysia (DID).




| Station ID | Station Name | Latitude (N) | Longitude (E) |
|---|---|---|---|
| 4929001 | Kg. Embong | 04 57 10 | 102 58 00 |
| 4930038 | Kg. Menerong | 04 56 20 | 103 03 40 |
| 5029034 | Kg. Dura | 05 04 00 | 102 56 30 |
| 5128001 | Sg. Gawi | 05 08 35 | 102 50 40 |

**Fig. 1** *Hulu Terengganu catchment*

## 2. Methodology

The main objective of this study was to investigate the changes of IDF curve due to climate changes adaptation. Therefore, the comparison between existing IDF curve in MSMA2 with the newly developed IDF curve was made. Fig. 2 shows the flow chart of the methodology. The analysis in this study can be divided into three major phases: (1) spatial downscaling of daily rainfall data obtained from these three GCMs (MRI-ESM2-0, CMCC-CM2-SR5, GFDL-ESM4) for SSP1-2.6, SSP2-4.5, and SSP5-8.5; and (2) development of the IDF curve for 2, 5, 10, 20, 50, 100 and 200 ARI with consideration of climate change impact. In the process of downscaling the rainfall data, the statistical downscaling type Linear Scaling (SD-LS) was employed to verify that the downscaled rainfall accurately represented the local rainfall. After annual maximum hourly rainfall series data had been gathered, the Gumbel (EVI) distribution was employed for conducting frequency analysis as part of the procedure for IDF curve development.

### 2.1 Climate Simulation using Statistical Downscaling Method

The climate simulation data from CMIP6 that forms the basis of the sixth assessment report (AR6) of the IPCC were used in this study. In order to anticipate the future climate, the GCMs from MRI-ESM2-0, CMCC-CM2-SR5, and GFDL-ESM4 under scenario of SSP1-2.6, SSP2-4.5, and SSP5-8.5 were used. The selected GCMs groups were based on their good ranked performances of Malaysia's climate [18], [19]. Table 1 shows the description of the selected GCM models. The daily rainfall simulation results for the historical period (1988-2020) and projected period (2040-2099) were collected from the CMIP6 portal (https://esgf-node.llnl.gov). Three shared socio-economic pathways (SSPs) scenarios—SSP1-2.6, SSP2-4.5, and SSP5-8.5—were used in this study as the latest climate scenarios and also consider the three difference levels of radiative forcing that will providing different impact to the future climate. In this work, the SD-LS approach was used to correct the biases of the three GCMs due to its effectiveness in downscaling climate data and conservation of time and effort compared to other methods [17].

