

Assessment the Potential of SRES Scenario for Kuala Sala, Malaysia

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Abstract: The diversity of SRES scenarios that has potential to produce different increment of climatic trend reflects to the future expectation on development patterns. The selection of an appropriate emission scenario is important to present the appropriate climatic trend suit to the site study. The main objective is to determine appropriate emission scenarios and potential increment of rainfall in the upcoming year $\Delta 2020$ and $\Delta 2050$ for site study. Two climate projection models; SDSM and PRECIS models were used to generate the future rainfall trends using A2, B2 and A1B scenarios. The result showed the B2 scenario has potential to produce similar trend to the historical for the Kuala Sala station, in Kedah, followed by the A2 scenario. Scenario A1B is estimated to underestimate/overestimate through a year affected by the coordinate gap selection of site study. Generally, the annual rainfall intensity predicted varies for different SRES scenarios and reflect to the future expectation on development patterns. The highest rainfall increment is predicted by using the B2 scenario (about 2638mm/year) until year $\Delta 2050$. A1B is predicted to produce the lowest increment. The heaviest monthly rainfall, predicted to occur twice a year, is influenced by the seasonal monsoon effects. This study proved that different emissions will produce diverse rainfall trends due to the influence of greenhouse gases.

Keywords: climate change; climate scenario, SDSM, PRECIS, climate projection

I. Introduction

Nowadays, global warming has become a global crisis. Karl *et al.* (2009) in their report stated about the unequivocal and worsened of the climate day by day over the last century. It has been projected that the changing precipitation pattern and increment of evapotranspiration are due to the rising of temperature that will increase the frequency and severity of droughts and floods at specific regions (Shaaban *et al.*, 2011). The climate uncertainties can be analysed based on the climate variability and climate changes. Climate variability refers to the fluctuation of the seasonally or yearly average or climate variables range. The measurement of climate variability is used to analyse and simulate the probability of climatic event in the future year as imperative information for the system designing tools. Meanwhile, climate change refers to the continuous changes of the climate variability in the long term to observe the climate transition in a general manner.

Currently, the global climate is divided into four basic groups of emission scenarios based on the country's development and expected level of greenhouse gases. The greenhouse gases consist of carbon dioxide, methane, nitrous oxide, hydrofluorocarbon, perfluorocarbon, and sulphur hexafluoride. These gases normally exist in the atmosphere in minimal concentration. The contaminant of these gasses depends on the population growth, urbanization, level of pollutions and land development in the region. These gasses could stay in the atmosphere in a long period of time and are well-mixed to form higher concentration levels. The increment of greenhouse gasses is due to the progressive development on the land surface that encourages contaminant growth in the atmosphere. In the projection of climate, the emission levels are taken into account in the physical of atmosphere, ocean, cryosphere, and land surfaces known as GCM. The Special Report on Emission Scenarios (SRES) produced by IPCC (2013) classified the emission scenarios into four groups there are A1, B1, A2 and B2 as possible future climate change.

The A1 scenario is referred to the regions that have the potential to acquire a higher development in terms of rapid economic growth, quick technologies growth, high population growth and could become as convergent world. In this scenario, there are three others subset families based on the emphasizing technologies which included A1FI (fossil-fuels), A1B (balanced in all energy sources) and A1T (non- fossil energy sources). On the other hand, the A2 scenario involved the continuous increment in the population growth and regional oriented economic development. Meanwhile, B1 and B2 scenarios explained the slower growth level from the A1 and A2 scenarios respectively due to reduction of material intensity and fragmented technologies. However, A2 and B2 scenarios are the common storylines among the three GCM models which are the Hadley Centre Coupled Model version 3 (HadCM3) by Collins *et al.* (2001), Canadian Centre for Climate Modeling and Analysis (CCCMA) by Kim *et al.* (2003) and Commonwealth Scientific and Industrial Research Organization (CSIRO) by Gordon and O'Farrell, 1997. These common storylines lead A2 and B2 scenarios to become

prominent in various regions. Horton *et al.* (2005) used A2 and B2 scenarios driven by HadCM3/HadAM3H, ECHAM4/OPYC3 and ARPEGE are seen to generate the seasonal temperature and precipitation of Swiss Alps during year 2070 - 2099. All the scenarios predicted the changes in the same trend at different amplitude and timing. Chu *et al.* (2010) applied A2 and B2 scenarios in the climate projection at Mekong River using PRECIS climate data. The precipitation and temperature at this region are estimated to increase higher in A2 scenario as compared to B2 scenario. It was proven that A2 and B2 scenarios had different interpretation of emission levels.

