# CLIMATE CHANGE IMPACT ON PRECIPITATION AND STREAMFLOW IN A HUMID TROPICAL WATERSHED

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To my beloved family:
Hassan Bin Kasim (Father)
Maimunah Binti Endot (Mother)
Zulhasnor Bin Hassan
Zulhairy Bin Hassan

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# ABSTRACT

The increasing rate of the global surface temperature in climate change will have a significant impact on local hydrological regimes and water resources. This situation leads to the assessment of the climate change impacts has become a priority. The objectives of this study are to determine the current and future climate change scenario using the downscaling methods and to assess the climate change impact on stream flow discharge. It describes the investigation on precipitation and temperature changes which influenced by the large-scale atmospheric variables for several selected rainfall stations in the Kerian watershed and one selected temperature station in the Ipoh watershed, Peninsular Malaysia. In this study, the Global Climate Models (GCMs) simulations from Hadley Centre 3rd generation with scenario A2 (HadCM3 A2) have been used, and downscaled into a fine resolution daily rainfall and temperature series appropriate for local scale hydrological impact studies. The proposed downscaling methods applied in this study are the Long Ashton Research Station Weather Generator (LARS-WG) and Statistical Down-Scaling Model (SDSM). The changes in stream flow discharge are assessed using Identication of Unit Hydrograph and Component Flows from Rainfall, Evaporation and Streamflow Data (IHACRES) and Artificial Neural Networks (ANN) methods. It describes the investigation on possible future stream flow changes for four selected flow gauging stations represent the Kerian watershed. The SDSM and LARS-WG similarly are able to simulate the mean daily rainfall satisfactory. However, the SDSM model is better than the LARS-WG model in downscaling of the daily maximum and minimum temperature. Both models give an increase trend on projection of future temperature for all months. The LARS-WG and SDSM models obviously are feasible and reliable methods for use as tools in quantifying effects of climate change condition on a local scale. The rainfall and temperature data downscaled with the SDSM and LARS-WG models obviously are not similar in the simulation of stream flow discharge using the ANN and IHACRES models. ANN yields a better performance than IHACRES. The study area is apparently will gain consistently increasing trend in the mean annual temperature of about 0.24-4.23$^{o}$C, and facing varying rainfall depth for the next 100 years. While the data downscaled with SDSM resulted in an increase in mean daily flow of about 10-40% in the coming 100 years, the one downscaled with LARS-WG resulted in a decrease in mean daily flow of up to 40%. This is a clear indication of how the outcome of a hydrologic impact study can be affected by the selection of any one particular downscaling technique over the other. The implication that the flood or drought may frequently experienced in the future corresponding to climate scenario HadCM3 A2.

# ABSTRAK

Peningkatan kadar pemanasan suhu permukaan global akibat perubahan iklim, telah memberi kesan ketara kepada kawasan hidrologi berskala tempatan, serta kepada kawasan pengurasan sumber air. Situasi ini membawa kepada keutamaan kajian berdasarkan kesan perubahan iklim. Objektif dalam kajian ini, adalah untuk menentukan perubahan senario iklim semasa dan masa hadapan, dengan menggunakan kaedah penurunan-skala (*downscaling methods*), serta penilaian kesan perubahan aliran air (*streamflow*) terhadap perubahan iklim. Dalam kajian ini, siasatan turut dijalankan kepada perubahan hujan dan suhu, berdasarkan pada pemboleh-ubah atmosfera berskala-besar (*large-scale atmospheric variables*) di beberapa stesen hujan yang terpilih di kawasan Kerian, dan satu stesen suhu yang terpilih di kawasan Perak, semenanjung Malaysia. Kajian turut dijalankan dengan menggunakan kaedah penurunan-skala dari *Global Climate Models (GCMs),* iaitu *Hadley Centre 3rd generation* dengan senario A2 (HadCM3 A2) bagi mendapatkan set hujan dan suhu yang mempunyai resolusi kecil, dan sesuai untuk digunakan untuk kajian mengenai kesan iklim terhadap hidrologi berskala tempatan. Kaedah penurunan-skala yang dicadangkan untuk diaplikasi dalam kajian ini ialah kaedah *Stochastic Weathers of Long Ashton Research Station Weather Generator* (LARS-WG) dan *Statistical Down-Scaling Model* (SDSM). Disamping itu, perubahan kadar aliran air dikaji dengan menggunakan kaedah *Identication of Unit Hydrograph and Component Flows from Rainfall, Evaporation and Streamflow Data* (IHACRES) dan *Artificial Neural Network* (ANN). Kajian turut dijalankan bagi mendapatkan kadar aliran air untuk masa hadapan di kawasan tadahan di Kerian, yang diwakili oleh empat stesen cerapan aliran air yang terpilih. Kaedah SDSM dan LARS-WG didapati, dapat mengsimulasi purata hujan harian dengan memuaskan. Walau bagaimanapun, model SDSM didapati lebih baik dalam menurun-skala suhu maksimum dan minimum, berbanding model LARS-WG. Disamping itu, kedua-dua model turut menunjukkan peningkatan suhu disetiap bulan pada masa hadapan . Oleh itu, model LARS-WG dan SDSM jelas adalah kaedah yang boleh dilaksanakan, dan boleh dipercayai untuk digunakan sebagai alat untuk mengukur kesan keadaan perubahan iklim pada skala tempatan. Data hujan dan suhu yang diturun-skala dengan model SDSM dan LARS-WG didapati tidak menghasilkan simulasi aliran air yang sama apabila menggunakan model ANN dan IHACRES. Didapati, ANN menghasilkan prestasi yang lebih baik daripada IHACRES. Kawasan kajian didapati menerima peningkatan perubahan suhu tahunan sebanyak 0.24-4.23$^{o}$C, serta menerima ketidaktentuan curahan hujan untuk 100 tahun akan datang. Data SDSM didapati akan meningkatkan aliran air harian sebanyak 10-40% untuk 100 tahun akan datang, berbanding data LARS-WG yang mengurangkan aliran air harian sebanyak 40%. Keputusan ini jelas membuktikan penilaian impak hidrologi dipengaruhi oleh penggunaan jenis kaedah penurunan-skala. Implikasinya ialah banjir atau kemarau yang kerap dialami pada masa hadapan turut disimulasi di kawasan kajian berdasarkan iklim senario HadCM3 A2.

