© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Climate Change and Its Impact on Rainfall

Aainaa Hatin Ahmad Tarmizi[1], Siti Nazahiyah Rahmat[1,*], Ahmad Tarmizi Abd Karim[1], Nurul Nadrah Aqilah Tukimat[2]

[1]Department of Water and Environmental Engineering, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Johor, MALAYSIA

[2]Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, 26600 Pahang, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2019.11.01.020
Received 03 July 2018; Accepted 10 December 2018; Available online 30 April 2019

Abstract: This paper reviews the climate change impact on rainfall as well as extreme events occurrences. The global extreme weather contributes to the uncertainties of the climate trend and water scarcity problems to the whole world. Thus, numerical models such as General Circulation Models (GCMs) have been developed to simulate the response of the global climate system to the expected increment of the greenhouse gases concentrations. However, the GCM cannot be directly applied to climate change impact studies, hence downscaling is needed. A large number of downscaling methods are available but there is no universal method exists at present that performs best for all conditions, depending on the application and this remains a subject of investigation. Therefore, this paper compares the performances among statistical and dynamical downscaling models that have been applied by different researchers in various purposes. It can be concluded that the statistical downscaling has been widely used and able to provide reliable climate projected results especially for Malaysia's climate variables. This review is very significant especially to the policy maker in deciding the reliable climatic methods for the long term planning and management of water resources. Besides, the reliable projected rainfall will be very beneficial in estimating water availability and water resource policy.

Keywords: Climate change, extreme events, rainfall, statistical downscaling model

1. Introduction

Climate change is a catastrophe that will lead to an increasing of the climatic extreme in term of the frequency and intensity. This issue might give direct impact to the global temperature rises, warming oceans, sea level rises and extreme drought and flood event [1]. Human activities are one of the major contributors to the climate change problem [2]. According to Kisakye et al. [3], climate change contributes to the water scarcity problem as it resulted to the negative effect on rainwater savings and reliability, and the consequences is more tragic during dry season. The uncertainty of the rainfall intensity and duration are also affecting to the transportation safety which lead to increase the accident frequency and congestion during peak hours [4].

There are four greenhouse gases (GHGs) that contribute to the climate change problem. These gases react as a layer in the atmosphere which block the heat from escaping and trapped into the earth system. It create warmer condition to the planet. However, this warm condition become hotter due to increasing of the GHGs emission into the atmosphere which uncomfortable for the life. These gases are refer to water vapor (H_2O), nitrous oxide (N_2O), carbon dioxide (CO_2) and methane (CH_2) [5]. H_2O increases as the Earth's atmosphere warms but at the same time increases the possibility of precipitation. Meanwhile N_2O is one of the most powerful GHGs produced by soil cultivation practices used in fertilizers and biomass burning. CO_2 is also an important component of the atmosphere that comes from deforestation, land use

*Corresponding author: nazahiya@uthm.edu.my

changes and other human activities. While, CH_2 is a hydrocarbon gas produced by natural sources and human activities such as wastes of landfills and agriculture, and it is proved that it is more active compared to CO_2 [6].

Effects of global climate change are related to one another and the impacts are humongous to earth and human. As for increasing in world temperature, ice-free world occurs and this led to ice melting and causes sea level rising [7]. The prospect of sea-level rise and increasing social and economic costs of flooding in coastal regions is a global climate change problem. Nowadays, urban areas are expand continuously and being as one of the contributor factors of the increasing sea-levels. More than 90% of the ice delivered from Antarctica to the oceans comes from fast moving ice streams [8]. Few studies suggested that global sea-rise will be between 0.2 m and 1.4 m over the next 50 years [9-10]. Change [11] concluded that the ocean in Guam Island, United States is becoming more acidic while the sea level is rising and warmer. The consequences of climate change can damage and destroy coral reef ecosystem, increase damages from flooding and typhoons, and reduce the amount of fresh water during drought season and random temperature rise.

Many of disasters were occurred globally which gave huge impact to the whole world. El Nino phenomenon is one of the most influential climate incidents on inter-annual time scales [12]. Recently, Typhoon Mangkhut known in the Philippines as Typhoon Ompong, struck the island of Luzon on September 14, 2018 and continued on its destructive path as it hit the southern coast of China and Bangkok. The maximum sustained winds went as high as 165 mph [13]. Typhoon Jebi attacked Osaka, Japan with up to 100 mph in the same month as Typhoon Mangkhut tragedy occurred. It was the strongest typhoon to hit Japan in more than 25 years and caused 11 death and 600 injury [15].