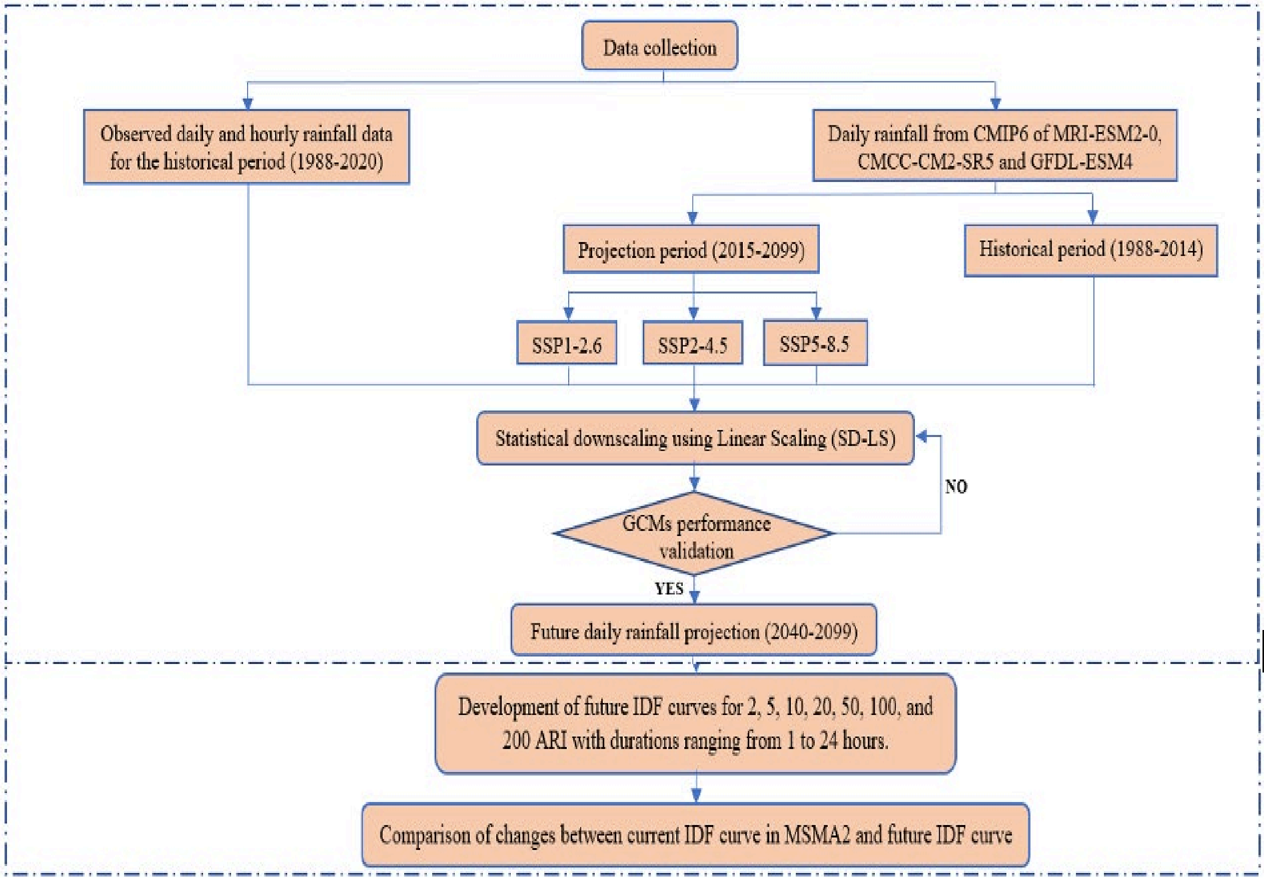



**Fig. 2** *Methodology of the study*

**Table 1** Details description of CMIP6 models used in this study

| Institution/Country | Abbreviation | Model | Resolution |
|---|---|---|---|
| Meteorological Research Institute, Japan | MRI | MRI-ESM2-0 | 1.12°x1.12° |
| Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy | CMCC | CMCC-CM2-SR5 | 1.00°x1.00° |
| NOAA Geophysical Fluid Dynamics Laboratory, USA | GFDL | GFDL-ESM4 | 1.00°x1.00° |

Before performing the climate analysis, all missing data must be addressed and treated to provide complete, homogeneous, and reliable data. Rainfall analysis is complicated as it is affected by both space and time. For long term projection, accurate estimation of the missing data is challenging and necessitates particular care. The missing data were filled using data from neighboring stations. One of the most well-known and widely-used method, especially when dealing with large scale missing data, is the Inverse Distance Weighted (IDW) method which is shown in Eqn. (1).

$$V_o = \frac{\sum_{i=1}^{n}(^{v_i}/_{D_i})}{\sum_{i=1}^{n}(^{1}/_{D_i})} \quad (1)$$

where $V_o$ is the assessed value of the missing data, $V_i$ is the value of same parameter at $i^{th}$ nearest station, $D_i$ is the distance between the station with missing data and the $i^{th}$ nearest station.

The procedure began by calculating a monthly adjusted factor using the difference between the monthly mean of the raw GCMs data and the observed historical data for the simulated period of 1988–2014. Once the bias correction factor had been multiplied by the raw GCMs data, the climatic data was obtained. The simulated results were then analysed using statistical analyses in terms of percentage different (% different), root mean square error (RMSE), and Pearson's correlation (r). The % difference used to measure the percentage different between the simulated result with the historical data. Meanwhile the RMSE is calculated in order to quantify the difference between observed data and forecasted data and how spread out the simulated rainfall to the historical data. Smaller value in RMSE indicates high accuracy on flood forecasting quality. The Pearson correlation coefficient measures the strength of a linear association between simulated and historical data. The r value presenting in 3 conditions; zero value indicates that there is no association between forecast and observed, +1 value indicates as the forecast increases, the observed also increases, and -1 value indicate as the forecast increases, the observed will be decreased.

$$Rcor,m,d = Rraw,m,d \times \left[\frac{\mu(Robs,m)}{\mu(Rraw,m)}\right] \quad (2)$$

$$Percentage\ Different\ \% = \frac{(x - y)}{(x + y)/_2} \text{ x } 100\% \quad (3)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y-x)^2} \quad (4)$$

$$Pearson\ Correlation, r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}} \quad (5)$$

where $R_{cor,m,d}$ is the bias-corrected rainfall data of the d-th day of the m-th month, $R_{raw,m,d}$ is the raw GCM data for the same day, and $\mu(R_{obs,m})$ and $\mu(R_{raw,m})$ is the monthly mean of observed historical data and raw GCM data of the m-th month, respectively. Meanwhile $x$ is the simulated data, $y$ is the observed data, $\bar{x}$ is the mean of simulated data, $\bar{y}$ is the mean of observed data, and $N$ is the total number of data points.

