Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 5, No. 10, October, 2019

Assessment of Future Climate Change Projections Using Multiple Global Climate Models

Han Thi Oo [a], Win Win Zin [a], Cho Cho Thin Kyi [a*]

[a] *Department of Civil Engineering, Yangon Technological University, Yangon and 11181, Myanmar*.

Received 27 June 2019; Accepted 14 September 2019

Abstract

Nowadays, the hydrological cycle which alters river discharge and water availability is affected by climate change. Therefore, the understanding of climate change is curial for the security of hydrologic conditions of river basins. The main purpose of this study is to assess the projections of future climate across the Upper Ayeyarwady river basin for its sustainable development and management of water sector for this area. Global Ten climate Models available from CMIP5 represented by the IPCC for its fifth Assessment Report were bias corrected using linear scaling method to generate the model error. Among the GCMs, a suitable climate model for each station is selected based on the results of performance indicators (R^2 and RMSE). Future climate data are projected based on the selected suitable climate models by using future climate scenarios: RCP2.6, RCP4.5, and RCP8.5. According to this study, future projection indicates to increase in precipitation amounts in the rainy and winter season and diminishes in summer season under all future scenarios. Based on the seasonal temperature changes analysis for all stations, the future temperature are predicted to steadily increase with higher rates during summer than the other two seasons and it can also be concluded that the monthly minimum temperature rise is a bit larger than the maximum temperature rise in all seasons.

Keywords: Hydrological Cycle; Climate Scenarios; Precipitation; Temperature; General Circulation Model.

1. Introduction

Climate change is a global phenomenon and one of the most interesting issues exhibited by three prominent signals, that is: (1) global average temperatures are gradually increasing; (2) changes in global rainfall patterns: and (3) rising of sea levels [1]. Increasing atmospheric carbon dioxide, other greenhouse gases, and human activities like land use changes, production of industrial effluents and other activities due to the development of society cause to change in global as well as regional climate [2]. The impact of climate change such as precipitation and temperature changes may lead the world to a more serious risk of storms, droughts, floods, and other events each year [3]. Due to the impact of climate change, water resources are facing uncertainties at the regional, national, and local levels [4]. Since the 1970s, global mean temperatures have increase 0.2˚C per decade and global mean precipitation increased 2% in the last 100 years with a high probability of warming of more than 2˚C over the next century [5]. Myanmar consists of eight major physiographic regions: The Ayeyarwady Delta, Northern Hilly Region, Central Dry Zone, Rakhine Coastal Region, Eastern Hilly Region, Southern Coastal Region, Yangon Deltaic Region, and Southern Interior Region [6]. Climate change impacts on rainfall intensity and rainfall pattern are significantly changed in some parts of the country because climate change is depending on the topographical condition in Myanmar [7].

According to the record by Department of Meteorology and Hydrology of Myanmar, climate change impact on

* Corresponding author: ccthinkyi@gmail.com

http://dx.doi.org/10.28991/cej-2019-03091401

different regions of Myanmar have been recorded based on some observed trends such as increase in mean temperature, an increase in overall rainfall in most areas, late onset and early termination of the south-west monsoon. Myanmar is one of the most vulnerable countries by changes in temperature and precipitation and it is expected that the security of water resources in Myanmar's river basin will face significant risks and vulnerability due to climate change [8]. Change of future temperature and precipitation trend are likely to have impact on the water resources of river basins. In Myanmar, Ayeyarwady river is the country's main and largest river and Ayeyarwady river basin is one of the world's top thirty high priority river basins, owing to strong biodiversity and high vulnerability to future pressure [9]. Therefore, it is essential to quantify and understand climate changes of this river basin in Myanmar and those likely to occur over the coming century. This is also a starting point that Myanmar's stakeholders can use to plan for more summer monsoon rainfall in agriculture, hydropower, conservation areas, dams and flood management.

It is impossible to respond the increasing greenhouse gases concentration rates in the atmosphere without the use of Global Climate Models (GCMs) [10]. It has been widely used climate models to predict the future meteorological parameters changes such and precipitation and temperature [11] and are needed to provide projections of future climate change on two-timescale, near term, and long term, and to evaluate how realistic the models are in simulating the recent past [2]. GCM simulation errors relative to observed climate variables are large. Hence, it is important to make correction procedure for the raw climate model outputs to produce better climate projections [12]. With these expected changes on future climate and water availability in the basin, appropriate adaptation and management strategies are to be developed. For climate change adaptation, both seasonal and annual climate projections are one of the key matters, because of significant effect on water availability and crop yields by seasonal precipitation and temperature changing. During summer, high rainwater increases water insecurity and stress and high seasonal temperature increases water scarcity [11].

2. Location and Present Climate of Upper Ayeyarwady

The Upper Ayeyarwady is situated at 15˚30'- 28˚50' north latitude and 93˚16'- 98˚42' east longitude and covered by Kachin State, Mandalay Division, the western part of Shan state and Southeastern part of Sagaing Division [13]. There are fourteen selected stations in my study area such as Hsipaw, Katha, Kyaukme, Lashio, Mandalay, Meikhtila, Moegaung, Moekok, Myitkyina, PutaO, Sagaing, Shwebo, Yamethin, and YeU. The study area is shown in Figure 1. Sagaing is the outlet of the Upper Ayeyarwady River and the watershed area for this Upper Ayeyarwady River is 152,264 km^2. Upper Ayeyarwaddy consists of some parts of Central Dry Zone and the Northern Hilly Region. The Central Dry Zone is a large inland swath of the country that is prone to extreme heat events and drought. Further inland is the cooler Northern Region which experiences heat waves, droughts, and floods (which can lead to landslides). Because of its higher elevation, the Northern Hilly Region has the lowest mean and maximum annual temperature for the hot and cool seasons.

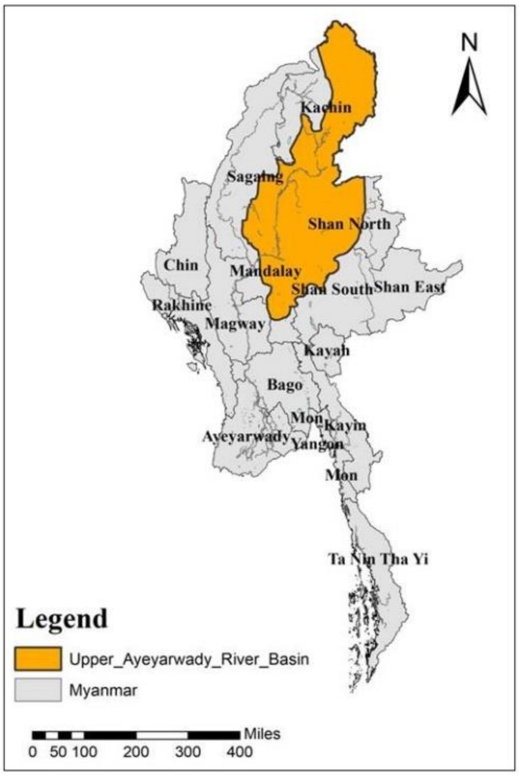

Figure 1. Location of the Upper Ayeyarwady River Basin

2.1. Precipitation

The collected daily precipitation data from the Department of Meteorology and Hydrology (DMH) for selected fourteen stations were analyzed, firstly and the variation of precipitation amount is wide within the basin. In Figure 2, monthly precipitation in Moegaung is the highest although all the stations have high precipitation from May to October. High precipitation is usually received for all stations from June to October which is the monsoon period of the basin.

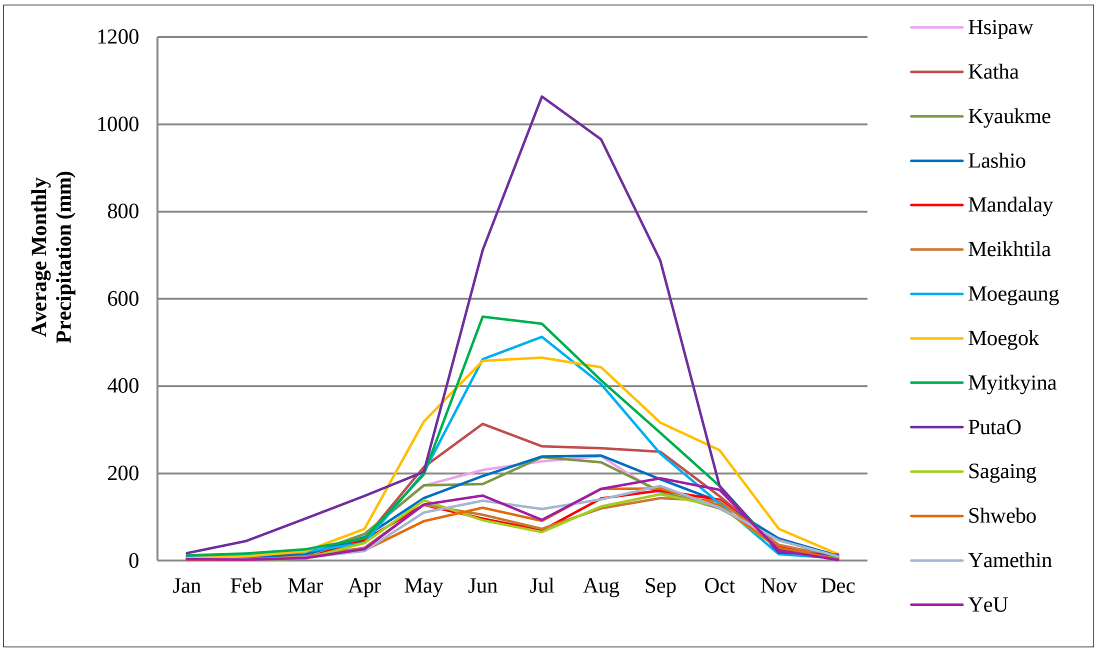

Figure 2. Average monthly precipitation for the period 1981 to 2015

This following Figure 3 shows the average annual precipitation from the year 1981 to 2015. Among the precipitation stations, Putao has the highest annual precipitation and the dry zone area such as Mandalay, Meikhtila, Sagaing, Shwebo, Yamethin, and Yeu have the lowest annual precipitation. The average annual rainfall varies from 778mm to 4140mm within the basin.