The biggest climate change impact in South East Asia was the Indian Ocean tsunami that involved several countries such Malaysia, India, Maldives, Indonesia and others as seen in Fig. 1 [14]. The most affected countries were Maldives, Sri Lanka, Indonesia and Thailand. This tragedy was the most eye-wakening to everyone on how big climate change impact can affect the world. The number of death poll on this tragedy was tremendously high with 184,167 people confirmed dead and 43,786 people missing [15]. Meteorological and hydrological events such as typhoons are hazards that may cause heavy rain, flooding, high wind and sea surges [14].

Fig. 1 - Locations affected by the Indian Ocean Tusnami [14]

The effects of climate change on earth are likely to be mostly negative and impact most of low-income countries where the capacity are too large. Outstanding strategies need to be made to distinguish some of the adverse impacts. With the climate change already underway, there is a need to assess vulnerabilities and identify cost-effective to prevent such disasters to happen. Early warning system and long term planning will be very significant to reduce future adverse impacts and natural disasters causes by climate changes.

2. Uncertainty of the Climate Trend Affected by the El Nino

El Nino is regarded as the most significant climate phenomenon on decadal time scales. El Nino is the unusual large warming that occurs every 3-5 years and changes local and regional ecology. Climate variability plays a massive role in the characteristics of annual cycle of El Nino [16]. El Nino is defined by a warmer than normal sea surface temperatures in the eastern tropical Pacific, and is associated with anomalous atmospheric circulation patterns known as the Southern Oscillation called ENSO [17]. Fig. 2 shows a normal condition in the tropical which warm water and air are pushed to the west resulted on upwelling of cold water on the eastern side and a shallow thermocline [18].

Besides, El Nino affects the surface temperature, precipitation and mid-tropospheric atmospheric calculation over extended regions in America, Australia, Europe, India and East Asia [18], [19]. As it affected the surface temperature of the earth, global surface temperature increases gradually. This mishap leads to changes in precipitation and atmospheric moisture hence resulting on changes in hydrological cycle [20].

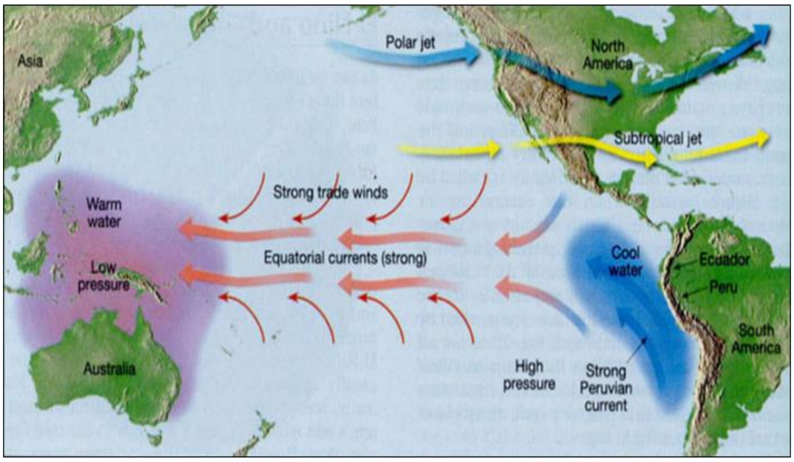

Fig. 2 - El Nino phenomenon [18], [19]

3. Climate Variability and Extremes

Intergovernmental Panel on Climate Change (IPCC) reported many extreme events have been recognized since 1950 and most of the changes occurred have been linked to human influences including the number of heavy precipitation events in a number of regions [21]. Moreover, recent detection of increasing trends in extreme precipitation will contribute to greater risks of flooding. As projected by IPCC in 2014 AR5 Synthesis Report [21], heat waves will occur more often and last longer, and precipitation events will become more intense and frequent for most part of the world (Fig. 3).