## 2.2 Development of IDF Curve under Climate Change Impact

Firstly, Scaling Properties (SP) had been used to convert daily rainfall data to hourly scales for a single site station to tackle the deficiency of high-resolution spatial and temporal rainfall data essential for hydrological applications. The scaling properties of rainfall intensity $I_d$ for a duration $d$ can be represented by the following relationship in Eqn. (6):

$$I_d = \left(\frac{d}{D}\right)^{-\eta} I_D \quad (6)$$

where $\eta$ is the scaling exponent (hourly coefficient) and $I_D$ is the rainfall intensity for duration $D$. The ratio $d/D$ is the scaling ratio between the known (actual or simulated) 24-hr duration (daily) of the rainfall intensities ($D$) and the desired hourly rainfall intensities for durations less than 24-hr ($d$). The equality refers to the same probability distribution function for both variables if the finite moment of order $q$ exists for both. The relationship between the moments of order $q$ was obtained by raising both sides of the equation to the power of $q$ and taking the expected values of both sides as per Eqn. (7).

$$E\left[I_d^q\right] = \frac{d}{D}^{-\eta(q)} E\left[I_D^q\right] \quad (7)$$

The scaling exponent $\eta$ was estimated by generating the log-log graph of moments $E\left[I_d^q\right]$ versus durations of different order $q$, and plotting the linear graph of slope (from moments versus durations line) and moments order $q$ [20]. If the resulting graph is a straight line, the value of $\eta$ which is the slope of a linear graph remains the same for different values of $q$, the data is considered simple scaling; otherwise, it is multi-scaling.

After the annual maximum hourly rainfall data for 24-hr durations obtained from the disaggregation process, the data were then fitted to a probability distribution function to estimate the amounts of rainfall with respect to the required return period. As the Gumbel (EV1) distribution showed a better result in previous studies as discussed in the literature review, it was employed for conducting frequency analysis in this study using the following equation:

$$x_t = \mu_z + K_T \sigma_Z \tag{8}$$

where $x_t$ = the magnitude of rainfall of the T year event, $\mu_z$ = the mean of the annual maximum hourly rainfall, $\sigma_Z$ = the standard deviation of the annual maximum hourly rainfall, and $K_T$ = the frequency factor depending on the return period T. The frequency factor, $KT$ is obtained using the relationship:

$$K_T = \frac{-\sqrt{6}}{\pi}\left[0.5572 + ln\left(ln\left(\frac{T}{T+1}\right)\right)\right] \tag{9}$$

## 3. Results and Discussions

The historical and future rainfall data projections obtained from GCMs under three different climate scenarios (SSP1-2.6, SSP2-4.5, and SSP5-8.5) were successfully downscaled and validated with the observed historical data. The future rainfall projections (2040-2099) were then compared with 33 years of observed historical data (1988-2020) on an annual and monthly basis to determine the future climate pattern for Hulu Terengganu. The data were presented in two selected time periods: 2040-2069 (Δ2050s) and 2070-2099 (Δ2080s). Finally, the annual maximum hourly rainfall data obtained from the disaggregation process were used to develop the IDF curves under the climate change impact. The developed IDF curves were based on two different periods: Δ2050s and Δ2080s. Then, the comparison pattern was made between developed IDF with current IDF curves in MSMA2 to determine the possibilities impact of the climate change.

### 3.1 Climate Projection Analysis

Fig. 3 shows the comparison performance between historical and simulated result from 3 GCM models (CMCC, MRI and GFDL). By using SD-LS model as a climate simulator, all GCM models were successfully to produce good simulation and consistent monthly rainfall pattern to the historical. As shown in Table 2, the simulated rainfall performed well by producing lower percentage different, ranging from 0.06 to 0.35% for all GCMs models. Besides, all GCMs models successfully simulated a comparable average monthly rainfall pattern as the observed historical data, with r values ranging from 0.97 to 1.00 and RMSE values ranging from 0.35 to 2.63. The results strongly indicated that the use of the SD-LS method in correcting the GCMs biases is acceptable as the downscaled rainfall accurately captures the local rainfall pattern. This is because most of the analysis involved in assessing the climate change impact is performed on coarser temporal resolution data such as a monthly or seasonal scale rather than daily which gives an advantage to the SD-LS method [17]. The good performance of the SD-LS method in correcting biases has also been proven by previous studies [21]-[24].

Meanwhile Fig. 4 depicts the future rainfall projections (2040-2099) with the 33 years of historical data (1988-2020) on an annual rainfall to determine the future climatic pattern of Hulu Terengganu. The result of future rainfall projections was presented in two separate time periods: 2040-2069 (Δ2050s) and 2070 – 2099 (Δ2080s). The projected rainfall covers a variety of emission levels and societal implications from three different climate scenarios, which are SSP1-2.6, SSP2-4.5, and SSP5-8.5 to provide a comprehensive understanding of future climate changes. As overall, all GCMs agreed that the largest average annual rainfall is estimated to produce increment rainfall trend until the end of the century. There was a maximum of 17.11% increase in the projected annual rainfall in Δ2050s (MRI) and 10.31% in Δ2080s (CMCC) produced by the SSP1-2.6 compared to the historical data. Besides, the result indicated that most of the climate scenarios from all GCMs models predicted an increase in future annual rainfall, particularly in the Δ2050s. It proved that the changing of future rainfall patterns is the result of climate change driven by an increase in GHG emissions. The increase in the projected annual rainfall pattern due to climate change impacts will increase the probability of future flooding events in Hulu Terengganu. Meanwhile the SSP5-8.5 shows a declining trend, particularly for MRI and GFDL models. According to Peng et al. [25], a climate scenario with a greater warming effect such as SSP5-8.5 might produce less rainfall over land and an increased risk of drought compared to other scenarios. However, the projected rainfall is more frequent and intense because of the higher rate of evaporation.