In Malaysia, the SRES A1B emission analysed by the regional climate model, Providing Regional Climates for Impacts Studies (PRECIS) is currently used to produce the projection of climate scenario for peninsular Malaysia, Sabah and Sarawak. Therefore, the objective of this study was to determine the appropriate emission scenarios and potential increment of rainfall in the upcoming year $\Delta 2020$ and $\Delta 2050$ for Kedah, Malaysia.

1.1 Site Study

The study is focused on Kedah state, north of Peninsular Malaysia. Kedah is well known as the rice bowl of Malaysia because most of the lands are cultivates of paddy as a staple food among Malaysian people. The project is under the Muda Agriculture Development Authority (MADA, Kedah). This area experiences the climate of four seasons which are the South-West monsoon (May - Sept), North-East monsoon (Nov - Mar), and two inter-monsoon seasons (Mar - May and Oct - Nov) within the same year. The month of Dec to Feb and Jun to Jul are considered as the warm season, while Apr to May and Sept to Nov are the humid season. The remaining months are expected to receive normal rainfall with the range of wind speed from 0 to 10 knots.

The rainfall station at Kuala Sala (5903151) located at 5.96°N, 100.32°E was selected to analyse the potential of emission scenarios as shown in Fig. 1. Referring to the historical data, the mean temperature in the study area was of 27°C to 32°C. The monthly temperature pattern showed the consistency of temperature reading. The highest monthly temperature was focused on Feb to Apr where it achieved 34°C and the lowest monthly temperature occurred from Nov to Jan in the average of 23°C. This proved that the temperature pattern is not affected by local monsoons. The mean daily ET and evaporation values at Kedah, Malaysia were in the range of 4.0mm/day to 6.3mm/day and 4.0mm/day to 7.0 mm/day respectively. The average rainfall depth at this area is 16 mm/day, 199 mm/month and 2390 mm/year.

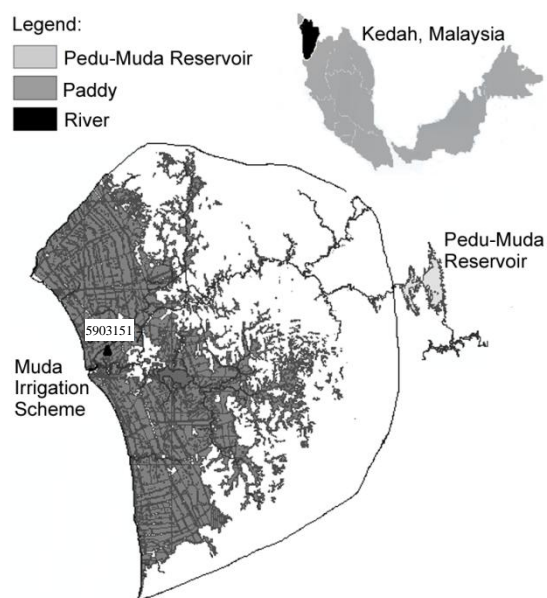


Fig. 1: Geographic location of Stn. Kuala Sala

II. Methodology of the Study

In this study, about three types of emission scenarios were used in classifying the best SRES group of climatic scenario for the region there are A1B, A2 and B2 scenarios. These scenarios were provided by Hadley Centre. The Statistical Downscaling Model (SDSM) and Providing Regional Climate for Impact Study (PRECIS) models were used to calibrate, validate and generate the rainfall trend at the region. Scenarios of A2 and B2 were used as emission baseline in SDSM model to downscale future climate trend. These common emissions are available in the SDSM model and become well prominent in various regions (Horton *et al.*, 2005; Chu *et al.*, 2010). The A2 scenario is referred to the regions that have continuous increment in the population

growth and regional oriented economic development. Meanwhile, B2 scenario explained the slower growth level from the A2 scenarios respectively due to the reduction of material intensity and fragmented technologies.