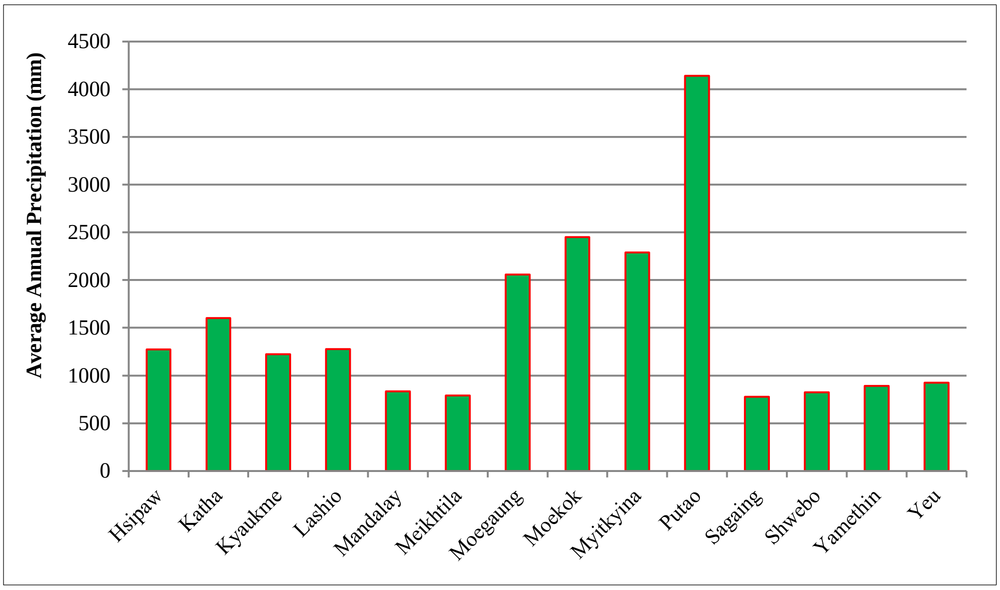

Figure 3. Average annual precipitation for the period 1981 to 2015

2.2. Temperature

Figures 4 and 5 show the basin's average monthly maximum temperature and average monthly minimum temperature from fourteen meteorological stations covering the whole basin for the baseline period 1981-2015. From this analysis, it was found that wide variation in both maximum and minimum temperature of the basin at a spatial scale. For example, the average monthly maximum temperature occurs in May at Yamethin which is about 40.6°C and the average monthly maximum temperature about 20.75°C is occurred in January for PutaO station.

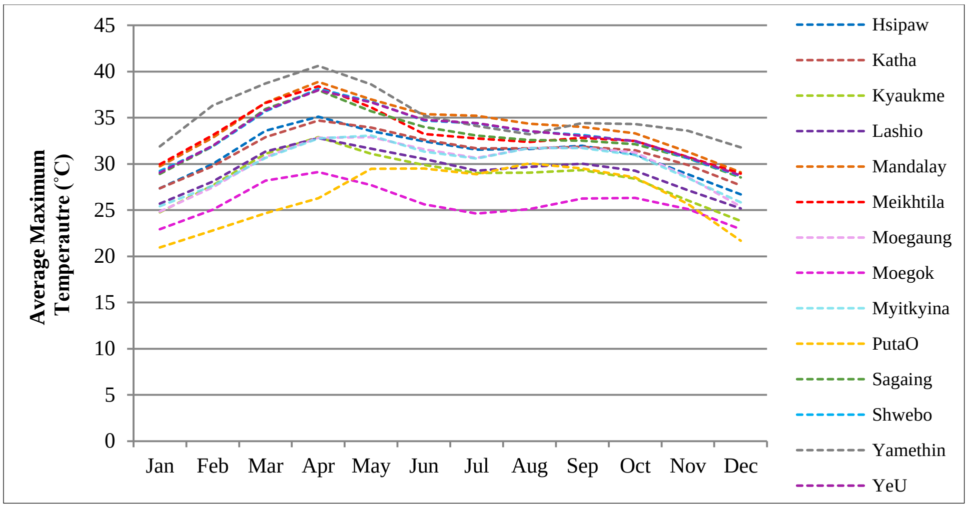

Figure 4. Average monthly maximum temperature

The hottest month is observed in April which is about 35.5°C on average over the basin and the coldest month is January with the value of 10°C on average over the basin. With the value of 26.5°C, the average minimum temperature is the highest in June at Sagaing station. And then, January was also the lowest with an average minimum temperature of 5.7°C at Moegok station during the baseline period for the whole basin.

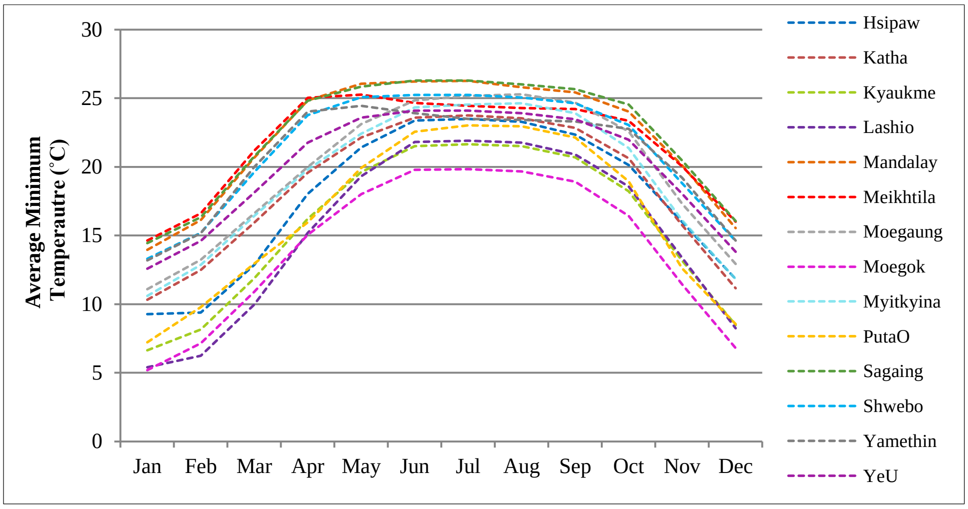

Figure 5. Average monthly minimum temperature

According to the average annual maximum and minimum temperature shown in Figure 6, the dry zone stations such as Mandalay, Meikhtila, Sagaing, Shwebo, Yamethin, and YeU have the highest annual maximum and minimum temperature over the basin.

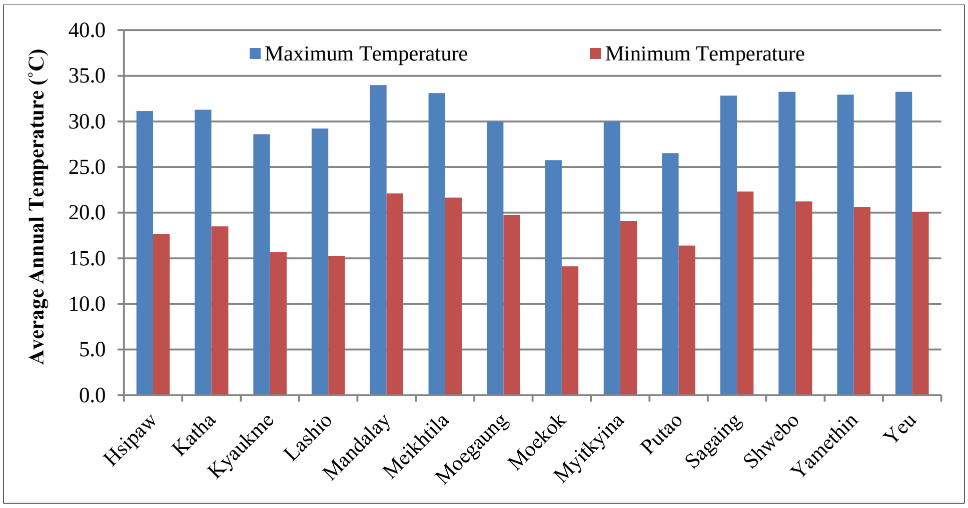

Figure 6. Average annual maximum and minimum temperature

3. Methodological Framework

The summary of methodology applied to complement this study is shown in the Figure 7 and the detailed procedure to achieve the objective of the study is explained.