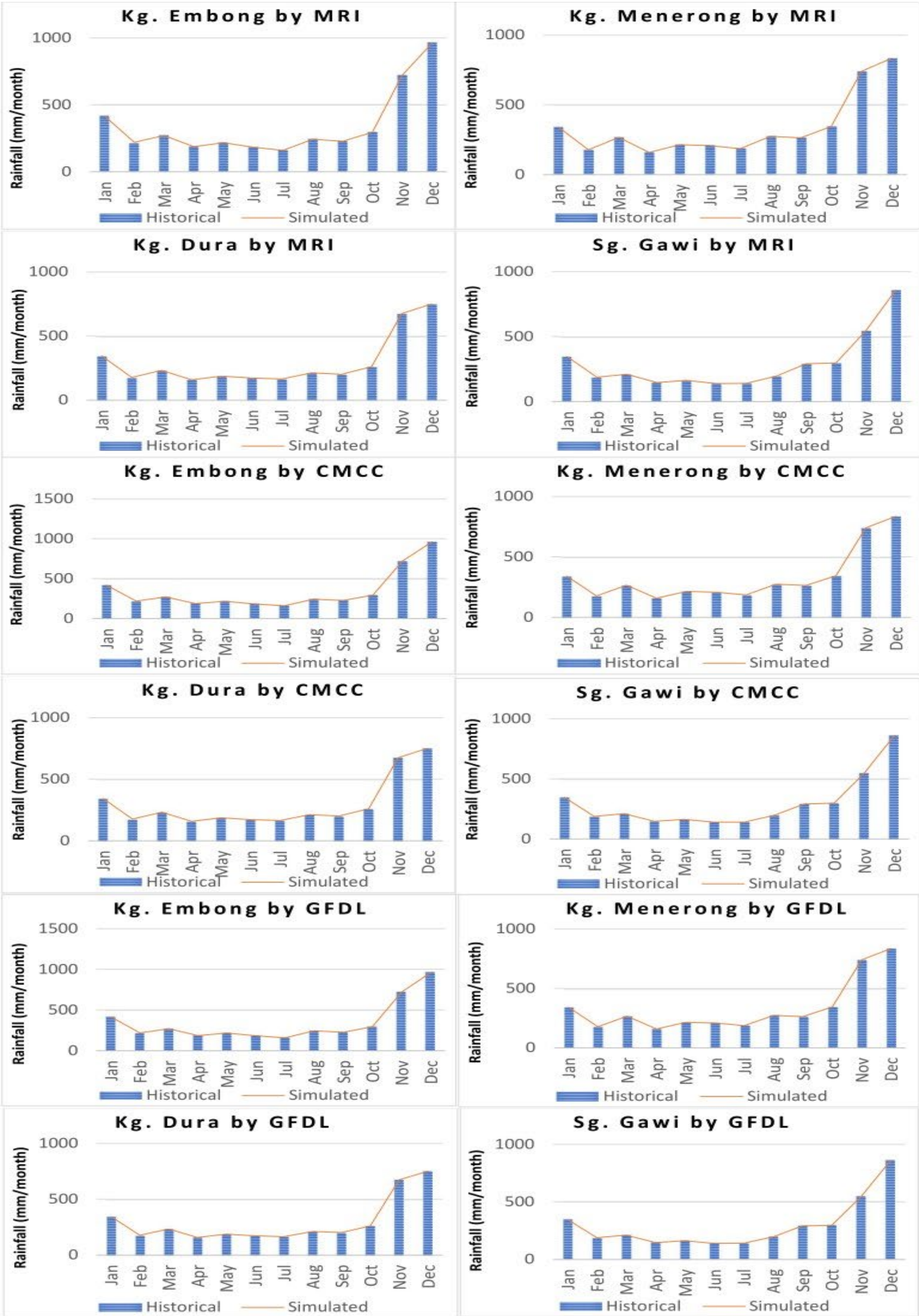



**Fig. 3** *Comparison between simulated monthly rainfall (1988-2014) by GCMs models with the observed* historical data

**Table 2** *Performance evaluation of the simulation periods (1988-2014) using statistical analyses*

| Rainfall Station | % Differences | | | RMSE | | | r | | |
|---|---|---|---|---|---|---|---|---|---|
| | MRI | CMCC | GFDL | MRI | CMCC | GFDL | MRI | CMCC | GFDL |
| Kg. Embong | 0.33 | 0.30 | 0.35 | 0.97 | 0.97 | 0.97 | 2.49 | 2.26 | 2.63 |
| Kg. Menerong | 0.11 | 0.06 | 0.10 | 0.99 | 1.00 | 0.99 | 0.66 | 0.35 | 0.62 |
| Kg. Dura | 0.17 | 0.14 | 0.20 | 0.99 | 0.99 | 0.98 | 0.85 | 0.70 | 1.02 |
| Sg. Gawi | 0.16 | 0.16 | 0.21 | 0.99 | 0.99 | 0.98 | 1.02 | 1.01 | 1.38 |