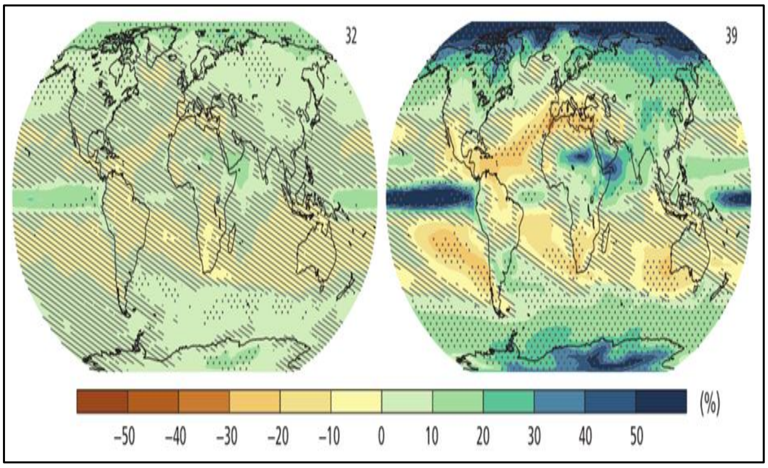

Fig. 3 - Change in average precipitation (1986-2005 to 2081-2100) [21]

Monitoring and prediction of future rainfall is needed as water resources systems have become more complex in minimizing flood and preparing for future extreme events. A study on rainfall characteristics using Standardised Precipitation Index (SPI) showed in increasing drought events for the most part of Peninsular Malaysia and expected to experience less wet events except for eastern and western regions [22]. The findings indicated that the southwest monsoon had the greatest impact on the western part of the Peninsular, particularly in characterizing the rainfall pattern of the northwest region. During this season, the northwest region could be considered as the wettest region since all rainfall indices tested were higher than in other regions of the Peninsular [22].

In Africa, there are three factors causes changing in precipitation patterns which are ENSO event, extreme drought and climate variability [20]. ENSO is the main event that responsible to climate variability over certain area of Africa. It appears to happen more vigorously and reduce rainfall and increase surface temperature. Recent study showed changes in climate variability in Africa, as rainfall has increased at the eastern parts of Africa [23]. Considering that, Southern part of Africa that is very close to Europe will experience dry period or receive less precipitation.

Hughes et al. [24] carried out a study on climate change in Australia. He concluded that the average temperature has increased about 0.8°C since 1910 and so did the precipitation especially on summer and winter. El Nino has given an impact for climate and sea variabilities in Australia. El Nino has also affected the Southeastern Australia (SEA) as it suffered 10 years from 1997 to 2006 of low precipitation [25]. Based on the projection of future climate variability, by 2030, the annual average temperature will be 0.4-2.0°C higher in most part of Australia. La Nina years will result in more intense rainfall mostly in summer and autumn as the rainfall will increase up to 10%. While El Nino years lead to more intense drought as this will indicate huge hydrological extremes. Unfortunately, the modeling predicts that return times for heavy rainfall will be decreasing [24].

4. Downscaling Methods for Climate Change Projections

The GCMs representing physical processes in the atmosphere, ocean, cryosphere and land surface are the most advanced tools currently available for simulating the response of the global climate system to increase greenhouse gas concentrations. Although GCMs are valuable predictive tools, however the model present in the coarse resolution and unable to account finer-scale heterogeneity for the local climate variability. Thus, the downscaling model has been applied in many studies all over the world to downscale the GCMs resolution to become finer which focused on the local climate trend [24, 26-32]. Basically the models have been used to forecast the local climate changes in the long term assessment with concern the expecting GHGs level in the future year.

4.1 Dynamical Downscaling

Dynamical downscaling relies on the use of a regional climate model (RCM), similar to a GCM in its principles but with lower resolution. RCMs take the large-scale atmospheric information supplied by GCM output at the lateral boundaries and incorporate more complex topography, the land-sea contrast, surface heterogeneities, and detailed descriptions of physical processes in order to generate realistic climate information at a spatial resolution of approximately 20–50 km. Similar to GCMs, RCMs have difficulty accurately simulating convective precipitation, which is a major concern for tropical regions. Most RCMs also do not accurately simulate extreme precipitation. Statistical bias corrections often need to be performed to better match the model output to the observations [33].