The PRECIS was used to downscale future climate trends under the A1B scenario which is practiced widely by MMD, Malaysia. The emission A1B is one of the A1 subset families where the region has higher development in term of rapid economic growth, quick technologies growth, high population growth, and could become a convergent world balanced in all energy sources. The daily rainfall data is used starting from year 1961 to 2099. The methodology structure is shown in Fig. 2

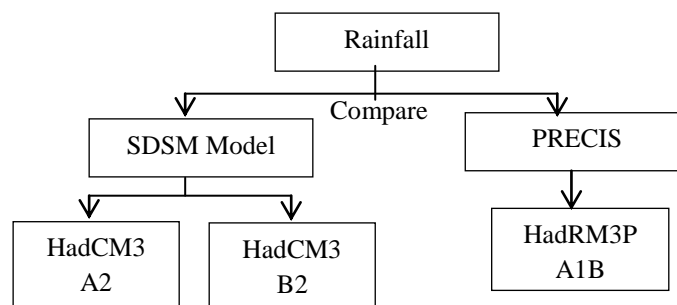


Fig. 2: Methodological structure of study

1.2 Statistical Downscaling Model (SDSM)

SDSM is analogous to the Model Output Statistic (MOS) and perfect approach used for short range numerical weather prediction (Wilby and Dawson, 2007). The model uses a weather generator method to produce a multiple realization of the synthetic daily weather sequence. The model interpret the statistical relationship between large scale (predictor) and local climate (predictand) using multiple regression techniques. These relationships were developed using an observed weather data and previously captured relationships among GCM-derived predictors. The SDSM downscaling used two types of data; viz. predictand and predictor at the grid box of 28X x 33Y.

The historical rainfall record (1976 - 1995) known as the predictand while the National Center for Environmental Prediction (NCEP) reanalysis data and GCM outputs of the Hadley Center General Circulation Model (HadCM3) under A2 and B2 scenarios were used as the predictor to simulate climate trend. The HadCM3 model was a modified version of HadCM2, made to improve the accuracy of the climate projection results without the application of flux adjustments. It has wider coarse spatial resolutions of 2.5° x 3.75° (latitude by longitude) which can be applied in many climatic regional studies. Samadi et al. (2010) considers HadCM3 as the best GCM model that is superior to other models such as CCSNIES, CSRIO, and GFDL. In this study, the A2 and B2 scenarios was chosen to give an upper bound and lower bound on future emissions, and were selected from an impacts-and-adaptation point of view – if it could adapt to a large climate change, it would have no problem with smaller climate change and the lower end scenario. The only setback is that low emissions scenario will have lesser information when such is the case (NARCCAP, 2007).

Fig. 3 illustrates the methodology of SDSM model. To downscale the local climate change, two types of data were required and those included the rainfall station known as predictand and two set of predictors at the grid box 28X x 33Y. The rainfall data at station Kuala Sala was presented in daily time series and was converted into month and annual period for analysis purposes. The predictors set were provided by the National Center for Environmental Prediction (NCEP) reanalysis data to be used for calibration and validation process and GCMs-variables to generate the future climate trend based on the expected increment of greenhouse gases at the region. The list of 26 predictors is shown in Table 3.

NCEP reanalysis is the atmospheric variables in the regional scale to construct the linear relationships with the local climate. The data were provided by the NOAA-CIRES Climate Diagnostics Centre which consists of air temperature, sea level pressure, geopotential height, specific humidity, and relative humidity between 500 hpa and 850 hpa. The NCEP data were applied directly in the screening process to select the appropriate predictors as downscaling agents. Then, the predictor selections were used in the calibration and validation by weather generator. The NCEP variables provide a guideline to the decision makers to view the predictor responses in the regional scale before simulating with the coarse scale resolutions (GCMs).