## 3.2 Comparative Performances of IDF Curve under Climate Change Impact

The developed IDF curves under the climate change scenarios were presented in a projected time periods of Δ2050s only. The downscaled and disaggregated outputs from the three GCMs under SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios were used to develop the IDF curves with durations ranging from 1 to 24 hours and return periods of 2, 5, 10, 20, 50, 100, and 200 years. In order to determine the possibilities of climate change's impact on rainfall intensities for the Hulu Terengganu, only the maximum rainfall intensities for each rainfall station are selected across all climate scenarios to be compared with MSMA2. The comparison of the projected rainfall intensities (for 1-hr, 5-hr, 10-hr, 15-hr, 20-hr, and 24-hr durations) in the Δ2050s with the MSMA2 for all rainfall stations is shown in Table 3.

According to the finding, the future rainfall intensities in the Δ2050s are projected to increase in all rainfall stations. The largest potential increase in the future rainfall intensity is predicted at Sg. Gawi, with percentages ranging from 2% to 86% based on the different return periods and rainfall durations. Meanwhile, Kg. Menerong is the least affected compared to other stations, with increased percentages ranging from 1% to 41%. The developed IDF curves indicated a higher increase in rainfall intensities for shorter durations under the same return periods of rainfall but a gradual decrease for longer durations. For example, at Sg. Gawi, a 20-year return period with the current rainfall intensities of 90.2 mm/hr and 15.1 mm/hr for 1-hr and 24-hr rainfall durations is expected to have intensities of 167.5 mm/hr (+86%) and 22.8 mm/hr (+51%) in the Δ2050s, respectively. The similar future rainfall intensity pattern was produced by Noor et al. [16] and Nasidi et al. [26] in their studies of climate change impact on the IDF curve in Peninsular Malaysia and Cameron Highland, respectively.

Fig. 5 shows an example of a detailed comparison of Kg. Embong's projected IDF curves in the Δ2050s with MSMA2 for each return period. In general, there is a potential increase in future rainfall intensity under climate change scenarios for Hulu Terengganu in the Δ2050s. Based on the projected rainfall intensities, the current rainfall event in MSMA2 with a return period of 1 in 100 years, might have a return period of 1 in 20 years by the Δ2050s. Based on the development of future IDF curves in the context of climate change, it can be concluded that the rainfall intensities of extreme rainfall events for various durations with different return periods are all likely to increase over the time in comparison with MSMA2. Besides, the overall results also suggest that under climate change in Hulu Terengganu, intense rainfall events are predicted to occur more frequently because there has been a consistent rise in the exceedance values of rainfall intensity during extreme events. The capacity of the current drainage and stormwater systems is anticipated to be insufficient to cope with the future rainfall intensity, which will cause more frequent and severe natural disasters such as floods in Hulu Terengganu.