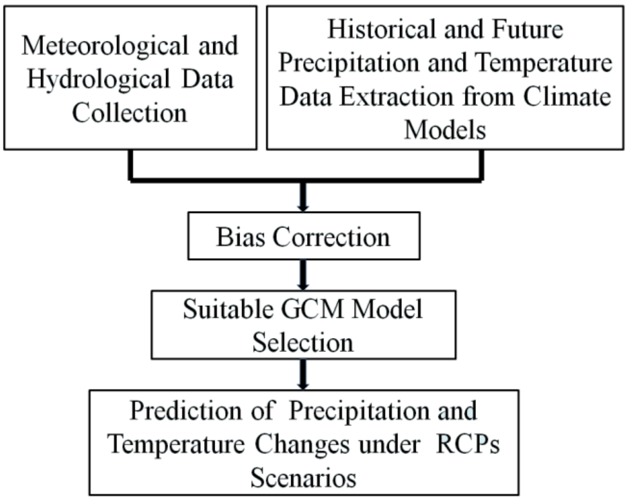

Figure 7. Methodological Framework

4. Materials and Methods

4.1. Global Climate Models (GCMs)

The Coupled Model Inter-comparison Project Phase 5 (CMIP5) is a new generation of state-of-the-art global climate models which developed by the World Climate Research Program (WCRP) modeling council. The new generations of GCM simulations are becoming available at the time of the 5^{th} assessment report (AR5) of IPCC [12]. They are the primary tools that provide reasonably accurate global, hemispheric, and continental-scale climate information and are used for weather prediction and climate simulation and projection under increased greenhouse gas concentrations [14]. Global climate models from the CMIP5 archive are intended to use in this study. The CMIP5 is newly developed data to conduct the research. It can promote the reliability of simulations of recent models, enhance the understanding of climate processes and their effects, and provide the future projections with two time scales: near term and long term [15]. Out of downloaded GCMs from CMIP5, only 10 GCMs (CanESM2, CCSM4, CMCC-CMS, GFDL-CM3, GFDL-ESM2G, MIROC ESM, MIROC ESM CHEM, MPI ESM LR, MPI ESM MR, MRICGCM3) are found to be suitable after checking the model compatibilities. Different GCMs have different grid-sizes and their coverage area is also different. This is why to apply a multi-GCMs approach rather than a single or a few GCMs [16].

4.2. GCM Models Selection

Many GCMs project global climate variables under different scenarios but their resolution, representativeness of the study domain and availability of data to the public make one to carry out some analysis before selecting particular GCM for the study purpose [17]. There is growing agreement that the climate change impact studies should be initiated by an ensemble of multi-GCMs analysis [18]. In comparison to the climate change impact studies in the earlier period of this century, more multi-GCMs approach studies are found in later years. However, careful and wise decision in selecting GCMs is required in either single GCM or multi-GCMs climate study. There are four main approaches in the selection of GCMs depending on the study requirements such as selection based on resolution, selection based on available data, selection based on previous study and selection based on the degree of performance indicator [4].

4.3. Selection of Bias Correction Method

Climate models are using to understand and quantify the cause and effect of climate change on water resources and other sectors. There are many uncertainties in the process of climate change impact assessment. Climate variables simulated by GCMs often do not agree with the observed time series due to systematic model errors [19]. Bias correction procedure is carried out for the purpose of minimizing the difference between simulated and observational data [20]. Among several bias correction approaches, the most common bias correction method is the linear scaling method. The linear scaling approach is a method that makes the output of climate models useful for basin scale. This approach operates with monthly scaling values based on the differences between observed and historical run values. Precipitation is typically corrected with equation (1) and temperature with equation (2) on a monthly basis [21]:

$$P_{cor,m,d} = P_{raw,m,d} \times (\mu(P_{obs,m}) / \mu(P_{raw,m})) \quad (1)$$

$$T_{cor,m,d} = T_{raw,m,d} + \mu(T_{obs,m}) - \mu(T_{raw,m}) \quad (2)$$

Where $P_{cor,m,d}$ and $T_{cor,m,d}$ are corrected precipitation and temperature, and $P_{raw,m,d}$ and $T_{raw,m,d}$ are the raw precipitation and temperature. $\mu(\text{-})$ represents the expectation operator (eg., $\mu(P_{obs,m})$ represents the mean value of observed precipitation at given month *m*) [21].

4.4. Performance Indicators to Evaluate Bias Correction for Suitable Climate Model Selection

The performance of the bias correction method is checked by some performance indicators such as coefficient of determination (R^2) and root mean square error (RMSE) between historical GCMs data and observed ground date of respective GCM after bias correction. R^2 values vary from 0 to 1, with values closer to 1 indicating better agreement between the data in comparison. Typically, R^2 that is bigger than 0.5 can be considered as a reasonable value [22]. RMSE is the most commonly used error statistics test and closer to zero indicates better performance of the model [23]. Models with as much variance as observation, least RMSE, and largest correlation are assumed to be the best performers [24]. Depend on the degree of agreement on performance indicators; GCM with the higher agreement is selected.

4.5. Climate Change Scenarios

For CMIP5, the climate projection scenarios are named as RCP scenarios which are used in the most recent IPCC Fifth Assessment Report (AR5) [24]. Four different scenarios for climate change projection are represented as RCP2.6, RCP4.5, RCP6.0, and RCP 8.5 and were proposed considering the effect of variability in the emission of greenhouse gases, aerosol concentrations in the atmosphere, Land-use change, population changes, changes in GDP, technological advancement as a whole [25]. The Representative Concentration Pathways emphasize on their primary purpose to provide time-dependent atmospheric greenhouse gas concentrations projections [26]. Here, the climate variables from RCP2.6, RCP4.5, and RCP8.5 scenarios were collected and used in climate projection for all selected GCMs to cover the low, medium and high ends of future climate projections. RCP scenarios are images of how the world is likely to envolve in the future in terms of greenhouse gas. The basic concept is that of RCPs, which are expressed in terms of watts per square metre of radiative forcing (W/m^2). RCP2.6 is called a low or peak-and decay scenario in which the radiative forcing is assumed to reach maximum in the middle of the twenty-first century and then it decline into normal level of 2.6 W/m^2 [27]. RCP4.5 is a stabilization scenario that leads to moderate greenhouse gas concentration levels [28]. RCP8.5 scenarios is known as high scenario which described by the radiative forcing throughout the 21st century before reaching a level of about 8.5W/m^2 at the end of the century [29].

5. Results and Discussions

5.1. Selection of Suitable Climate Models for Each Station in Precipitation and Temperature

The statistical parameters used for the performance of bias correction method by linear scaling approach in best climate model selection are coefficient of determination (R^2), root mean square error (RMSE). The parameter values before and after bias correction are compared. Improvement in the higher value of R^2 and the lower of RMSE is the criteria for the best result. Table 1 shows the lists of best climate model which is selected based on the results of thirteen models and statistical results of each station in precipitation. Here, BC means before correction and AC means after correction. Linear scaling method could improve the performance of parameters but there is no significant trend and the performance of R^2 and RMSE values are lower in precipitation.

Table 1. Lists of Suitable Climate Models and Statistical Results of Each Station in Precipitation

Stations	GCM Model	R^2 BC	R^2 AC	RMSE BC	RMSE AC
Hsipaw	CanESM2	0.3725	0.5521	110	73
Katha	CCSM4	0.2646	0.4837	126	106
Kyaukme	CanESM2	0.3686	0.5133	131	95
Lashio	CanESM2	0.3403	0.5128	123	78
Mandalay	CanESM2	0.1629	0.4002	137	68
Meikhtila	MIROC-ESM-CHEM	0.2547	0.4161	111	58
Moegaung	CCSM4	0.1774	0.5583	130	101
Moegok	CanESM2	0.3616	0.6079	196	143
Myitkyina	GFDL CM3	0.4496	0.6831	172	129
PutaO	GFDL-ESM2G	0.2823	0.7822	403	196
Sagaing	CanESM2	0.131	0.4354	145	61
Shwebo	CanESM2	0.1189	0.4139	144	67
Yamethin	CanESM2	0.1674	0.4931	108	110
YeU	CanESM2	0.1674	0.439	143	74

Table 2 and Table 3 show the lists of best climate model and the statistical performance of each station in maximum and minimum temperatures unbiased data and biased data using linear scaling methods. The performance of linear scaling method for both maximum and minimum temperature is good in all climate models with good correction results with observed data. The correction relationships before and after simulation for maximum temperatures are increased in all stations with values ranging from 0.512 to 0.786. According to the list of best climate models for the minimum temperature shown in Table 3, MRI CGCM3 has comparatively better R^2 value in most of the stations and the values range from 0.659 to 0.958.