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| | | |
|---|---|---|
| % | - | percentage |
| $km^2$ | - | square kilometer |
| $^oC$ | - | degree celcius |
| $^o$ | - | degree |
| ‘ | - | minute |
| “ | - | second |
| $E^2$ | - | Nash-Sutcliffe coefficient |
| GHz | - | gigahertz |
| Ha | - | hectare |
| hpa | - | hectopascal |
| *i.e* | - | example |
| m | - | meter |
| mm | - | millimeter |
| $m^3/s$ | - | cubic metre per second |
| *obs* | - | observed |
| *P, rk* | - | rainfall |
| *pred* | - | predicted |
| *Q* | - | flow/runoff |
| *R* | - | coefficient of correlation |
| $R^2$ | - | determination coefficient |
| *SE* | - | standard error |
| *T* | - | temperature |
| $T_{max}$ | - | maximum temperature |
| $T_{min}$ | - | minimum temperature |
| *TRAINSCG* | - | Scaled Conjugate Gradient |
| *TRAINGDX* | - | Variable Learning Rate Backpropagation |
| *TRAINCGB* | - | Powell-Beale Restarts |

| | | |
|---|---|---|
| *RMSE* | - | Mean standard error |
| *x* | - | multiple |
| ACRU | - | Agricultural Catchments Research Unit |
| ANN | - | Artificial Neural Network |
| AR4 | - | IPCC Fourth Assessment Report |
| ASCE | - | American Society of Civil Engineers |
| CATCHMOD | - | Catchment-scale Management Of Diffuse Sources |
| CMD | - | Catchment Moisture Deficit |
| DD | - | dynamic downscaling |
| DID | - | Department of Irrigation and Drainage Malaysia |
| ET | - | evapotranspiration |
| GCM | - | Global Climate Model |
| GIS | - | Geographic Information System |
| HadCM3 | - | Hadley Centre 3$^{rd}$ Generation |
| HSPF | - | Hydrological Simulation Program-Fortran |
| IHACRES | - | Identification of unit Hydrographs And Component flows from Rainfall, Evaporation and Streamflow |
| IPCC | - | Intergovernmental Panel on Climate Change |
| LARS-WG | - | Long Ashton Research Station Weather Generator |
| LRA | - | Linear Regression Analysis |
| MLP | - | Multilayered Feed-Forward Network |
| NCAR | - | National Center for Atmospheric Research |
| NCEP | - | National Centers for Environmental Prediction |
| NRA | - | Non-Linear Regression Analysis |
| PE | - | Potential evaporation |
| PSONN | - | Particle Swarm Optimization Feedforward Neural Network |
| RCMs | - | Regional Climate Models |
| PRECIS | - | Providing REgional Climates for Impacts Studies |
| REW | - | Representative Elementary Watershed |
| R-R | - | Rainfall-Runoff |
| SD | - | Statistical (empirical) downscaling |
| SDSM | - | Statistical Down-Scaling Model |
| SHE | - | Hydrologique Europeen |

| | | |
|---|---|---|
| SRES | - | IPCC Special Report on Emission Scenarios |
| UH | - | Unit Hydrograph |
| UK | - | United Kingdom |
| US | - | United State of America |
| WGs | - | Stochastic Weather Generators |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of the Problem