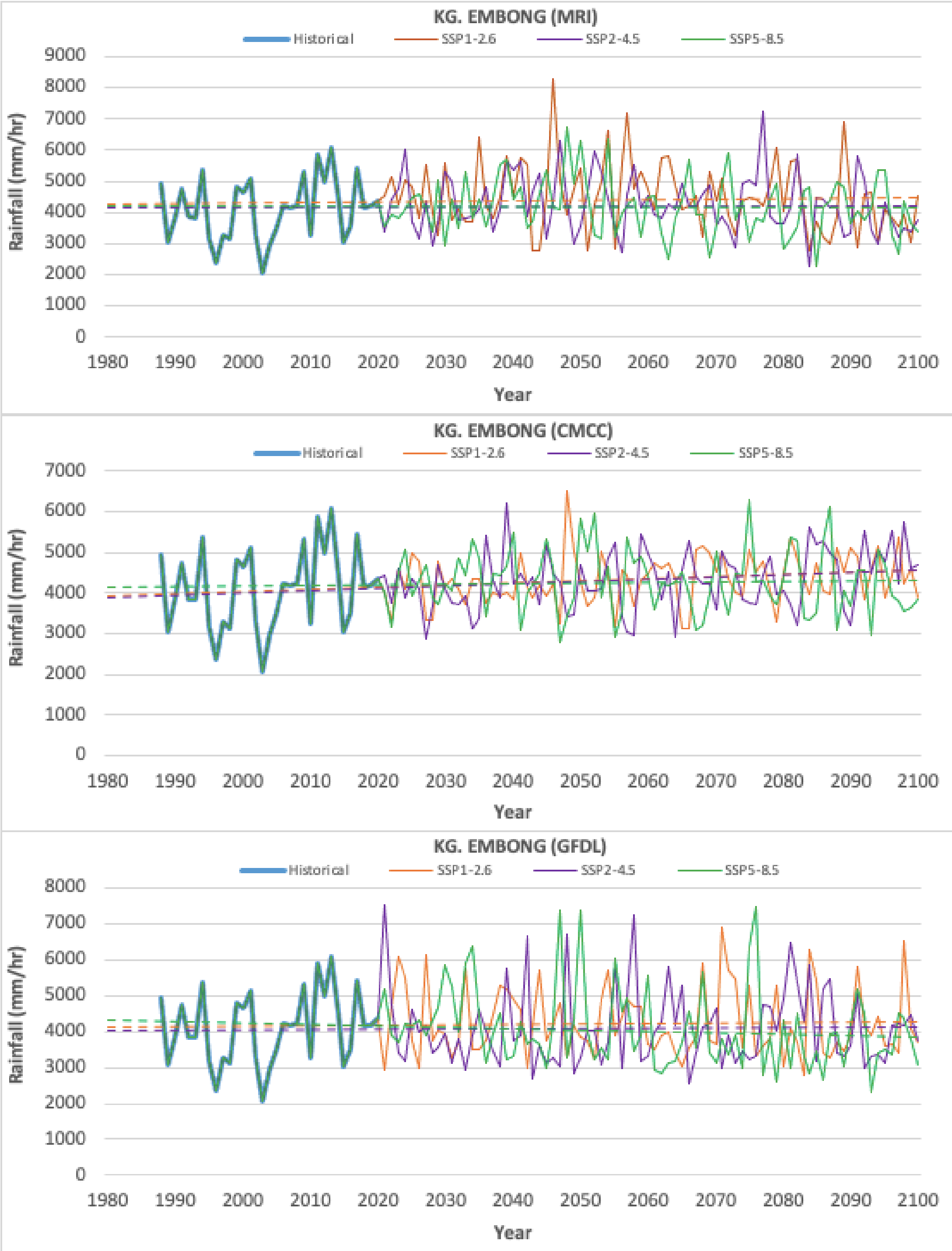



**Fig. 4** *The annual rainfall trend from 1988-2099 in Kg Embong, Hulu Terengganu*

**Table 3** *Comparison of IDF curves between future and current reference (MSMA2)*

**Kg. Embong**

| ARI/ Hours | MSMA2 (mm/hr) | | | | | | | Δ2050s (mm/hr) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 | 200 | 2 | 5 | 10 | 20 | 50 | 100 | 200 |
| 1 | 67.2 | 81.0 | 93.3 | 107.4 | 129.5 | 149.2 | 171.8 | 75.0 | 114.2 | 140.9 | 166.6 | 199.7 | 224.6 | 249.4 |
| 5 | 26.8 | 32.3 | 37.2 | 42.9 | 51.7 | 59.6 | 68.6 | 28.3 | 43.1 | 53.1 | 62.8 | 75.3 | 84.7 | 94.0 |
| 10 | 17.9 | 21.6 | 24.9 | 28.6 | 34.5 | 39.8 | 45.8 | 18.6 | 28.3 | 34.9 | 41.2 | 49.5 | 55.6 | 61.8 |
| 15 | 14.1 | 17.0 | 19.6 | 22.6 | 27.2 | 31.4 | 36.1 | 14.5 | 22.1 | 27.3 | 32.3 | 38.7 | 43.5 | 48.3 |
| 20 | 11.9 | 14.4 | 16.6 | 19.1 | 23.0 | 26.5 | 30.5 | 12.2 | 18.6 | 22.9 | 27.1 | 32.5 | 36.5 | 40,6 |
| 24 | 10.7 | 12.9 | 14.9 | 17.2 | 20.7 | 23.8 | 27.4 | 10.9 | 16.6 | 20.5 | 24.3 | 29.1 | 32.7 | 36.3 |

**Kg. Menerong**

| ARI/ Hours | MSMA2 (mm/hr) | | | | | | | Δ2050s (mm/hr) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 | 200 | 2 | 5 | 10 | 20 | 50 | 100 | 200 |
| 1 | 67.2 | 81.0 | 93.3 | 107.4 | 129.5 | 149.2 | 171.8 | 78.5 | 107.0 | 129.7 | 151.5 | 179.7 | 200.8 | 222.1 |
| 5 | 26.8 | 32.3 | 37.2 | 42.9 | 51.7 | 59.6 | 68.6 | 28.8 | 39.2 | 47.5 | 55.5 | 65.8 | 73.6 | 81.3 |
| 10 | 17.9 | 21.6 | 24.9 | 28.6 | 34.5 | 39.8 | 45.8 | 18.7 | 25.5 | 30.8 | 36.0 | 42.7 | 47.7 | 52.8 |
| 15 | 14.1 | 17.0 | 19.6 | 22.6 | 27.2 | 31.4 | 36.1 | 14.5 | 19.9 | 23.9 | 28.0 | 33.2 | 37.1 | 41.0 |
| 20 | 11.9 | 14.4 | 16.6 | 19.1 | 23.0 | 26.5 | 30.5 | 12.1 | 16.7 | 20.0 | 23.4 | 27.7 | 31.0 | 34.2 |
| 24 | 10.7 | 12.9 | 14.9 | 17.2 | 20.7 | 23.8 | 27.4 | 10.8 | 15.0 | 17.9 | 20.8 | 24.7 | 27.6 | 30.6 |

