

Estimation of Climate Change Impacts on Frequency of Precipitation Extremes

Case study: Klang Watershed, Malaysia

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Abstract. This paper presents a statistical downscaling using SDSM tool to link between large-scale climate variables GCMs simulation to the estimation of design storms at a local site based on a daily extreme precipitation data. Key focus of this study was to evaluate the impact of climate change on the occurrence of floods in Klang catchment in Malaysia. The approach poses a statistical downscaling method for estimating the frequency analysis relations that could take into account the climate changes given by GCMs for current as well as for future climatic conditions. The method was tested using simulations from HadCM3 GCMs under the A2 scenario and annual maximum precipitation data available in study area. The Frequency Analysis relations and the resulting design storms for present and future periods (2020's, 2050's and 2080's) were constructed. It was found that annual precipitation and design storm rainfall intensities downscaled from the HadCM3A2 indicate increasing precipitation trends in the future generated three time slices.

Keyword: Frequency Analysis, Downscaling methods, GCM, SDSM, climate change.

1. Introduction

Extreme rainfall events are very likely to be globally more frequent and more intense in future decades (IPCC, 2007). Thus, the hypothesis of stationary precipitation occurrences appears highly questionable in prospect of climate change. Frequency analysis is a technique of fitting a probability distribution to a series of observations for defining the probabilities of future occurrences of some events of interest such as estimate of a flood magnitude corresponding to a chosen risk of failure. The maximum rainfall amount for a given duration and for selected return period is often required for the planning and design of urban drainage systems. It is therefore important in water management studies particularly in the design of hydraulic structures due to safety and environmental considerations.

However, a single station in a catchment does not provide reliable data. This is because the rainfall in a catchment scale can be significantly varied spatially due to variability in physical catchment. The distribution is assumed as the underlying probability distributions for next 50–100 return periods Extreme precipitation events and is analyzed using annual daily maximum precipitation observed data at the selected rainfall station.

The Global Climate Models (GCMs), are well known to be able to project climate data for future at the global scale. However, the GCMs resolution are too coarse for being used directly in hydrological studies since the hydrological boundaries are normally characterized by a short response time due to small surface area size and high imperviousness level. (e.g., Wilby et al., 2004). Therefore outputs from GCMs should be downscaled to provide climate simulations at appropriate temporal and spatial scales that are required for

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accurate estimation of hydrological characteristics for the fine resolution. Key aim of this paper is to evaluate the impact of climate change on the occurrence of floods in the study area using the daily annual maximum observed precipitation and downscaled GCMs precipitation. It proposes a statistical downscaling method for estimating the frequency of precipitation extremes relations that could take into account the climate information given by GCMs for current as well as for future climatic conditions. Therefore, it can be estimated Frequency analysis of extreme values using the daily annual maximum observed precipitation and downscaled GCMs precipitation in the area of study.

2. Material and Methodology

This study uses a series of precipitation analysis:

1- Daily Precipitation for period 1961-1990 was used. Daily time series for the period 1975 to 2001 corresponding to rainfall station namely Kampung Sungai Tua (K.S.T) located at $03^{\circ} 16' 12''$ N latitude and $101^{\circ} 40' 48''$ E longitude situated in upper Klang at the Selangor state of Peninsular Malaysia.

2- National Centre for Environmental Prediction (NCEP) reanalysis data which are outputs from a high resolution atmospheric mode. These data are composed of 25 daily atmospheric variables for the same period which are selected at grid box covering each of the stations. NCEP data can be obtained from <http://www.cics.uvic.ca/scenarios/index.cgi>

The grid box of (28-X, 34-Y) was extracted from the NCEP data for the scope of area.

3- GCM simulations Hadley Centre 3rd generation (HadCM3) coupled oceanic-atmospheric general circulation model (Wilby and Wigley, 2001). The Hadley circulation provides a useful framework for understanding the nature of large scale flow, the actual circulation in the tropics involves substantial zonal and regional variations.

