Analysis of Climate-Net Unit Generated (NUG) Relationship for the Hydroelectric Power Station

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Abstract. Global climate change has influenced the sustainability of hydroelectric power generation caused by the uncertainties of the air temperature and rainfall pattern. Current reservoir water management practices may not be robust to survive impacts of climate changes particularly in sufficiency of long term water demand-supply. In addition, the electricity demand is also increasing year by year because of extreme daily weather. Higher temperature will increase the electricity demand which is good income generation however this has resulted high operation cost and reduction of water storage. Therefore, the main objective of the study was to determine the relationship between climate change with net unit generated (NUG) at Sultan Mahmud Hydro Electric Power Station. To achieve the objective, a Statistical Downscaling Model (SDSM) was applied to identify the best atmospheric variables which influenced the long term climate formation at the area. The climate-NUG relationship had been analyzed based on statistical equation. The finding shows inversed proportional relationships between rainfall and temperature. During wet seasons, the maximum rainfall achieved 60mm/month and the temperature recorded was around 26◦C. Minimum rainfall recorded during dry seasons was <10mm/month with maximum temperature reading up to 28.5◦C. In terms of power generated, the maximum NUG data were often recorded in wet season. The highest NUG recorded during dry seasons were 1 000 000-300 000 000 kWh while the value of NUG during wet seasons were 50 000 000-240 000 000 kWh.

Keywords: Climate Changes, Hydroelectric Power, NUG, SDSM, Statistical Analysis.

1 Introduction

Significant climate change has become one of the extreme challenges of the twenty-first century. Climate change refers to prolonged variability, both natural and anthropogenic, and is often related with warming temperatures. On average, global surface temperature has increased around 0.74°C over the previous century [1]. For instance, according to [2], global mean temperature might rise from 1 to 6°C over the century. This situation would cause to various and heterogeneous variations in local climates. Some places would experience higher warming than others. However, some areas would receive more rainfall while others would become drier. Climate at East Coast of Malaysia is warm with high temperature but at the same time has high humidity due to copious rainfall [3].

Electricity is a vital part in the growth of domestic economy. Electric power cannot be kept in large amounts, while the power generation and its consumption must be balanced in real time. The prediction of electric net generation is very crucial to balance the power generation and consumption. It affords great consequence to rationally allocate the power generation material and make an ideal power planning judgement by the power sector of a country [4]. The sustainability of the hydropower generation is depending on the availability water storage in the reservoir. The water level in the hydropower reservoir is significantly to maintain under the minimum design level to sustain the daily hydropower generation supply as well as to avoid any spillage. NUG is the quantity of electricity produced by a power plant that is transmitted then distributed to consumer. NUG is less than the total gross power generation as some power produced is spent within the plant itself to power supporting tools such as motors, pumps and pollution control devices. NUG might varies widely from season to season, depending on precipitation and stream flows. Meanwhile [5] claimed the temperature variation is also effect the performance of other climatic variables such as precipitation, humidity and wind speed.

According to the World Energy Council Report, hydroelectric production may double by year 2050. In prediction of population growth, energy consumption, water, food and dam development from interval year 2010 to 2050, [5] expect around 36,813 dams worldwide, with an overall reservoir capacity of 9204 km^3 in year 2050 meanwhile in year 2010, there were 32,473 dams with a capacity of 7975 km^3. Energy consumption is expected to growth from 134,000 to 183,000 TWh. The dams will be built in the developing countries and emerging economies such as Southeast Asia, South America and Africa. About 75% of the dams will be of medium and small size (1–100 MW) and 93% of the upcoming hydroelectric power capacity will be provided by large dams (>100 MW) [6].