Alamdari et al. [34] carried out a study at 17 locations across the United State of America and used predictors from American Regional Climate Change assessment program (NARCCAP) as inputs to the Rainwater Analysis and Simulation Program (RASP) model. RAINBOW software was then used to examine drought characteristics as an evidence of climate change in two agro-climatic zones. The results showed that runoff capture reliability was decreasing while increasing in water supply in eastern, northwestern and southwestern U.S. sites. RAINBOW is a software to carry out hydro-meteorological frequency analyses and test the homogeneity of climatic data [35]. This paper proclaimed rainfall uncertainty and drought characteristics under climate change of Southern Nigeria. Data was collected from Nigeria Meteorological Agency over a period of 30 years (1984-2014) and 5 stations were selected. The result showed that farmers that has predicted longer dry seasons is correct as it has become a recurrent event. Secondly, rainfall is more reliable from the month of May until July and the opposite of reliable on March, August and October [32].

Musayev et al. [36] used a stochastic weather generator (LARS-WG) to simulate synthetic daily rainfall using historic weather data and the simulated results were used to downscale GCMs. LARS-WG was used to simulate 50 years of annual precipitation at the 94 selected climate stations to determine mean precipitation variations between climate zones. The emissions scenarios include the A2, A1B, and B1 and the time periods are 2011–2030, 2045–2065, and 2080–2099. The A2 Separated World scenario is the worst case, highest emission scenario while the B1 Sustainable World scenario assumes the world takes more aggressive actions to reduce emissions. The A1B Rich World scenario is in between these two with steadily increasing emissions.

4.2 Statistical Downscaling

Statistical downscaling involves the establishment of empirical relationships between historical and/or current large-scale atmospheric and local climate variables. Once a relationship has been determined and validated, future atmospheric variables that GCMs project are used to predict future local climate variables. Statistical Downscaling Model (SDSM) is freely available software in which multiple linear regression methods are used to spatially downscale daily with 17 types of predictor-predictand relationship [28]. SDSM provides climate information at specific location for daily, monthly or yearly data that are adequate to calibrate the model, as well as archived GCM output [29]. Outputs can be applied over a range of climate impact sectors and include site-specific daily scenarios for maximum and minimum temperatures, precipitation and humidity. A range of statistical parameters such as variance, frequencies of extremes and spell length are also produced [30].

Haylock et al. [29] tested six statistical and two dynamical downscaling models by downscaling seven seasonal indices of heavy precipitation. The statistical model was found to be the best model though strong negative biases found which have tendency to underestimate extreme events. Kisakye et al. [3] used 20 years of historical rainfall data and analysed using six (6) GCMs to study the effect of climate change on reliability of RWH system with the help of daily water balance model to simulate the performance of RWH system in Uganda. The reliability increased in September, October and November while showed large reduction in March, April and May. SDSM and Quantile Mapping (QM) were used in Feyissa et al. [27] to predict future daily maximum and minimum for temperature and precipitation as well as extreme events identification at Euthopia. Based on the downscaled results, Addis Abba of Ethiopia will experience an increase of temperature resulting from climate change. Precipitation was expected to rise due to global climate change.

Endris et al. [37] carried out a study in Africa and projected rainfall from 2070-2099 using General Climate Model (GCMs) on Representative Concentration Pathway 8.5 (RCP 8.5) was first divided in 3 seasons which were; Jun until September (JJS), March until May (MAM) and October until December (OND). From the analysis, OND rainfall events to be increase while MAM and OND to be decreasing on most of Africa regions. Dunning et al. [38] predicted more intense rainfall under future climate change with prediction from year 2080-2099 using CMIP5 under RCP 4.5 and RCP 8.5. Higher average rainfall was found in West Africa, Southern Africa and Central Africa.

Statistically downscaled CMIP5 of dataset all over Southeast Asia provided from National Aeronautics Space Administration (NASA) Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) for year 1976-2005. Fig. 4(1) and Fig. 4(2) shows spatial distribution of climatology on distribution of precipitation for 1976-2005. Fig. 4(1) is the CRU observation that indicates increase in precipitation about 0.12 mm per decade. However, Fig. 4(2) is NEX-GDDP observation that shows mild increase about 0.03 mm per decade [39].