Finally, the similar types of predictor selections with the NCEP reanalysis, this time provided by the GCMs variables, were used to generate the local climate change. The GCMs were provided by the Hadley Center General Circulation Model version 3 (HadCM3) since 1999 considering the increase in the level of greenhouse gases into the atmosphere. It was an advanced model that did not include flux adjustment in the simulation but can still perform well in the projection of climate (Reichler and Kim, 2008). It covered a spatial resolution of 2.5° x 3.75° (latitude by longitude) in the grid box resolution of 96 x 73 grid cells (Gordon *et al.*,

2000). The A2 scenario was chosen to capture the future temperature and rainfall trend at this region because by providing medium-high emission scenarios it would be more suitable with the study area. Hence, the A2 scenario was applied widely in the study area due to the efficiency of the climatic projection results (Chu *et al.*, 2010; Horton *et al.*, 2005). The projection results produced by this model were used as data input for hydrological analysis, crop water requirement, and optimization models.

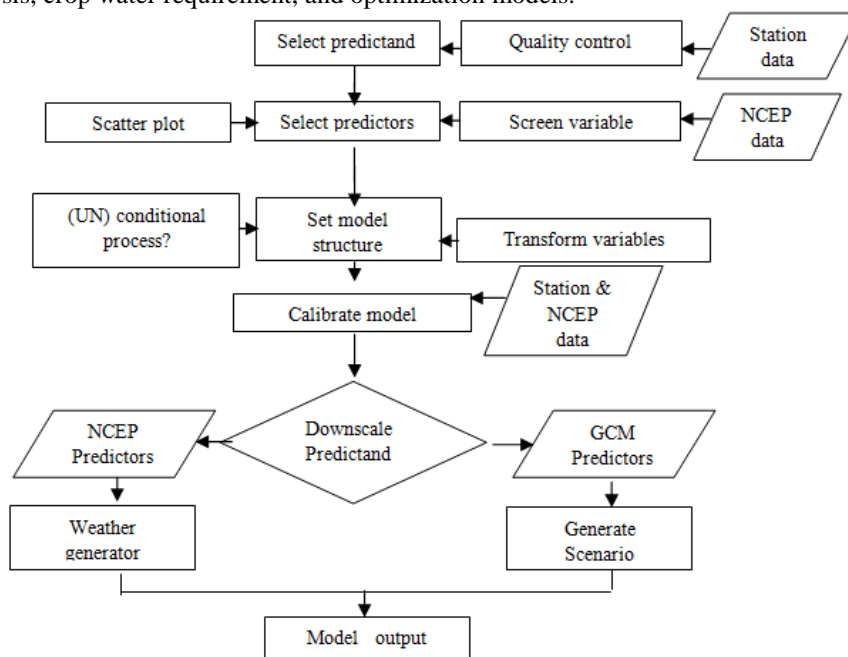


Fig 3: Schematic diagram of SDSM analysis (Source: Wilby and Dawson, 2007)

1.3 Providing Regional Climates for Impacts Studies (PRECIS)

PRECIS is one of the regional climate modelling system (RCM) developed by Met Office Hadley Centre. The model was configured to cover horizontal grid resolution of 0.22°×0.22° and 19 levels of hybrid vertical coordinate from ground up to 0.5 hpa (Jones *et al.* 2004). For Peninsular and East of Malaysia, the modelling is focused on 95°E to 123°E and 7.5°S to 14°N respectively. In contrast with statistical modelling, PRECIS downscales with coarser spatial resolution from the GCMs output in the range of 50km. It considers natural forcing (orbital, solar, and volcanic) and anthropogenic forcing (greenhouse gases emission and land use) in describing the feedback mechanisms of climate in terms of orographic rainfall, temperature variation, and other climatic phenomenon in the finer sub-grid scales. The complexity of this model is from the range of the resolutions where it is coarser than the local observation resolutions. In addition, an adequate selection in the boundary condition and climate parameters for the region could also influence the accuracy and the biased parameters (Deser *et al.*, 2012). For this model, scenario of A1B has been used by Malaysia’s agency to present the level of country’s development. The projections of climatic results started from year 1961 to 2099 were provided by MMD, Malaysia. The coordinate of 5.96°N 100.32°E is the best selection in presenting the climatic region of study.