Climate change would cause continuous increase of rainfall, temperature and weather related extreme events [7]. Global studies contrast in their predictions of effects on hydropower generation due to increasing temperatures and fluctuating precipitation patterns [8]. The uncertainties of rainfall pattern which affected by the climate changes brings direct impact to the sustainability and reliability of the water resources in terms of quality and quantity [9]. Many studies were successfully to prove the strong relationship between climate changes with hydrological circulation across the world [10]. Climate change provide huge impact to the rainfall variability and the formation of extremes events. It is necessary to discover the potential distributional variations of rainfall features over time. Multiple Climate Hazard Index considered Southeast Asia as one of the most vulnerable areas to climate change [11].

Energy demand in Malaysia is expected to increase in the future year due to increment of population demand. Therefore, the renewable energy sources has been studied and expand to fulfill the long term demand. Besides, the construction of new hydropower plants and develop new technologies are also one of the efforts from the authority to increase the efficiency [12]. Therefore, the main purpose was to determine the relationship between climate changes with the net unit generated (NUG). It is very importance to make sure that the influence of the climate change on the hydropower energy production still under control, although with strong variances between the wet and dry areas. Enhanced water management, drought and flood control, might additionally preserve and optimise water use. Therefore, the climate change is a challenge for hydropower and a prospect for development and making the world better.

2 Study Area

The Sultan Mahmud Hydro Electric Power Station is run by Tenaga Nasional Berhad. The power station is a hydroelectric power station, using four turbines of 400megawatt (MW). The dam fill volume is 15.20million m^3 with 150m in height above foundation and its crest length is 800m. The minimum operating level is 120m and a maximum of 145m. The reservoir surface area at 145m ASL is 370km², and with a catchment area of 2,600km² as shown in Fig. 1.

The Kenyir Dam is constructed from earth core rock fill type. The crest level and the dam height are equal. The constructions of 8 saddle dams were completed from the total amount 8.7 million m^3 of earth fill. The spillway of Kenyir dam is uncontrolled concrete ogee type. Its control the full supply level in the reservoir by discharging excess in flow waters in the reservoir into Sungai Terengganu. On the other hand, it will protect against overtopping. After the construction of Kenyir Dam, its help to decrease the flood levels at the lower Terengganu River basin.

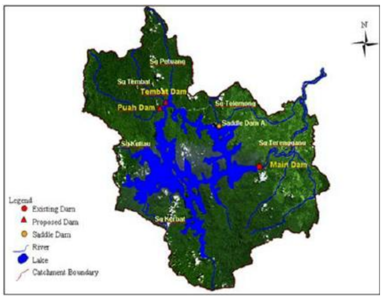


Fig. 1. Kenyir Dam.

2.1 Data Sets

The return periods for extreme events are projected from observational datasets [13]. About 9 years (2006–2014) daily rainfall records from 2 stations and daily temperature from 1 station obtained from the Department of Irrigation and Drainage (DID) of Malaysia, Tenaga Nasional Berhad (TNB) and Malaysian Meteorological Department (MMD) were used in this study. The 2 selected rainfall stations which were Gawi and Kenyir were measured and monitored by DID and TNB respectively. Data for net unit generated (NUG) at Sultan Mahmud Power Station from 2006 to 2014 were obtained from TNB.

3 Methodology of the Study: Statistical Downscaling Model (SDSM)

SDSM is a hybrid tool to predict the changes of the local climate. This model linked the local climate variables with the huge scale atmospheric variables to develop the daily weather equation using multiple regression technique. The downscaling needs two types of data there are local climates (so called as predictand) and atmospheric variables (so called as predictor).

There are two sub-models in SDSM known as unconditional and conditional. The conditional is suitable for a conditional (dependent) variable like precipitation while the unconditional sub-model is run for an independent variable such as temperature. SDSM version 4.2 was used to downscale the precipitation (rainfall) and temperature in the study area over the years 2006–2014. Fig. 2 shows the SDSM Version 4.2 analysis [14].