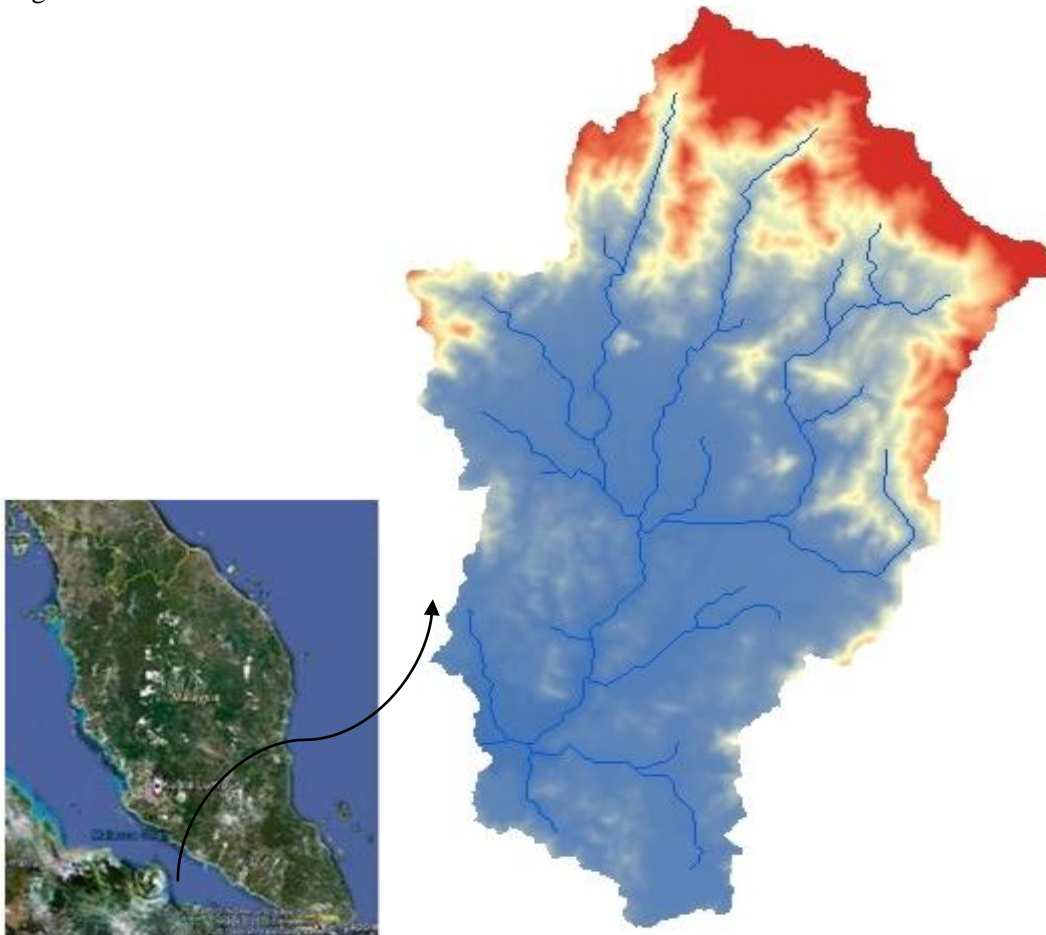


Figure 1 Location of the study area

There are two steps to construct frequency analysis at the site of interest corresponding climate change scenario:

- 1- A spatial downscaling method to link large-scale climate variables as provided by HadCM3 simulations with daily extreme precipitations at a local site using SDSM. and,
- 2- A temporal downscaling procedure to describe the relationships between daily extreme precipitations with sub-daily extreme precipitations using the fitting distribution.

2.1. Statistical Downscaling

Statistical Downscaling Model (SDSM) which is regression-based method developed by (Wilby et al., 1999) is used as the basic model to present the initial view of how significant the projections of climate change scenarios will affect the precipitation variability for the site under study area. The main advantages of statistical downscaling are that they are cheap, computationally undemanding and readily transferable, providing local information most needed in many climate change impact applications and ensembles of climate scenarios permit risk or uncertainty analyses. SDSM is well documented and has been successfully tested in numerous studies (e.g. Wilby et al., 2004; Haylock et al., 2006; Khan et al., 2006). Compared to other downscaling methods, the statistical method is relatively easy to use and provides station-scale climate information from GCM-scale outputs (Wilby et al., 2002). Thus, statistical downscaling methods are the most widely used in anticipated hydrologic impact studies under climate-change scenarios. The linear regression based downscaling method allows the development of the linear statistical linkages between large-scale predictors from GCMs and local observed predictands. The GCM climatic variable data are from Hadley Centre Coupled Model (HadCM3), Hadley Centre, United Kingdom.