III. Results and Discussions

The selection of appropriate SRES scenarios is foremost in representing the level of country’s development, emission and pollutant. The 4 storylines created are A1, A2, B1, and B2 based on economic growth, population, and exploration of new efficient technologies. A1F1, A1T, and A1B are under the A1 scenario based on technological emphasis. IS92a scenario is excluded from the discussion below. Fig. 4 shows the disparity of greenhouse gases emission which consists of CO₂, N₂O, CH₄, and SO₂ for each scenario for the future year. It is proven that these scenarios have strong inter-connection with the level of development, emission and air pollutants into the atmosphere. The A1F1 scenario is the highest contributor to the CO₂ and N₂O into the air because the country development under this scenario has higher fossil intensity especially gasoline and diesel for transportation purposes. This is followed by A2 and A1B scenarios where the country’s development is slower than the A1F1 scenario. However, the A2 scenario is expected as the biggest contributor of CH₄, and SO₂. It is affected by the concentration of tropospheric ozone which rises up to 60% for the ozone below 25mb and the potential to increase 2.5 times for CH₄, 2.6 times for NO_x, and 1.8 times for CO into the air due to fossil fuel combustion including 33% increase of SO₂ levels due to coal burning (Meehl, *et al.*, 2007).

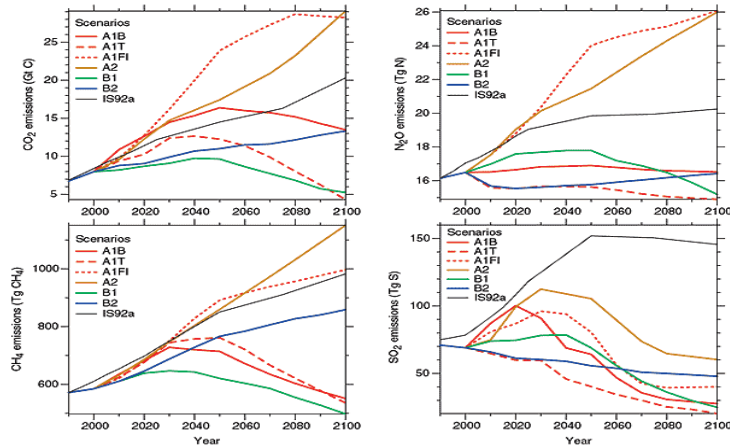


Fig. 4: Anthropogenic emissions of CO₂, CH₄, N₂O and sulphur dioxide for the six illustrative SRES scenarios (Source: IPCC, 2014)

Fig. 5 shows the comparison performances between A2 and B2 according to the 5 selective of GCMs predictors that have been used in the SDSM model. The purpose of the GCMs predictors are to evaluate the probability of climate change in the future, the surface water response at the region, and the ability of the reservoir system to achieve the objectives for regional water resources (Yano et al., 2007). The selection was based on the inter-correlation relationship between historical rainfall (predictand) and GCMs predictors (Tukimat & Harun, 2013). There are 500hPa of zonal velocity (p5_u), airflow strength (p_f), 500hPa relative humidity (r500), 850hPa meridional velocity (8_v) and specific humidity (shum). Based on the historical trend, the A2 and B2 scenarios have similar climate response. In 2020s, B2 scenario produces in average 25% higher climatic response compared to the A2 except in p5_u and r500. Meanwhile in 2050s, A2 scenario is estimated to have 19% bigger climatic responses in 8_v, r500, and shum compared to the B2 scenario. These trends show that the estimated amount of emission contaminant for A2 and B2 scenario are uncertainty based on the type of climatic responses.