Table 2. List of Suitable Climate Models and Statistical Results of Each Station in Maximum Temperature

Stations	GCM Model	R^2	R^2	RMSE	RMSE
		BC	AC	BC	AC
Hsipaw	GFDL CM3	0.262	0.659	4	2
Katha	GFDL CM3	0.178	0.515	5	2
Kyaukme	MPI ESM MR	0.674	0.679	2	2
Lashio	MPI ESM MR	0.656	0.582	3	2
Mandalay	MPI ESM MR	0.698	0.709	5	2
Meikhtila	GFDL CM3	0.493	0.786	5	1
Moegaung	GFDL CM3	0.155	0.618	5	1
Moegok	MRI CGCM3	0.586	0.512	4	2
Myitkyina	MRI CGCM3	0.667	0.578	3	2
PutaO	MRI CGCM3	0.291	0.707	6	2
Sagaing	GFDL CM3	0.277	0.645	5	2
Shwebo	MPI RSM MR	0.727	0.725	4	2
Yamethin	GFDL CM3	0.506	0.785	5	1
YeU	MPI RSM MR	0.666	0.723	4	2

Table 3. List of Suitable Climate Models and Statistical Results of Each Station in Minimum Temperature

Stations	GCM Model	R^2	R^2	RMSE	RMSE
		BC	AC	BC	AC
Hsipaw	MRI CGCM3	0.262	0.659	4	2
Katha	MRI CGCM3	0.823	0.888	3	2
Kyaukme	MRI CGCM3	0.841	0.951	4	1
Lashio	MRI CGCM3	0.228	0.958	6	1
Mandalay	MRI CGCM3	0.912	0.938	3	1
Meikhtila	MRI CGCM3	0.742	0.928	2	1
Moegaung	MPI ESM MR	0.903	0.939	2	1
Moegok	MRI CGCM3	0.842	0.935	6	1
Myitkyina	MRI CGCM3	0.856	0.946	3	1
PutaO	MPI ESM MR	0.905	0.947	2	1
Sagaing	MRI CGCM3	0.783	0.927	3	1
Shwebo	MRI CGCM3	0.771	0.907	3	1
Yamethin	MRI CGCM3	0.88	0.94	2	1
YeU	MRI CGCM3	0.836	0.868	3	2

According to the model performance indication of selected fourteen stations for precipitation, R^2 values for dry zone stations cannot give satisfied values if compared with values for northern hilly region stations. Therefore, it can be said that GCMs are not so good for the projection of precipitation in the dry zone area of Myanmar. Based on the statistical results of precipitation and temperature, the results of maximum and minimum temperature indicate that the linear scaling approach could improve R^2 value to an acceptable limit for all fourteen stations within the basin. The performance of RMSE is lower in precipitation than in temperature using the linear scaling method because the RMSE values are high for precipitation before correction and there is no significant change after correction. Therefore, it can be noticed that GCMs are more reliable in the simulation of temperature rather than precipitation and the performance of linear scaling method for maximum and minimum temperature are good in all climate models.

5.2. Analysis of Future Precipitation Changes

5.2.1. Average Seasonal Precipitation

The seasonal changes are one of the key matters that should be incorporated in climate projection studies and such analysis can also be found in several types of research [14]. Future precipitation changes for GCM-scenario combinations with respect to the baseline were done using the period change approach of 25-year time segments centered on three prescribed future periods of the Near Future (2021-2045), Middle Future (2046-2070) and the Far Future (2071-2095). Figure 8 shows the box and whisker plots of the average seasonal precipitation change projected under three periods for the summer season in Myanmar, compared to the observed data with baseline period (1991-2015) for all RCPs. The average future projection is calculated based on the selected fourteen stations within the basin. Currently, Myanmar has a tropical monsoon climate with three seasons and the seasonal climate in Upper Ayeyarwaddy River Basin is classified as summer from 16 February to 31 May, rainy (Monsoon) from 1June to 30 September and winter from 1 October to 15 February. Here, the first quartile, Q1, is the 25th percentile. The second quartile, Q2, is the 50th percentile or median and third quartile, Q3, as the 75th percentile. Future seasonal precipitation changes have expected to decrease on average within the basin under all RCP scenarios.

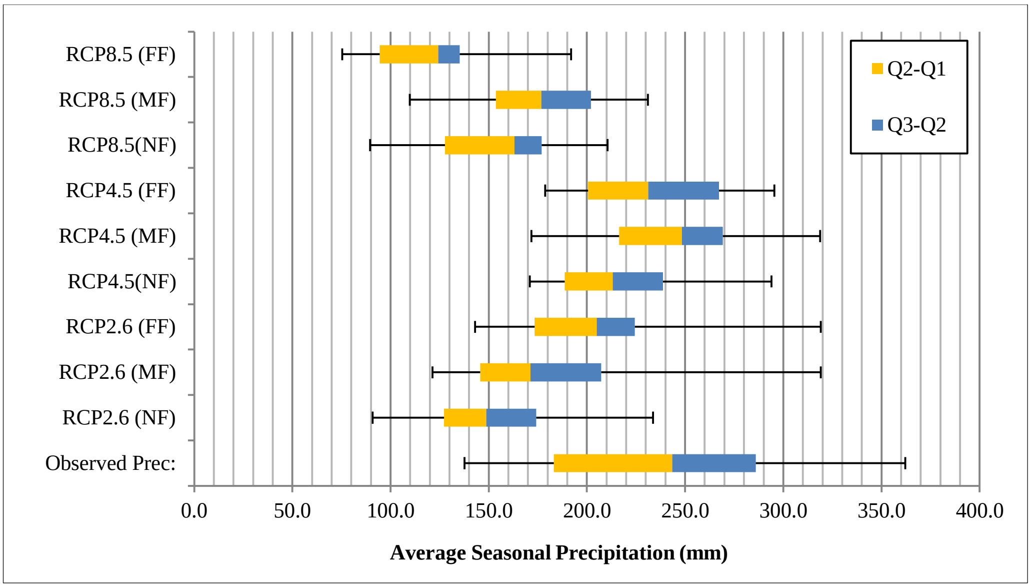

Figure 8. Projected average seasonal precipitation for summer season

The average seasonal precipitation for the wet season is described in Figure 9. Under RCP2.6, the future average seasonal precipitation has a higher increasing trend than the two other scenarios although all three RCP scenarios are expected to increase if compared with the baseline period.

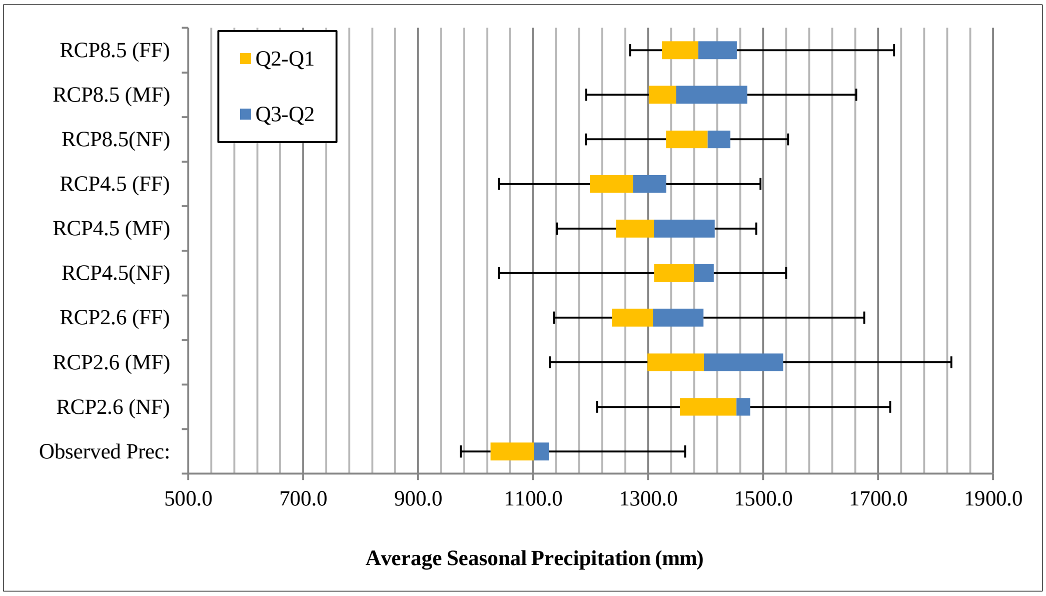

Figure 9. Projected average seasonal precipitation for rainy season

The average seasonal precipitation changes by three time periods for the winter season are described in Figure 10 and precipitation is expected to increase under all RCP scenarios. For all RCPs, the rainfall increased in amount, the lowest and highest value of the precipitation varies between about 110mm to 680mm.According to on average overall analysis for ten GCMs, the box and whisker plots of each time period indicate that precipitation in summer is seen to reduce further while it is seen to increase in rainy and winter season.