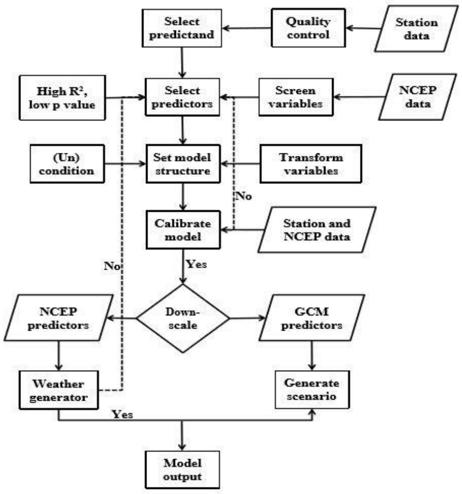


Fig. 2. SDSM Version 4.2 analysis.

4 Results and Analysis

4.1 Validated Performances of Rainfall

Daily rainfall records from 2 stations and daily temperature from 1 station for 9 years (2006–2014) were analyzed using SDSM. The 2 selected rainfall stations which were Gawi and Kenyir while the temperature station was Kuala Terengganu. All data were divided into 2 groups: for the periods 2006-2010 and 2011-2014 in purpose of model calibration and validation.

Fig. 3 shows the calibrated and validated performances between modelled and observed rainfall data at Gawi station, respectively. It clearly shows the highest rainfall intensity were on November-January affected by the North-East monsoon along East Coast states including Terengganu. The highest rainfall was recorded on December for both groups of particular years. For 2006-2010, the heaviest rainfall was 772.3mm while for 2011-2014 the highest value was 1460.5mm. The biggest error was recorded on March for calibration (-24.8%) and validation (20.3%) as shown in Table 1. The error occured due to a lot of missing data on the raw data.

Table 1. Calibrated and validated errors at Gawi station.

Month	Calibrated Error (%)	Validated Error (%)
J	-10.4	17.3
F	5.2	3.7
M	-24.8	20.3
A	14.2	13.7
M	12.0	9.4
J	20.6	-3.7
J	7.6	-8.0
A	3.2	15.9
S	1.0	-2.7
O	9.1	9.6
N	3.0	-20.1
D	0.3	-1.9

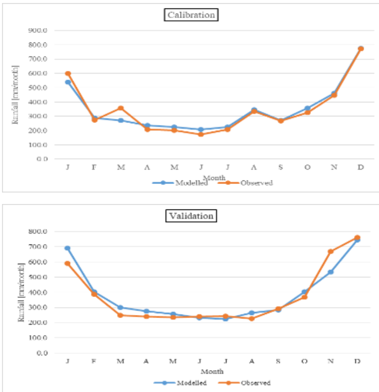


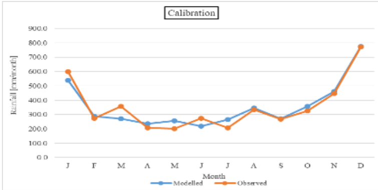
Fig. 3. Calibrated and validated results at Gawi station.

Meanwhile Fig. 4 shows the performances of calibrated and validated results at Kenyir station. Consistent at Gawi station, the heaviest rainfall was on November-January meanwhile the least rainfall occurred on April. The maximum rainfall was recorded on December for both groups of particular years which were 879.1mm for 2006-2010 and 1831.0mm for 2011-2014. All graphs for rainfall data have the curved U-shape that portrayed the distribution of wet and dry seasons at study area. In terms of error as shown in Table 2, the biggest error was recorded on May for calibration (26.9%) and at validation part, the biggest error was in February (27.0%).

Table 2. Calibrated and validated errors at Kenyir station.

Month	Calibrated Error (%)	Validated Error (%)
J	-10.4	19.2
F	5.2	27.0
M	-24.8	-5.5
A	14.2	5.1
M	26.9	26.9
J	-20.0	1.2
J	21.2	-5.4
A	3.2	14.8

S	1.0	1.7
O	9.1	20.8
N	3.0	-17.8
D	0.3	-6.4



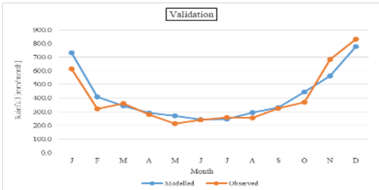


Fig. 4. Calibrated and validated results at Kenyir station.