The model calibration process uses a specified predictand and predictors to construct downscaled models, based on multiple linear regression equations. The thirty year daily precipitation data used was divided into a calibration data set (1975–1990) and an independent verification set for (1991 to 2001). In this context, atmospheric data for the period 1975 to 1990 from NCEP re- analyses data set have been identified using empirical relationships with station data. The best performance predictors were selected based on higher correlation and lowest standard errors for every month between years.

During validation, mean and variance of downscaled daily precipitation are adjusted by bias correction and variance inflation factor to force the model to replicate the observed data. Bias correction compensates for any tendency to over or under estimates the mean of downscaled variables.

2.2. Frequency Analysis

Several probability models have been developed to describe the distribution of extreme rainfalls at a single site (Zalina et al., 2002). SMADA software was used to fit statistical distributions. It consists of a number of powerful, flexible, user-friendly mathematical tools that can be used for the statistical analysis of extreme events. The comparison of fitting function is based on number of parameters of the fitted probability distribution and the confidence interval. The best distribution is selected based on SMADA comparison of fitting function. For the data, Gumbel Type I Extreme Value, is the best fit distribution. SMADA fits a Gumbel Type 1 distribution to the data using the annual maximum series after the method of (Shaw 1994).

$$F(X) = 1 - e^{-e^{-(x-\mu)/\sigma}} \quad (1)$$

The annual maximum for a return period of T-years can be calculated from:

$$Q_T = \bar{Q} + K(T)S_Q \quad (2)$$

$$K(T) = -\sqrt{6}/\pi \left(\gamma + \text{Ln Ln} \left[\frac{T(X)}{T} (X) - 1 \right] \right) \quad (3)$$

Which,

Q is the mean of the annual maximums,

S_Q is the standard deviation of the maximums,

K(T) is a frequency factor,

$T(X)$ is the return period in years, and γ is a constant equal to 0.5772.

3. Results

3.1. Downscaling Climate Variables Corresponding to Future Climate Change A2 Scenarios of Kampung Sungai Tua (K.S.T)

After the above analysis, we used the calibrated downscaling model to generate the precipitation data for the current (1975 to 2001) and future periods (2020s, 2050s, 2080s) based on the CGCM2 predictors. Table 1 indicates increasing increment Max daily precipitation of most of the months with in year of future generated precipitation for 2020's, 2050's and 2080's, in comparison to observed precipitation of 1975-2001 due to climate change A2 scenario.

Table 1 Comparison of mean and Maximum precipitation for observed and simulated average daily precipitation of K.S.T using SDSM model

Month	Observed (1975-2001)		2010-2040 (the 2020's)		2041-2070 (the 2050's)		2071-2099 (the 2080's)	
	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum
January	13.8	92	13.12	125.09	12.6	125.3	11.39	115.3
February	12.99	91	11.27	95.25	12	94.7	14.54	108.13
March	13.07	141.5	14.55	105.72	15.85	111.48	17.56	118.36
April	13.67	127	14.42	130.92	13.89	123.5	12.91	116.97
May	14.48	103	14.38	135	14.43	127.94	14.5	119.85
June	14.6	133.5	17.15	158.43	20.2	177.88	25.32	225.61
July	14.34	85	12.54	129.35	12.31	114.56	11.3	106.5
August	12.8	92	12.32	105.15	13.69	106.37	15.4	108.06
September	15.41	98	19.08	159.21	22.85	178.64	29.99	185.3
October	15.26	168.5	12.4	120.15	10.82	112.32	8.47	103.62
November	13.68	93.5	13.3	122.19	13.91	126.31	14.67	139.1
December	11.57	76.5	11.43	119.62	12.85	112.99	14.37	126.79