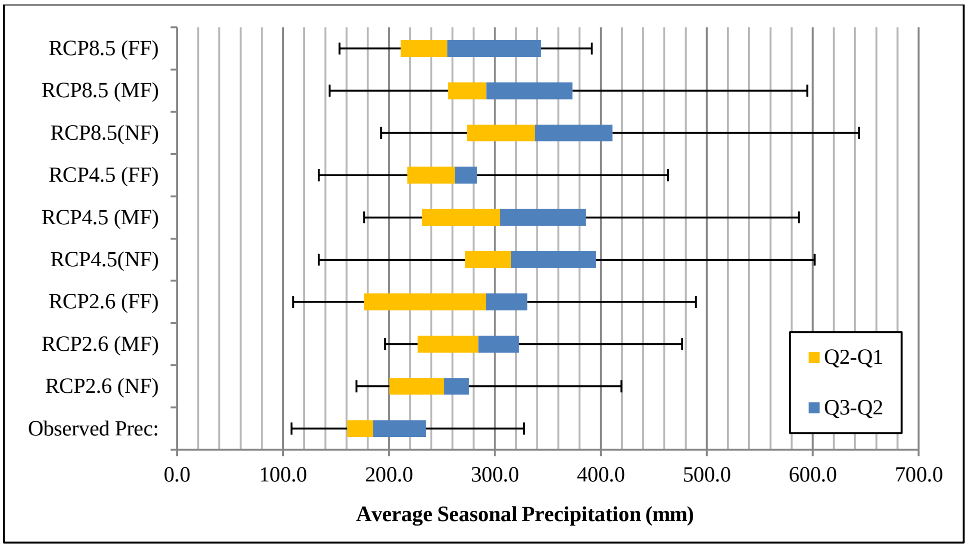

Figure 10. Projected average seasonal precipitation for winter season

5.2.2. Average Monthly Precipitation

The projected changes of monthly precipitation are analyzed by making a fraction with the precipitation of base period and projection was also made under three future periods: Near Future (2021-2045), Middle Future (2046-2070) and Far Future (2071-2095). The variation of future changes in precipitation for Near Future (2021-2045) is presented in Figure 11. If the fraction value is 1, there is no change in future and if the value is larger than 1, future precipitation has an increasing trend and less than 1 means that precipitation will decrease in future. The projected changes in all the time period indicate the decreasing trend in March, April and May (summer season) and it is observed that the rainy (monsoon) and winter season are getting wetter in future. The highest rate of increase in rainfall is generally observed in November under all RCP scenarios. The variations of precipitation changes in RCP4.5 and RCP8.5 are more than that of RCP2.6 with an obvious trend.

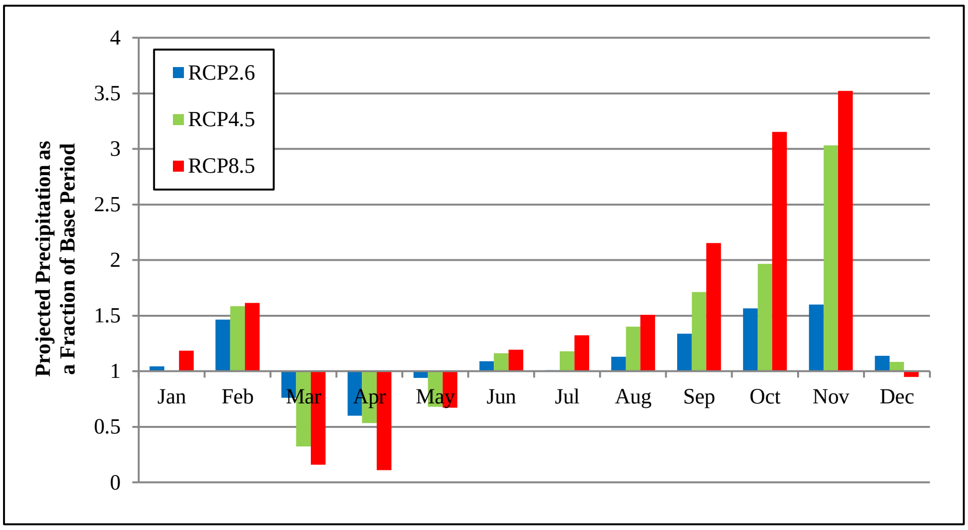

Figure 11. Projected average monthly precipitation as a fraction of base period for Near Future

Average monthly precipitation as a fraction of base period for Middle Future (2046-2070) within the basin is shown in Figure 12. The monthly precipitation has decreased for RCP2.6 in January and for RCP8.5 in December and it has decreased significantly for the month Marth to May under all RCP scenarios. From January to May and December for all time periods, the average monthly precipitation fluctuates and the increasing trend occurs from the months of June to November.

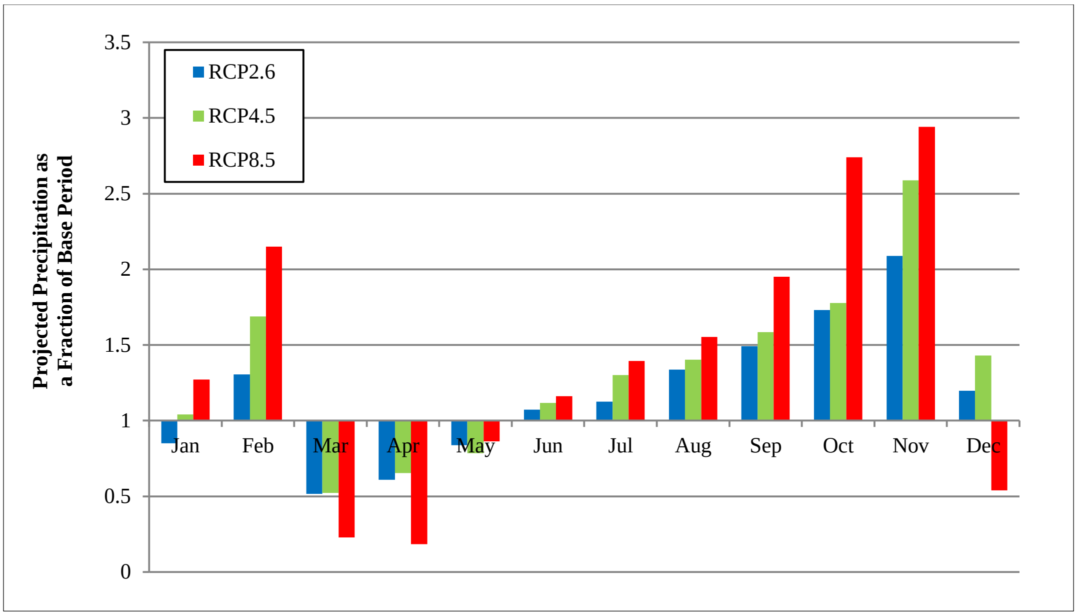

Figure 12. Projected average monthly precipitation as a fraction of base period for Middle Future

The projected precipitation for Far Future (2071-2095) has also increasing trend in January for RCP4.5 and RCP8.5, March to May under all climate scenarios and December for RCP8.5 according to Figure 13. All RCP scenarios highlight that the future monthly precipitation will increase with the higher rate at February and September to November. March, April, and May are months where precipitation is expected to decrease and some minor increase precipitation is expected to increase in January, June, July and August in all of the scenarios under all future periods.

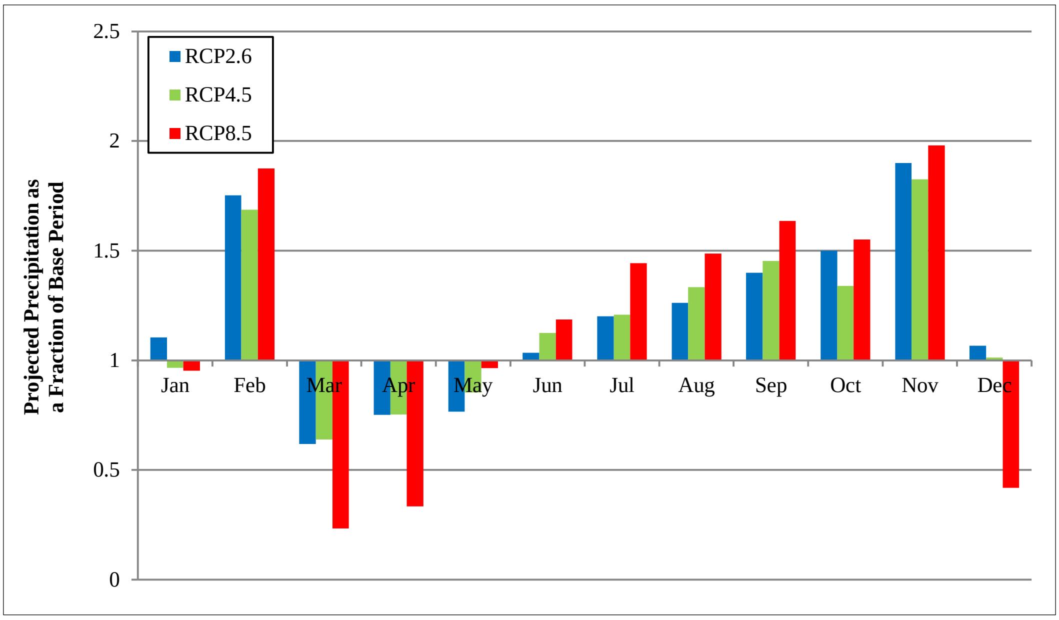

Figure 13. Projected average monthly precipitation as a fraction of base period for Far Future

5.3. Analysis of Future Temperature Changes

Maximum and Minimum temperature changes are initially stated to understand the future climate variation in terms of both monthly scale and seasonal scale.