4.2 Validated Performances of Temperature

The maximum, mean and minimum temperature analyses were depending on the Kuala Terengganu station. The calibration and validation processes were based on year length of 2006-2010 and 2011-2014, respectively and the performances as shown in the Fig. 5. The highest temperature was recorded on May for all situations (maximum, mean and minimum) except for calibration process for minimum temperature where the highest value was on April. Meanwhile the lowest temperature was recorded on January for every situation (maximum, mean and minimum) except the value was recorded on February for validation process. The highest and lowest error between the modelled and observed data were recorded on November (2.6%) for validation process and on August (-0.1%) for calibration process of mean temperature.

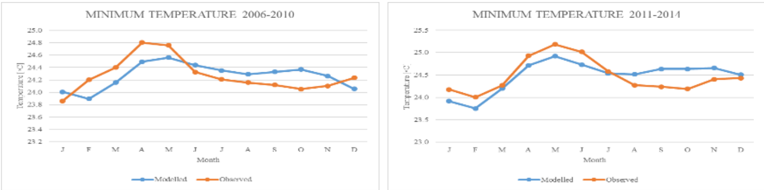


Fig. 5. Calibrated and validated results for maximum, mean and minimum temperature.

The graphs of mean temperature gave the clear picture about the distribution of wet and dry seasons at the study area. November to January had the lower temperature than other months. The *n curved shape* refer that drier seasons were on the middle of the year while the wet seasons were at the end and the beginning of the year. The observed values of maximum, minimum and mean temperature shows the intangible differences and it was support by [15] with the statement that temperature generally shows much less variability than rainfall in time and space.

4.3 Analysis of Climate-NUG Relationship

The relationship between rainfall and temperature explained according to 2 groups of particular years which were categorized for calibration (2006-2010) and validation (2011-2014) processes as elaborated in previous sections. Fig. 6 clearly showed that the relationship between rainfall and temperature was inversely proportional. [16] quote that climate change will cause a steady increase of temperature and variations in rainfall pattern.

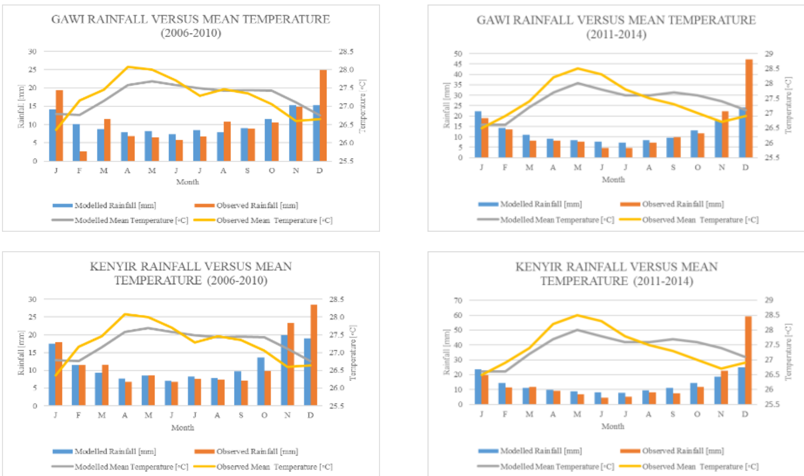


Fig. 6. Rainfall versus Mean Temperature.

The amount of NUG at Sultan Mahmud Power Station are observed by quarter. The 1st quarter is September-November, 2nd quarter is December-February, 3rd quarter is March-May and 4th quarter is June-August. Fig. 7 shows the NUG by quarter from 2006 to 2014. The maximum values of NUG were often recorded on the 2nd and 3rd quarter. It was recorded 4 times in 3rd quarter (2006, 2009, 2011 and 2013), 3 times in 2nd quarter (2008, 2010 and 2012) and 2 times in 1st quarter (2007 and 2014). The 2nd quarter was the wet season while 3rd quarter was the dry season at the study area. The diversity of NUG values can be seen clearly in the Fig. 7. Quarter 2 and 3 recorded a higher level of fluctuation than quarter 1 and 4. Global climate change, linked to the greenhouse gases emission, influences hydroelectric power generation mostly because of the growth in air temperature and variations in the precipitation [17]. Regarding energy sources, hydroelectric plants are probable to be extra affected by variations in annual and seasonal precipitation and the rise in temperature [18]. The relationship between rainfall and temperature at study area was inversely proportional. The lower rainfall will record the higher temperature and vice versa. The potential hydropower production will be negatively affected that proved the need for assessing hydropower generation in future climates is crucial.