3.2. Frequency Analysis Results Corresponding to Future Climate Change A2 Scenarios of Kampung Sungai Tua (K.S.T)

It has been attempted to construct the Frequency curves for the several periods at the station. It was shown in the table 2 and also figure 2 to estimate the changes in the predicted precipitation intensity as compared with the current period precipitation intensity. Daily rainfall durations (24-hour) and return periods (ranging from 10-year to 100-year) are considered. The analysis results are presented and discussed for the station in the following. For illustrative purpose, Figure 2 presents the probability plots of annual daily maximum precipitations of observed for the period (1975-2001) and three future projection generated scenarios for the periods 2020's, 2050's and 2080's of generated precipitation.

Table 2 Return periods associated with observed and generated rainfall series for K.S.T station

Return period	Observed (mm)	Generated (mm)		
	1975-2001	2020's	2050's	2080's
100	172.58	207.81	236.91	288.17
50	159.05	193.78	218.01	261.41
25	145.64	179.65	198.96	234.44

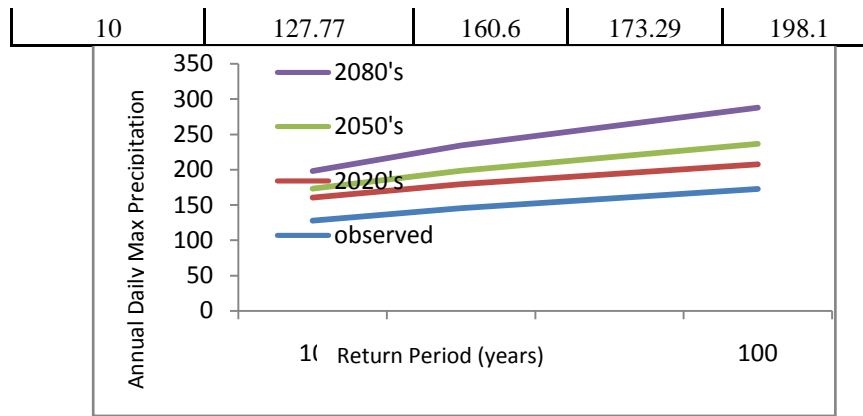


Figure 2 Gumbel distribution of annual daily maximum precipitation among observed and 2020's, 2050's and 2080's

4. Discussion and Conclusion

The Maximum Annual Precipitation series is obtained at the station for different durations and fitted to the statistical distributions. The distribution selected based on fitting comparison criteria of SMADA statistical software. Key focus of this study was to evaluate the impact of climate change on the occurrence of floods in the study area. Therefore, the Gumbel Type I Extreme Value distribution is assumed as the underlying probability distributions for next 100 return periods Extreme precipitation events of were analysed using annual daily maximum precipitation observed data at the selected rainfall station Kampung Sungai Tua (K.S.T) and climate scenarios downscaled results denoted by for future 2020s, 2050s, and 2080s period. Results of frequency analysis clearly indicate that future generated 2020's, 2050's and 2080's, representing the increasing precipitation scenario.

Frequency analysis of annual daily maximum of observed for the period 1975 to 2001 and three future scenarios 2020's , 2050's and 2080's was carried out to determine the impact of potential climate change on the occurrence of storm depths of any given magnitude revealed for the increasing extreme precipitation values for future projection periods.

Estimations of future modifications in rainfall due to increase in greenhouse gas concentrations depend on response from global climate models. Because of the inherent uncertainties, the developed Frequency curves from HadCM3 are unable to provide an accurate estimate of future extreme rainfall but it finds the fact that the future climate will not be the same as the historical climate. In presence of uncertainties in future precipitation of one single site may suffer from under or overestimation of the risks. Climate change will likely result in an increase in the intensity and frequency of extreme precipitation events in most regions in the future. As a result, the values will optimally need to be updated more frequently than in the past and climate change scenarios might eventually be drawn upon in order to inform Frequency calculations.

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