5.3.1. Average Seasonal Maximum and Minimum Temperature

Seasonal maximum and minimum temperature changes are highly important to understand the long-term climate change impact on the region. The temperature for three scenarios, RCP2.6, 4.5 and 8.5 are projected with selected suitable GCM models based on the average values of selected fourteen stations within the basin and compared with the baseline period (1991-2015). The future projections of average seasonal maximum and minimum temperature in summer, rainy and winter season are shown in Figure 14, Figure15 and Figure 16 respectively.

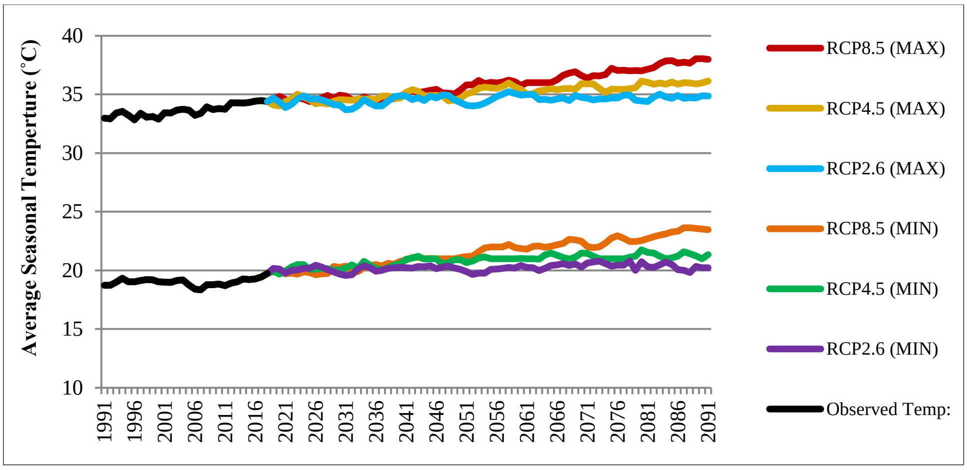

Figure 14. Future projection of average seasonal temperature for summer season

Maximum temperature increases with the rate of nearly 4˚C under RCP8.5, 2.5˚C under RCP4.5 and 2˚C under RCP2.6 compared from 1981 to 2100 for the summer season. For minimum temperature, about 4˚C under RCP8.5, 2.5˚C under RCP4.5 and 1.5˚C under RCP 2.6 will be exceeded from 1981 to 2100.

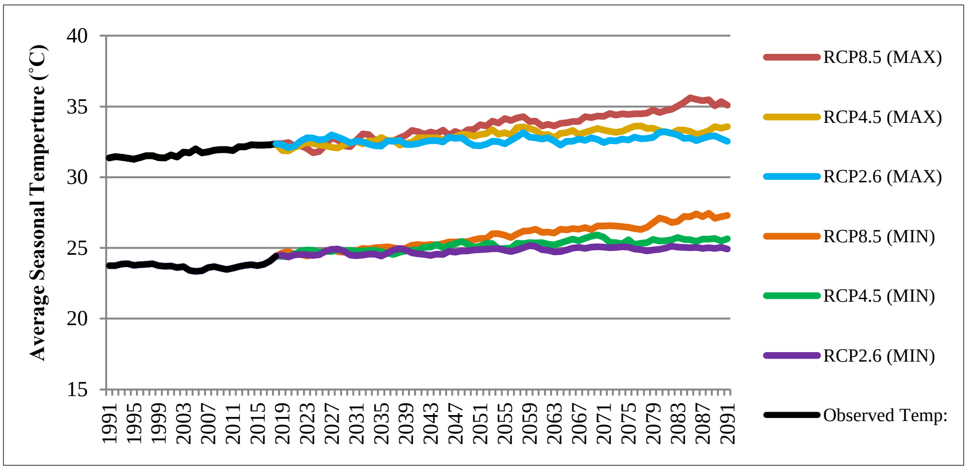

Figure 15. Future projection of average seasonal temperature for rainy season

The projected maximum temperature varies from 1˚C to 3˚C under all RCP scenarios at the end of the 21st century for the rainy season. Change in minimum temperature also varies depending on future scenarios. Under RCP2.6, the minimum temperature is predicted to increase from about 1˚C in near future to 1.5˚C in far future. About 1.5˚C for near future, 1.7˚C for middle future and 2.5˚C for far future are projected to increase under RCP4.5. For RCP8.5, the increasing amount varies in the range of 1.5˚C to 3.5˚C by 2100 after comparing the baseline period. Here, it can be projected that the intensity of temperature depends on the scenarios and is higher under RCP8.5 than RCP 4.5 and RCP2.6.

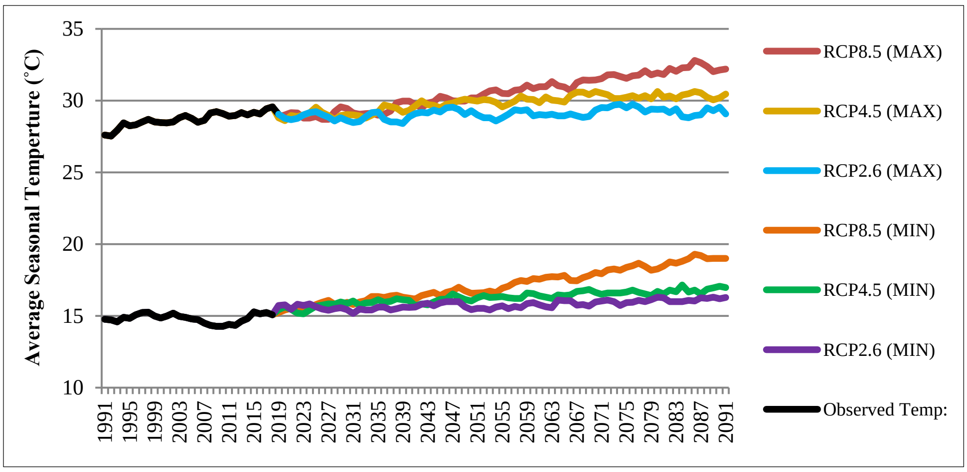

Figure 16. Future projection of average seasonal temperature for winter season

Maximum temperature is projected to reach about 3.5˚C in RCP8.5, 2˚C in RCP4.5 and 1˚C in RCP2.6 for the winter season at the end of the 21st century. And then, the projected change in minimum temperature is likely to slightly increase in all climate scenarios. With reference to the projected average seasonal temperature results, both maximum and minimum temperature in the upcoming century is likely to a significant increase in all three RCP scenarios

5.3.2. Average Monthly Maximum and Minimum Temperature

Figures 17 and 18 show the changes in the basin's average monthly maximum and minimum temperature from the year 2020 to 2100 for Near Future related to the baseline period (1981-2015) under three RCP scenarios. In all months except January and February, the monthly maximum temperature is projected to increase; while for January and February a slight decrease in average temperature can be observed. Here, May is found to be the hottest month with nearly 2˚C. The average monthly minimum temperature is expected to increase in the range of 0.45-1.5˚C, 0.7-1.5˚C and 0.9-1.6˚C respectively by all climate scenarios.

In Middle Future from Figures 19 and 20, both average monthly maximum and minimum temperature are forecasted to increase under all RCP scenarios except maximum temperature for RCP2.6. The high increment of average maximum temperature will increase up to about 3˚C of RCP8.5, 2.5˚C of RCP4.5 and 2˚C of RCP2.6. The high increment of average minimum temperature will also increase up to about 3˚C of RCP8.5, 2˚C of RCP4.5 and 1.5˚C of RCP2.6. The average monthly maximum and minimum temperature for Far Future which are shown in Figures 21 and 22 are projected to increase with the highest increasing rate about from 3˚C to 4˚C under RCP8.5, nearly 1.5˚C to 2.5˚C will increase under RCP4.5 in far future. But, the maximum temperature and minimum temperature is likely to change in the range of about 0.5 ˚C to 1.5˚C and 1˚C to 1.5˚C respectively under RCP2.6. These all figures indicate that both maximum and minimum temperature will increase in the whole year for all future periods, not including January and February in Near Future.