**Kg. Dura**

| ARI/ Hours | MSMA2 (mm/hr) | | | | | | | Δ2050s (mm/hr) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 | 200 | 2 | 5 | 10 | 20 | 50 | 100 | 200 |
| 1 | 66.9 | 81.9 | 95.4 | 111.1 | 135.9 | 158.3 | 184.4 | 77.4 | 108.4 | 134.8 | 160.2 | 193.0 | 217.6 | 242.0 |
| 5 | 25.8 | 31.6 | 36.8 | 42.9 | 52.4 | 61.1 | 71.1 | 27.5 | 38.6 | 48.0 | 57.0 | 68.6 | 77.4 | 86.1 |
| 10 | 16.9 | 20.7 | 24.1 | 28.1 | 34.4 | 40.0 | 46.6 | 17.6 | 24.7 | 30.7 | 36.5 | 44.0 | 49.6 | 55.2 |
| 15 | 13.2 | 16.2 | 18.8 | 21.9 | 26.8 | 31.2 | 36.4 | 13.6 | 19.0 | 23.7 | 28.1 | 33.9 | 38.2 | 42.5 |
| 20 | 11.1 | 13.5 | 15.8 | 18.4 | 22.5 | 26.2 | 30.5 | 11.3 | 15.8 | 19.7 | 23.4 | 28.2 | 31.8 | 35.3 |
| 24 | 9.9 | 12.1 | 14.1 | 16.4 | 20.1 | 23.4 | 27.3 | 10.1 | 14.1 | 17.5 | 20.8 | 25.1 | 28.3 | 31.4 |

**Sg. Gawi**

| ARI/ Hours | MSMA2 (mm/hr) | | | | | | | Δ2050s (mm/hr) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 | 200 | 2 | 5 | 10 | 20 | 50 | 100 | 200 |
| 1 | 55.0 | 67.0 | 77.7 | 90.2 | 109.9 | 127.5 | 148.0 | 68.8 | 115.6 | 139.3 | 167.5 | 204.1 | 231.5 | 253.4 |
| 5 | 22.4 | 27.3 | 31.6 | 36.7 | 44.7 | 51.9 | 60.2 | 25.1 | 42.1 | 50.8 | 61.1 | 74.4 | 84.4 | 92.3 |
| 10 | 15.1 | 18.4 | 21.4 | 24.8 | 30.3 | 35.1 | 40.8 | 16.2 | 27.3 | 32.9 | 39.5 | 48.2 | 54.6 | 59.8 |
| 15 | 12.0 | 14.7 | 17.0 | 19.8 | 24.1 | 27.9 | 32.4 | 12.6 | 21.2 | 25.5 | 30.7 | 37.3 | 42.4 | 46.4 |
| 20 | 10.2 | 12.5 | 14.5 | 16.8 | 20.5 | 23.7 | 27.6 | 10.5 | 17.7 | 21.3 | 25.6 | 31.2 | 35.4 | 38.7 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **24** | 9.2 | 11.2 | 13.1 | 15.1 | 18.4 | 21.4 | 24.9 | 9.4 | 15.8 | 19.0 | 22.8 | 27.8 | 31.5 | 34.5 |