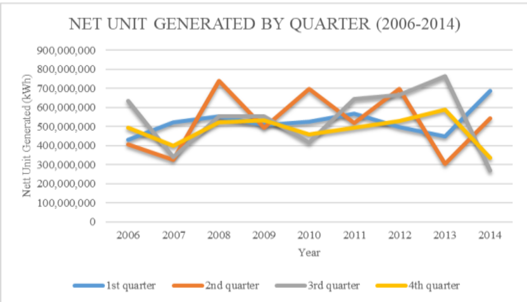


Fig. 7. Net Unit Generated (kWh) by Quarter from 2006 to 2014.

The highest amount of rainfall or wet season at study area is on November and December while the dry season with least amount of rainfall is on February and March. Fig. 8 shows the relationship between both seasons with NUG. The graph clearly shows that the maximum NUG was recorded during the dry season. The highest NUG was more than 300 000 000 kWh while the lowest NUG almost reach 1 000 000 kWh during dry season. On the wet season, both stations recorded the highest amount of rainfall approximately 1500 mm/month. The range of NUG was between 50 000 000-240 000 000 kWh, lower than NUG recorded during dry season. The findings showed that hydroelectric power production is ruled by water incomes, and hence, by precipitation in its region. [19] found out that the amount of power generated in wet season was high compared to the amount generated in the dry season. This means low power generation could be attributed to low or no rainfall in February-March within and outside the study area.

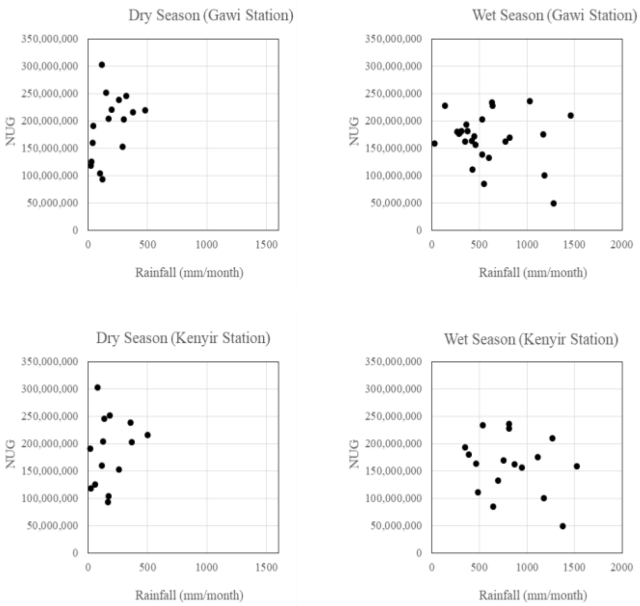


Fig. 8. Relationship between dry season (Feb-Mar) and wet season (Nov-Dec) with NUG.

Graph of relationship between local temperature and NUG was shown in Fig. 9. The distribution of the temperature was between 23-33◦C. The maximum temperature was recorded during dry season with low rainfall. According to previous findings, the low power generation could be attributed to low or no rainfall at all. This situation clearly shown in Fig. 9 where NUG at maximum temperature was lower than NUG with minimum temperature. Electricity demand is directly related to outdoor air temperature, but electricity production is moreover weather-dependent. In particular, the temperature rise and strongly reduced precipitation causes a steep drop of runoff and hydropower production [20].