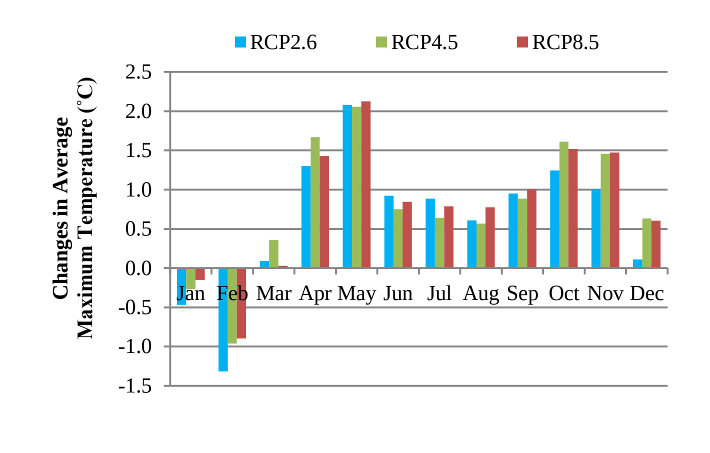

Figure 17. Changes in average monthly maximum temperature for Near Future

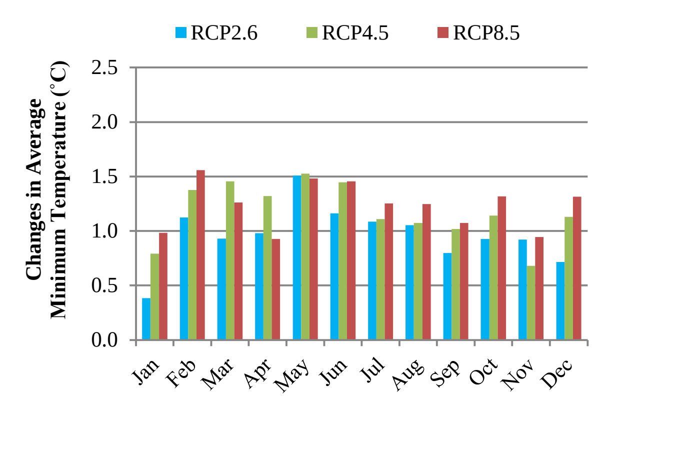

Figure 18. Changes in average monthly minimum temperature for Near Future

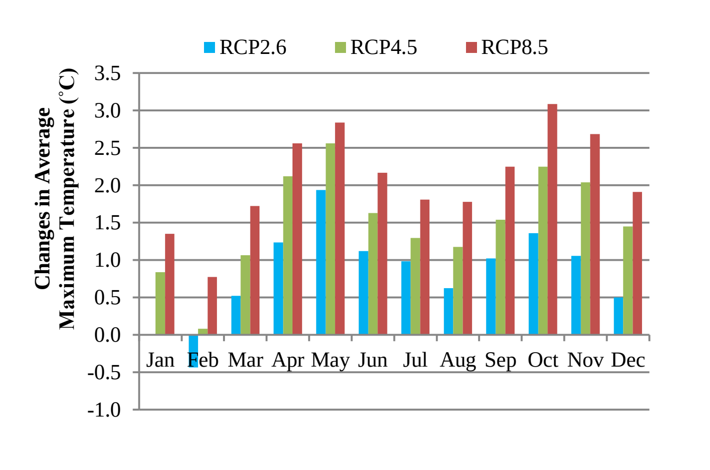

Figure 19. Changes in average monthly maximum temperature for Middle Future

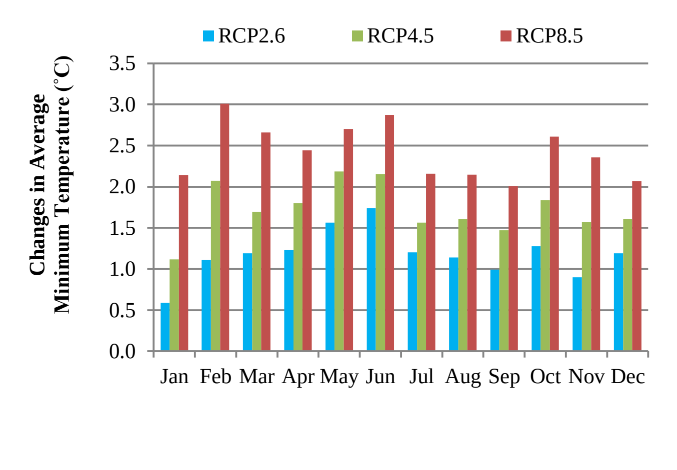

Figure 20. Changes in average monthly minimum temperature for Middle Future

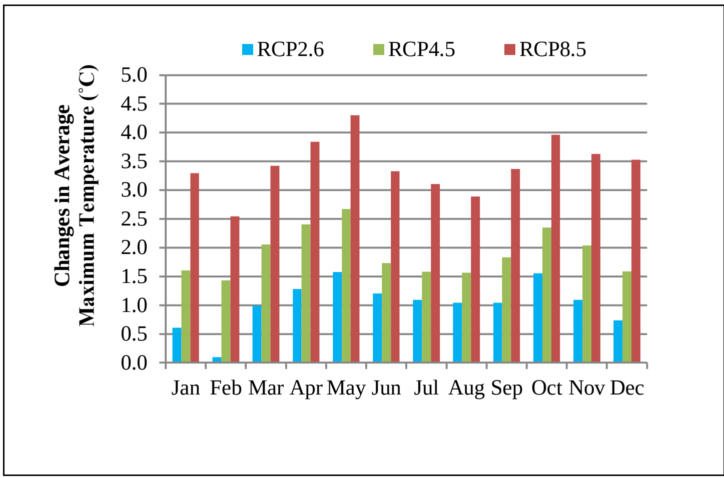

Figure 21. Changes in average monthly maximum temperature for Far Future

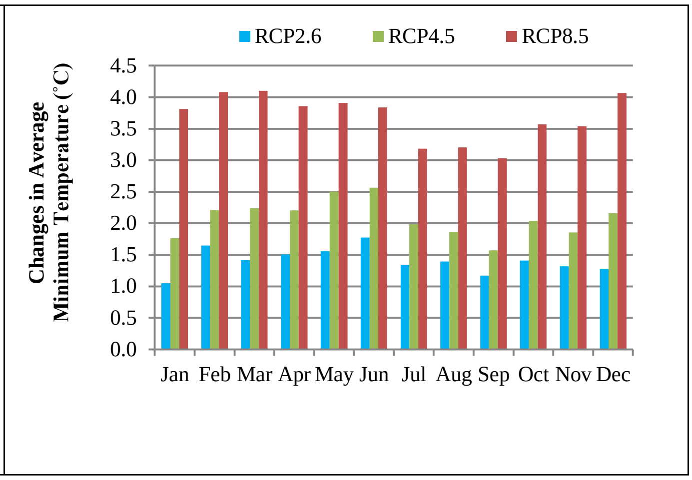

Figure 22. Changes in average monthly minimum temperature for Far Future

6. Conclusion

Nowadays, it is very important to study the assessment of climate change impacts on river basin level by analyzing the different climate scenarios. In this study, the thirteen global climate models (GCMs) of CMIP5 experiment are considered to investigate the uncertainty in the future climate scenarios based on observed records. The correction procedure using linear scaling approach is used to identify the difference in trend changes and intensity gaps between observed ground data and simulated climate variables. According to the model performance results as the coefficient of determination (R^2) and root mean square error (RMSE), a suitable climate model among ten GCMs is selected for each station in order to make the future projection. Future climate (2020 to 2100) under different climate change scenarios are projected under RCP scenarios by using model results from historical simulation (1981 to 2005). The box and whisker plots of each time period indicate that maximum values of precipitation are expected to increase in rainy and winter season and decrease in summer. Change amount the projected changes of 75th percentiles, median, 25th percentiles, and minimum values are not unidirectional and vary depending on RCP scenarios, climate models and time periods. The same pattern can be seen in the average monthly precipitation changes for the whole basin under all scenarios, with March to May and December showing a decreasing trend and January, February and June to November is an increasing change. But the intensities are varied depending on the scenario and rate of change under RCP2.6 is less than RCP4.5 and RCP8.5.

In term of seasonal changes, both maximum and minimum temperature will increase by the highest rate in summer under most of the RCPs. The intensity of increase in summer is more likely to higher than rainy and winter season corresponding to their scenarios. In monthly temperature changes, the slight decrement about 1˚C occurred in January and February for maximum temperature and a slight increment about 1.5˚C is from March to December for maximum and from January to December (the whole year) in minimum temperature which is in near future under all climate scenarios. The monthly temperature changes for middle future and far future under all RCP scenarios are also estimated to exceed with the increasing rate after comparing with the baseline period. The overall conclusion of this research is that it is estimated as the Upper Ayeyarwady area will be encountered excessive precipitation especially in the rainy season and extreme temperature especially in the summer season for future. Myanmar's climate is still under the effect of RCP2.6 condition and therefore, it is necessary to control and reduce this situation. If not, consequences of climate change such as more violent weather phenomena, rising sea level, flooding, drought events, and other risks will suffer more and more corresponding to the RCP scenarios that will face in the future.