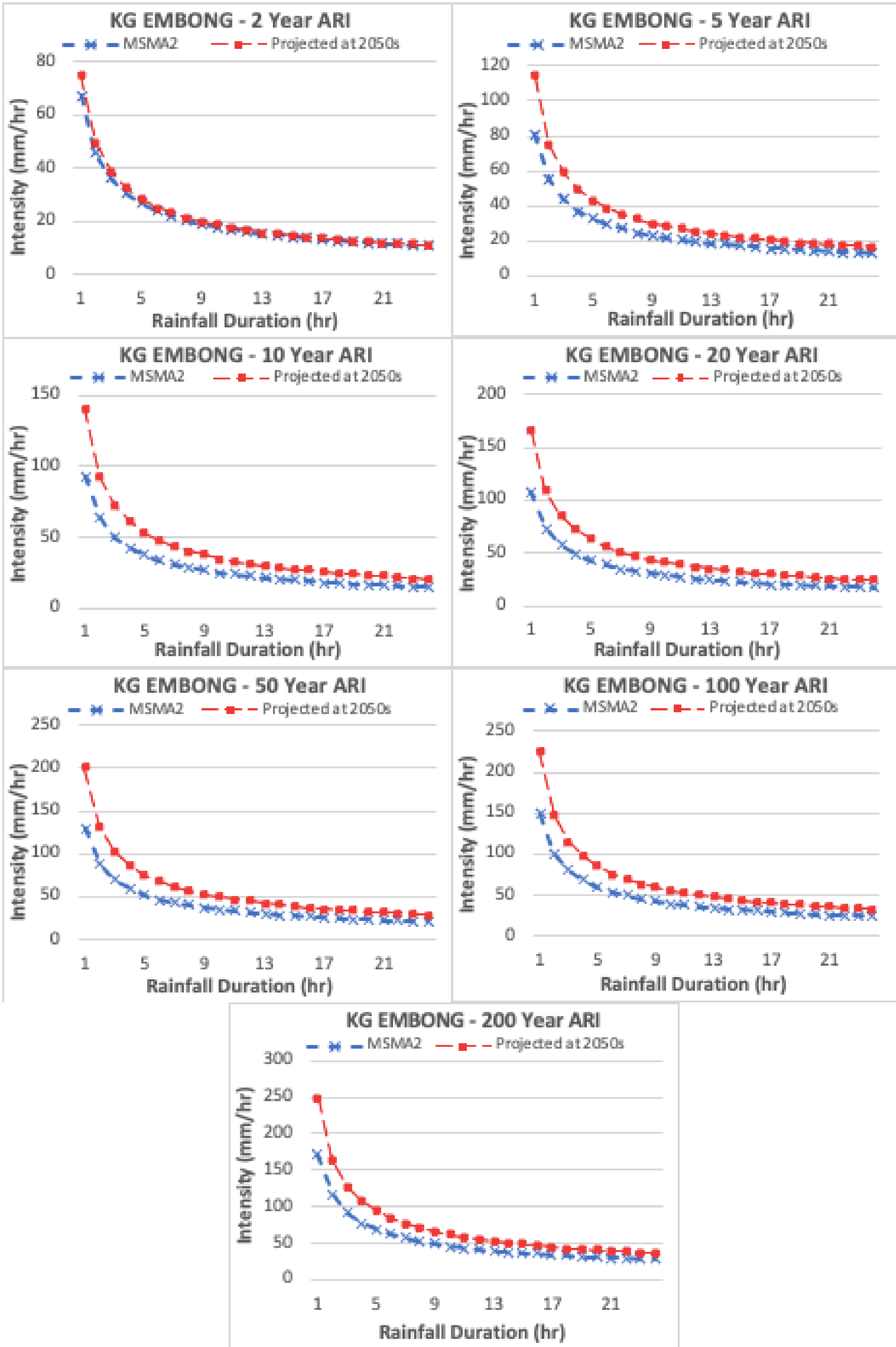



**Fig. 5** *Comparison of projected IDF curves in the Δ2050s with MSMA2 for Kg. Embong, Hulu Terengganu*

## 4. Conclusions

The developed IDF curves for all rainfall stations under different climate scenarios were then developed based on the return periods of 2, 5, 10, 20, 50, 100, and 200 years for the rainfall duration of 1 to 24 hours. The future IDF curves were compared to the current IDF curves used in MSMA2. In order to determine the possibilities of climate change's impact on rainfall intensities for Hulu Terengganu, only the maximum rainfall intensities from each rainfall station are selected across all climate scenarios. According to the analysis, the future rainfall intensities is expected to increase within Hulu Terengganu catchment. The largest potential increase in future rainfall intensity is predicted at Sg. Gawi, with percentages ranging from 2% to 86% based on the different return periods and rainfall durations. Meanwhile, Kg. Menerong is the least affected compared to other stations, with increased percentages ranging from 1% to 41%. Thus, it could change the pattern of IDF curve that been developed based on projected rainfall by various SSPs. The developed IDF curves shows higher rainfall intensities in a shorter duration under the same return periods and the 20-year return period produced the highest increasing percentage of future rainfall intensities compared to other return periods. Overall, the future rainfall intensities of extreme rainfall events for various durations with different return periods are all likely to increase over the time compared to MSMA2. As we move towards the end of the 21$^{st}$ century, the current return period of 1 in 100 years from MSMA2 might be reduced to 1 in 20 years (Δ2050s). Therefore, comprehensive action must be taken immediately to control and manage the impact of climate change by introducing clear policies and enforcing more effective laws.

## Acknowledgement

This research was supported by Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme (No. FRGS/1/2020/WAB02/UTHM/02/8) and Universiti Malaysia Pahang Al Sultan Abdullah, Malaysia (University reference RDU220338).

## Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

## Author Contribution

*The authors confirm contribution to the paper as follows:* ***Manuscript Writer:*** *Wan Amirul Syahmi Wan Mazlan and Nurul Nadrah Aqilah Tukimat;* ***Climate Projection and Statistical Analyses****: Nurul Nadrah Aqilah Tukimat;* ***Disaggregation Techniques:*** *Siti Nazahiyah Rahmat; and* ***IDF Development in the context of Climate Changes****: Hartini Kasmin, Samera Samsudin Sah and Wan Amirul Syahmi*

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