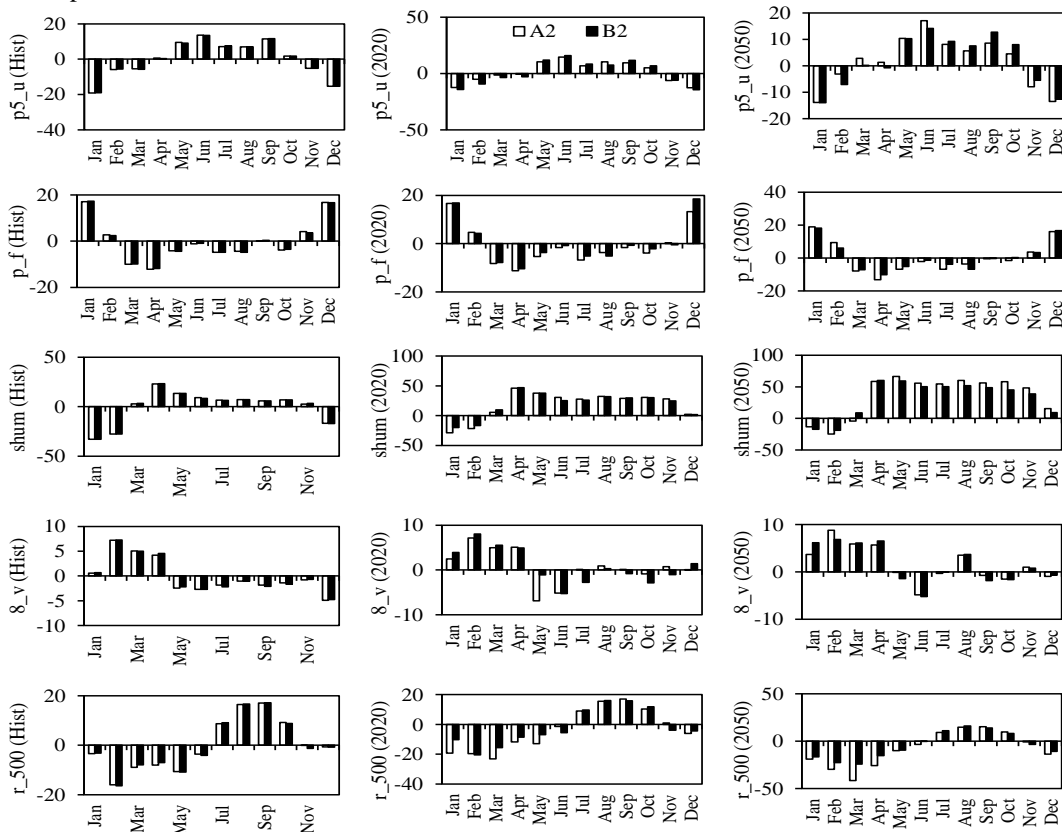


Fig. 5: Comparison between the SRES A2 and B2 for selective of predictors in SDSM model

The performances of scenarios with historical record

Fig. 6 revealed the performances of climatic projection using A1B, A2 and B2 scenarios. The coordinate of 5.96°N 100.32°E is the best location for A1B scenario to present the region meanwhile station Kuala Sala is used for A2 and B2 scenarios. Based on the graph, the validated result produced by B2 scenario was spreading closer to the mean historical rainfall with average error is less than 1%. The bigger error was expected occur on Feb and Dec that will affecting the projection climate result. A2 scenario was the second best performer with error less than 10% whereby the estimation is slightly higher on Feb, May, and Aug. Even the GCMs predictors for A2 and B2 scenarios are consistent however the climatic response of 8_v was slightly differ between these scenarios. Predictor of 8_v was refers to the direction of wind speed that will directly influence the advection of moisture in the region (Jinqiang & Simona, 2008) and potentially to influence the climatic system to produce higher rainfall intensity. Supported by Mohamed & Lahcen, 2015 revealed the B2 scenario has potential to produce less drought compared to the A2 scenario for Bouregreg basin, Morocco.

Meanwhile, scenario A1B is underestimated about 40% from the annual historical record. It might because of the coordinate selection which not presenting at exact location of region. Even the rainfall location for A1B scenario was selected nearest to the station Kuala Sala, however, the rainfall trend in Malaysia is non-uniform whereby contributes to the spatial variation of rainfall pattern.