7. Acknowledgements

First of all, the author would like to express her deep appreciation to Dr. Nyan Myint Kyaw, Professor, and Head of Civil Engineering Department of the Yangon Technological University. Especially, the author is thankful to her supervisor Dr. Win Win Zin, Professor, and Dr. Cho Cho Thin Kyi, Associate Professor of the Department of Civil Engineering of Yangon Technological University, for their advice and valuable guidance. Finally, the author offers her thanks to all persons from Department of Meteorology and Hydrology for providing the meteorological data of fourteen stations in study area.

8. Conflicts of Interest

The authors declare no conflict of interest.

9. References

[1] Dlamini, Nkululeko Simeon, Md Rowshon Kamal, Mohd Amin Bin Mohd Soom, Mohd Syazwan Faisal bin Mohd, Ahmad Fikri Bin Abdullah, and Lai Sai Hin. "Modeling Potential Impacts of Climate Change on Streamflow Using Projections of the 5th Assessment Report for the Bernam River Basin, Malaysia." Water 9, no. 3 (March 20, 2017): 226. doi:10.3390/w9030226.

[2] Kundu, A., S. Dwivedi, and V. Chandra. "Precipitation Trend Analysis over Eastern Region of India Using Cmip5 Based Climatic Models." ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XL–8 (December 23, 2014): 1437–1442. doi:10.5194/isprsarchives-xl-8-1437-2014.

[3] Saleh Zakaria, Nadhir Al-Ansari, and Seven Knutsson. "Historical and Future Climatic Change Scenarios for Temperature and Rainfall for Iraq." Journal of Civil Engineering and Architecture 7, no. 12 (December 28, 2013). doi:10.17265/1934-7359/2013.12.012.

[4] Min Khaing, "Multi-model analysis of the climate change impact and adaptation of hydropower generation in the Myitnge river basin." Asian Institute of Technology, School of Engineering and Technology, Thailand (May, 2014).

[5] Perry, Martin, O. Canziani, J. Palutikof, P. V. D. Linden, and C. Hanson. Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press for the Intergovernmental Panel on Climate Change, 2007.

[6] Horton, Radley, Manishka De Mel, Danielle Peters, Corey Lesk, Ryan Bartlett, Hanna Helsingen, Daniel Bader, Pasquale Capizzi, Shaun Martin, and Cynthia Rosenzweig. "Assessing Climate Risk in Myanmar: Technical Report." New York, NY, USA: Center for Climate Systems Research at Columbia University, WWF-US and WWF-Myanmar (2017).

[7] Myanmar Climate Change Alliance. "Impact of climate change and the case of Myanmar." (2016). https://myanmarccalliance.org/en/climate-change-basics/impact-of-climate-change-and-the-case-of-myanmar. (Accessed Mar, 2019).

[8] ADB. "Building Cllimate Resilience in the Agriculture Sector in Asia and the Pacific." Mandaluyong City, Philippines (2009). http://hdl.handle.net/11540/190.

[9] Simmance, A. "Environmental flows for the Ayeyarwady (Irrawaddy) river basin, Myanmar." Unpublished. UNESCO-IHE Online Course on Environmental Flows (a)(b) (April, 2013).

[10] F. Adam, C. Neil, and G. Bill. "Selecting a global climate model for understanding future projections of climate change." Environment Canada, University of Toronto. http://projects.upei.ca/climate/files/2012/10/Book-1_Paper-5.pdf. (Accessed Feb, 2019).

[11] Aung Ye Htut. "Assessment of climate change and land use change impacts on the hydrology and water resources of the Bago River Basin in Myanmar." Asian Institute of Technology, School of Engineering and Technology, Thailand (May 2015).

[12] GCM Downscaled Data Portal. "Research program on climate change, agriculture and food security." (2014). https://ccafs.cgiar.org/downscaled-gcm-data-portal#.XQ5y8-gzbIU. (Accessed Jun, 2019).

[13] Aung, Su Wai, and Nilar Aye. "Sediment Yield Simulation in Upper Ayeyarwady Basin." American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS) 27, no. 1 (2017): 405-418.

[14] Trzaska, Sylwia, and Emilie Schnarr. "A review of downscaling methods for climate change projections." United States Agency for International Development by Tetra Tech ARD (2014): 1-42.

[15] Helfer, Fernanda, Charles Lemckert, and Hong Zhang. "Impacts of Climate Change on Temperature and Evaporation from a Large Reservoir in Australia." Journal of Hydrology 475 (December 2012): 365–378. doi:10.1016/j.jhydrol.2012.10.008.

[16] Christy, John R., Benjamin Herman, Roger Pielke, Philip Klotzbach, Richard T. McNider, Justin J. Hnilo, Roy W. Spencer, Thomas Chase, and David Douglass. "What Do Observational Datasets Say About Modeled Tropospheric Temperature Trends Since 1979?" Remote Sensing 2, no. 9 (September 15, 2010): 2148–2169. doi:10.3390/rs2092148.

[17] Bhusal, Shyam Prasad, Mukand S. Babel, Sylvain Roger Perret, Roberto S. Clemente, and Ashim Das Gupta. "Assessment of future climate and its impact on stream flow: a case study of Bagmati Basin, Nepal." PhD diss., MSc thesis, Asian Institute of Technology, Pathumthani, 2010.

[18] Hawkins, Ed, and Rowan Sutton. "The Potential to Narrow Uncertainty in Regional Climate Predictions." Bulletin of the American Meteorological Society 90, no. 8 (August 2009): 1095–1108. doi:10.1175/2009bams2607.1.

[19] Tumbo, S. D., H. Ngongolo, C. Sangalugembe, F. Wambura, and P. Mlonganile. "Tanzania CMIP5 Climate Change Projections." (2016). http://www.suaire.suanet.ac.tz:8080/xmlui/handle/123456789/1640.

[20] Viceto, Carolina, Susana Cardoso Pereira, and Alfredo Rocha. "Climate Change Projections of Extreme Temperatures for the Iberian Peninsula." Atmosphere 10, no. 5 (April 29, 2019): 229. doi:10.3390/atmos10050229.

[21] Fang, G. H., J. Yang, Y. N. Chen, and C. Zammit. "Comparing Bias Correction Methods in Downscaling Meteorological Variables for a Hydrologic Impact Study in an Arid Area in China." Hydrology and Earth System Sciences 19, no. 6 (June 2, 2015): 2547–2559. doi:10.5194/hess-19-2547-2015.

[22] Santhi, C., J. G. Arnold, J. R. Williams, W. A. Dugas, R. Srinivasan, and L. M. Hauck. "VALIDATION OF THE SWAT MODEL ON A LARGE RWER BASIN WITH POINT AND NONPOINT SOURCES." Journal of the American Water Resources Association 37, no. 5 (October 2001): 1169–1188. doi:10.1111/j.1752-1688.2001.tb03630.x.

[23] T. W. Chu, A. Shirmohammadi, H. Montas, and A. Sadeghi. "Evaluation of the SWAT Model's Sediment and Nutrient Components in the Piedmont Physiographic Region of Maryland." Transactions of the ASAE 47, no. 5 (2004): 1523–1538. doi:10.13031/2013.17632.

[24] Min Thu Aung. "Assessment of climate change impacts on hydrology and hydropower generation in Belu river basin of Myanmar." Asian Institute of Technology, Thailand (May, 2016).

[25] Sung, Jang Hyun, Hyung-Il Eum, Junehyeong Park, and Jaepil Cho. "Assessment of Climate Change Impacts on Extreme Precipitation Events: Applications of CMIP5 Climate Projections Statistically Downscaled over South Korea." Advances in Meteorology 2018 (October 23, 2018): 1–12. doi:10.1155/2018/4720523.

[26] Egeru, Anthony, Bernard Barasa, Josephine Nampijja, Aggrey Siya, Moses Tenywa Makooma, and Mwanjalolo Gilbert Jackson Majaliwa. "Past, Present and Future Climate Trends Under Varied Representative Concentration Pathways for a Sub-Humid Region in Uganda." Climate 7, no. 3 (February 26, 2019): 35. doi:10.3390/cli7030035.

[27] Van Vuuren, Detlef P., Michel G. J. den Elzen, Paul L. Lucas, Bas Eickhout, Bart J. Strengers, Bas van Ruijven, Steven Wonink, and Roy van Houdt. "Stabilizing Greenhouse Gas Concentrations at Low Levels: An Assessment of Reduction Strategies and Costs." Climatic Change 81, no. 2 (February 13, 2007): 119–159. doi:10.1007/s10584-006-9172-9.

[28] Clarke, L.E., Edmonds, J.A., Jacoby, H.D., Pitcher, H., Reilly, J.M., and Richels, R. "Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations." Sub-report 2.1a of Synthesis and Assessment Product 2.1, Climate Change Science Program and the Subcommittee on Global Change Research, Washington DC (2007). https://globalchange.mit.edu/publication/14399.

[29] Riahi, Keywan, Arnulf Grübler, and Nebojsa Nakicenovic. "Scenarios of Long-Term Socio-Economic and Environmental Development under Climate Stabilization." Technological Forecasting and Social Change 74, no. 7 (September 2007): 887–935. doi:10.1016/j.techfore.2006.05.026.