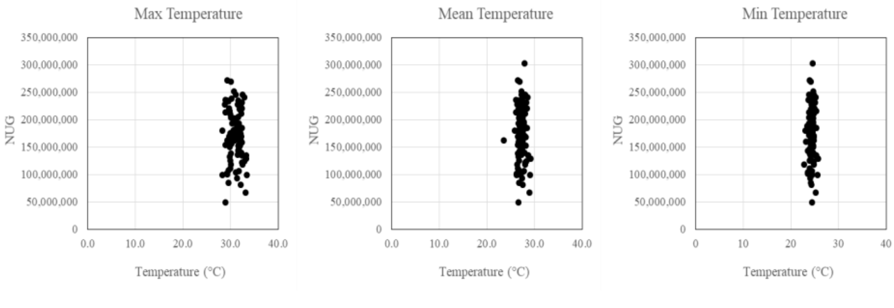


Fig. 9. Relationship between local temperature with NUG.

The relationship between rainfall temperature and NUG was analyzed using Pearson correlation (r) and correlation (R^2) by SPPS software to examine the strength of relationship between the variables. Table 3 shows the relationship between all the variables in the study area within the period of study. The r value for rainfall at Gawi station was 0.82 and this is close to 1. The r value for rainfall at Kenyir station was 0.61 but still show the strong relationship between the variables. This means that there is strong relationship between the two variables and changes in one variable strongly correlate with changes in the other. An increase in rainfall will leads to growth in the amount of power generated as confirmed by [21]. For temperature, the r value was 0.1-0-0.45, this is far lower than 1 and closer to 0. This means that the relationship between the two variables are weak and changes in one variable does not lead to major changes in the other. This also means that there is weak relationship between temperature and the amount of NUG in study area within 2006-2014. This simply means that temperature does not really affect NUG in the study area. The values of R^2 also portrayed the same results for both rainfall and temperature.

Table 3. Correlation analyses between climates and NUG.

	Temperature			Rainfall	
	Max	Mean	Min	Gawi	Kenyir
Pearson Correlation (r)	0.45	0.21	0.10	0.82	0.61
Correlation (R^2)	0.20	0.04	0.01	0.67	0.37

5 Conclusion

Climate change effects are probable all over the energy system. On the demand side, the balance of cooling and heating demand patterns is varying due to increasing temperatures. The SDSM analysis indicate the maximum rainfall event was on November-January that related to monsoon season for East Coast states generally or specially Terengganu. The maximum rainfall at Gawi were recorded on December for 2006-2010 (24.9mm) while for 2011-2014 the value was 47.1mm. The maximum rainfall at Kenyir were recorded on December which were 28.4mm for 2006-2010 and 59.1mm for 2011-2014. All graphs for rainfall data have the *curved U shape* that portrayed the distribution of wet and dry seasons at study area. The maximum temperature values were recorded on May and June (32.2◦C) for 2006-2010. The highest value (32.9◦C) was recorded in May for 2011-2014. The lowest temperature values were recorded on January (23.9◦C) and February (24.0◦C). The maximum values recorded on April to June for both processes. November to January had the lower temperature than other months. The *n curved shape* refer that drier seasons were on the middle of the year while the wet seasons were at the end and the beginning of the year. The relationship between rainfall and temperature was inversely proportional. The lower rainfall will record the higher temperature and vice versa. The maximum values of NUG were often recorded on the 2nd and 3rd quarter. It was recorded 4 times in 3rd quarter (2006, 2009, 2011 and 2013), 3 times in 2nd quarter (2008, 2010 and 2012) and

2 times in 1st quarter (2007 and 2014). The 2nd quarter was the wet season while 3rd quarter was the dry season at the study area. For Sultan Mahmud Power Station basin hydroelectric power generation will be much influenced by local climate change. Upcoming precipitation variations and temperature rise will trigger fluctuations in the hydrological cycle. Therefore, it's expected that Sultan Mahmud hydropower productions will have to face a challenging prospect.

6 Acknowledgements

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