Future climatic trend

Fig. 7 shows the trend of monthly rainfall for year Δ2020 and Δ2050 projected by SDSM (A2 and B2 scenarios) and PRECIS (A1B scenario) models. Generally, the annual rainfall intensity is predicted vary for different SRES scenarios reflect to the future expectation on development patterns. Emission of B2 scenario is estimated to have increment of rainfall intensity during year Δ2020 in 3% and continuous increase to 5% during year Δ2050 achieving 2638mm/year. In contrast, A2 and A1B scenarios showed the different rainfall trend. The annual rainfall using A2 scenario is predicted to decrease about 8% during year Δ2020 but then rises drastically up to 12% during year Δ2050 achieving 2507mm/year. A1B scenario shows the lowest rainfall intensity compared to the A2 and B2 scenarios. Contrast to the others scenarios, the highest and the lowest rainfall are focused on Apr and Jan respectively. Based on the normal Malaysia's climate, Apr is also categorized as secondary maximum rainfall at Peninsular Malaysia except east coast and southwest states. However, this pattern is slightly different with the secondary maximum historical rainfall focused on May.

As in expectation, the low prediction of rainfall intensity in the future year is affected by the underestimation of historical rainfall amount. Even though, the annual rainfall of A1B scenario is also predicted to rise during year Δ2050 achieving 2230mm/year. Normally, hydrological cycle becomes anomalous affected by the global warming. Higher temperature on the earth surface will evaporates more water surface than normal condition to form water vapour in the atmosphere and then condensate as heavy rainfall. As reported by Kevin, 2011, the water vapour has potential to increase about 7% for every 1°C warming and encourage more intense precipitation event.

Generally, lesser rainfall intensity is focused on Jan to Mar (dry season) and higher rainfall intensity is expected to occur on Sept to Dec (wet season). The heavier rainfalls are expected to occur twice within a year there are May and Nov. The heaviest monthly rainfall is expected to change from Sept to Nov for scenario B2 while the A2 scenario is consistent on Sept. These trends are expected to be influenced by the seasonal monsoon affected by land and sea breezes on the general wind flow pattern namely the northeast and southwest monsoons that happen twice a year in Malaysia.

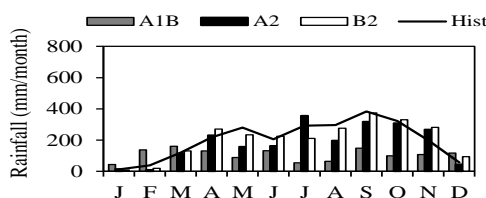


Fig 6: Comparison the performances between SRES scenarios with the historical data

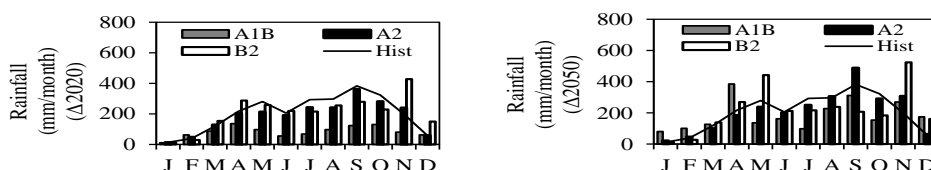


Fig. 7: Projection of rainfall for A1B, A2 and B2 for year Δ2020 and Δ2050

IV. Conclusion

The study analyzed and compared the potential difference on the projected rainfall trend using A2, B2 and A1B SRES emission during year $\Delta 2020$ and $\Delta 2050$. Two climate models were applied; the SDSM and PRECIS models in projecting the future rainfall trend at the Kuala Sala station. Each emission produces various climatic trends depending on country development and expected greenhouse gases level in the future years. The A2 scenario is considered the biggest contributor of CO₂, N₂O, CH₄, and SO₂ rather than B2 and A1B scenarios. It shows that the country that was categorized in the A2 scenario has the potential to develop bigger impacts of global warming compared to other scenarios. The B2 scenario is the appropriate SRES scenario in presenting the level of emission and development for this study site with error less than 1% compared to the historical record. Even the intensity of rainfall projection varies for every scenario. However, all the scenarios agreed that the rainfall has potential to increase continuously until year $\Delta 2050$. Less rainfall happens on Jan to Mar (dry season) and high rainfall intensity is expected to occur from Sept to Dec (wet season). The rainfall amount is underestimation using the A1B scenario could be due to the coordinate gap selection which was not present at the exact location of region. Even though the rainfall location for A1B scenario was selected nearest to the station Kuala Sala, the rainfall trend in Malaysia is non-uniform which contributes to the spatial variation of rainfall patterns.

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