While, Fig. 4(a) and Fig. 4(b) is the spatial distribution of precipitation under RCP 4.5 for year 2020-2050 and 2070 and 2099, respectively. Fig. 4(c) and Fig. 4(d) are the distribution for year of 2020-2050 and 2070-2099, respectively under RCP 8.5. Projection of future rainfall for year 2020-2050 and 2070-2099 under RCP 4.5 and RCP 8.5 has shown an increase in surface temperature more than 3.5°C and increase extreme rainfall over most of Southeast Asian land mass, except over some southern islands of Indonesia [39].

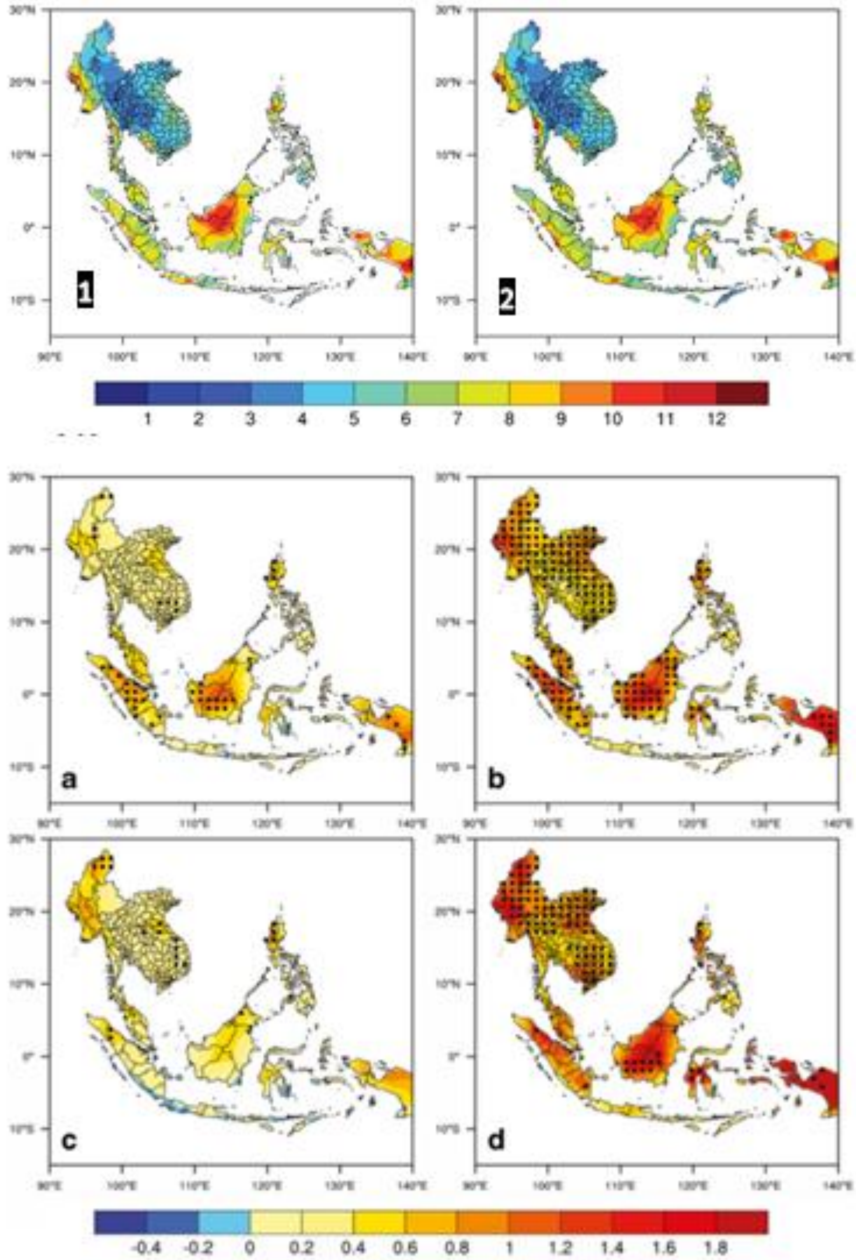

Fig. 4 - Spatial distribution of precipitation in Southeast Asia [39]

Possible changes in rainfall patterns in Sarawak were investigated using statistical downscaling of GCM. Historical rainfall data were used to downscale the future rainfall projections from 20 ensembles GCMs of Coupled Model Intercomparison Project phase 5 (CMIP5) for four Respective Concentration Pathways (RCP). The results showed that the future projection of the annual rainfall was increasing and decreasing simultaneously on the region-based and catchment-based basis due to the influence of the monsoon season affecting the coast of Sarawak and mainly showing a trend decreasing rainfall during the first period (2010-2039) followed by increasing rainfall for the period of 2070-2099 [31].