Human activities, primarily the burning of fossil fuels and changes in land cover and use, are nowadays believed to be increasing the atmospheric concentrations of greenhouse gases (Xu 1999). Those activities are perturbing the global energy balance, heating up atmosphere, and causing global warming. In terms of hydrology, climate change can cause significant impacts on water resources by resulting changes in the hydrological cycle. Temperature and precipitation are main parameters that closely related to the climate change. Changing on both parameters can have a direct consequence on the quantity of evapotranspiration and on both quality and quantity of the runoff component. Therefore, there is a growing need for an integrated analysis that can quantify the impacts of climate change on various aspects of water resources such as precipitation, hydrologic regimes, drought, dam operations, etc. Although the impact of climate change is forecasted at the global scale, the type and magnitude of the impact at a catchment scale are not investigated in most part of the world. Hence, study a local impact of climate change at the watershed level is needed. It will give enough room to consider possible future risks in all phases of water resource development projects such as changes in water availability and crop production under climate change scenarios.

To estimate future climate change resulting from the continuous increase of greenhouse gas concentration in the atmosphere, Global Climate Models (GCMs) are used. GCMs output cannot directly be used for hydrological assessment due to their coarse spatial resolution. Hydrological models deal with small catchment scale processes, whereas GCMs simulate planetary scale and parameterize many regional and smaller-scale processes (Yimer et al., 2009; Dibike and Coulibaly, 2005). Therefore, statistical downscaling methods which Statistical Down-Scaling Model (SDSM) and Long Ashton Research Station Weather Generator (LARS-WG) are used in this study to convert the coarse spatial resolution of the GCMs output into a fine resolution. Both models have their own advantages on downscaling rainfall and temperature corresponding to GCMs model.

The relationship between climate and water basin can be investigated and studied by the hydrological models (Xu, 1999). Identication of Unit Hydrograph and Component Flows from Rainfall, Evaporation and Streamflow Data (IHACRES) and Artificial Neural Networks (ANNs) are applied. Both models are metric based model. The successes of both models depend on the expertise of the modeler with prior knowledge of the information input being modeled. This tedious nonlinear structure calibration process sometime may produce uncertainty results due to the subjective factors involved. Therefore, the study also focuses on developing an effective and efficient calibration procedure.

## 1.2 Statement of the Problem

According to the Intergovernmental Panel on Climate Change (IPCC) report, the global temperature surface has increased by $0.74^{0}$C in 1906-2005, and the increasing rate is about $0.13^{0}$C per 100 years in the next 20 years (IPCC, 2007). The report also state that the temperature would increase by about 1.1–6.4°C during the next century. It will have significant impact on hydrological cycles and subsequent changes in river flow regimes, and toward agriculture production.

Therefore, the only way to study climate changes is by studying GCMs model. The coarse resolution of GCMs model cannot be used directly for a small catchment study. It is necessary to study the effect of climate change at this scale in order to take the effect into account by the policy and decision makers when planning water resources management (Shaka, 2008). Hence, SDSM and LARS-WG model are applied to downscale GCMs into catchment scale. Both models have their own advantages and disadvantages (Dibike and Coulibaly, 2005). Comparisons of both models are well discussed in many journal papers, but the relationship between both models and hydrological models are still not well published. Normally, hydrologic impacts of climate change are usually analyzed by using conceptual and/or physically based hydrological models (Dibike and Coulibaly, 2005). Therefore, the study will use IHACRES and Artificial Neural Networks (ANNs) which applied metric based hydrological models to assess climate change assessment. The success of both depends on the expertise of the modeller with prior knowledge of the information input being modelled. This tedious nonlinear structure calibration process sometime may produce uncertainty results due to the subjective factors involved. Therefore, the study also focuses on developing an effective and efficient calibration procedure.

## 1.3 Objectives

The main aim is to explore and establish the relationship between climate change model with hydrological response using various climate downscaling models and hydrological models. The specific objectives are outlined as follows;

i. To calibrate the statistical downscaling models in a tropical agricultural area.
ii. To simulate the future rainfall and temperature variation based on the climate change scenario.
iii. To simulate the future flow variation using rainfall-runoff models.
iv. To evaluate the climate change impact on the rainfall, temperature and flow variations.

## 1.4 Scope of the Study

The study will focus on the calibration and simulation of the climate models by using the SDSM and LARS-WG models for the future rainfall and temperature. Hence, result of the climate models, will be used as an input to the hydrological models, which are IHACRES and ANN. In addition, a few statistical methods and drought indices will be used to evaluate the climate change impact. The study has focused on 13 selected rainfall stations in the Kerian watershed, and one selected temperature station in the Ipoh watershed. The investigation on the possible future stream flow for four selected flow gauge stations represent the Kerian watershed also being discussed in this study.

## 1.5 Significance of the Study

There are several benefit and significance of the study, which are;

I. Find the way to manage the water in irrigation.
II. Increasing the irrigation efficiency with the data that we obtain from climate simulation programs.
III. Change in land use or change in life style of people with adaptation to climate change.

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