SDSM and Artificial Neural Network (ANN) were compared in projecting climate variables in the tropical Langat River Basin [26]. Using GCM3.1 under A2 emission scenario these two statistical downscaling were calibrated and validated to project future scenarios (2030s and 2080s). SDSM showed more capability to catch the wet-spell and dry-spell length than the ANN models as ANN indicated a decrease in the dry spell and an increase in the wet spell length [26].

Data from single rainfall station located in the Kurau River were used as input of the SDSM model. The study included the calibration and validation with large-scale National Centres for Environmental Prediction (NCEP) reanalysis data and the projection of future rainfall corresponding to the GCMs-variable (HadCM3 A2). The study resulted on during calibration and validation stage, the SDSM model can be well accepted in regards to its performance in the downscaling of the daily and annual rainfall. For the future period (2010-2099), the SDSM model estimates that there were increases in the total average annual rainfall and generally, the area of rainfall station become wetter [40].

Based on the SDSM simulation results from Tukimat and Harun [41], the climate trend was not much different from the historical data but it is expected to increase continuously for every interval period from the year 2010 to 2099. The increasing of temperature is predictable up to 32ºC during south-west monsoon season and 40ºC during north-east monsoon season. The rainfall pattern shows that the intensity is estimated to focus on the middle area of Kedah such as Kota Setar, Pendang, Yan, Kuala Muda, Sik, and Baling district and is expected to increase during north-east monsoon season even when the wet spell during that period is relatively short. The longest dry spell which is expected to assault Kedah Peak and Kodiang in the future may cause water scarcity at critical areas [41].

A study carried out in Pahang, Malaysia, concluded that dry period for 30 years will occur in the future. Spatial data of GCMs were initialized in SDSM to downscale the daily scenarios from the selected predictor-predictant relationships. The results of GCMs were estimated using SPI to find the correlation between predictor-predictand chosen. Resulted on suggestion of effective water management planning in the future as dry scenario scene was detected within 30 years ahead [42]. From 2011 to date, more than 300 papers have been published focusing on SDSM as downscaling method for climate data. The most prominent research categories are water and flood risk management as shown in Table 1 [29].

Table 1 - Research category that applied SDSM [29]

Rank	Category
1	Water
2	Unspecified
3	Flood
4	Agriculture
5	Urban

5. Conclusions

There is no serious doubt about the fact that our climate is changing. The uncertainty of rainfall will lead into disaster of unpredictable of rainfall event or zero rainfall occurrence. With El Nino and La Nina occurrences, temperature for certain countries especially Australia and Asian regions will get affected. It has also been reported that an increase in possibilities of having extreme dry events and flood events all over the world. Even though SDSM has been used by many countries and sectors, Malaysia has not really acknowledged the use of SDSM to predict rainfall or temperature. Only few studies have been found using SDSM as discussed earlier. Hence, the uses of SDSM to predict future rainfall in a certain region of Malaysia is good for preparing on planning of natural disaster management as Malaysia is expected to flood during monsoon season and it has gone worsen each year.

Acknowledgement

The authors would like to thank Universiti Tun Hussein Onn Malaysia (UTHM) under Graduate Incentive Scheme (Vote H021) for providing financial support to the first author. Also thank to Ministry of Higher Education (MOHE), Malaysia, in funding the project through Fundamental Research Grant Scheme (FRGS) (Vote 1523).

References

[1] Kandji, S. T., Verchot, L., and Mackensen, J. (2006). Climate Change and Variability in Southern Africa: Impacts and Adaptation Strategies in the Agricultural Sector. UNEP: United Nations Environment Programme.

[2] Oreskes, N. (2004). The scientific consensus on climate change. In The Science Magazine (pp 1686-1686).

[3] Kisakye, V., Akurut, M., and Van der Bruggen, B. (2018). Effect of Climate Change on Reliability of Rainwater Harvesting Systems for Kabarole District, Uganda. Water, 10(1), 2073-4441.

[4] Koetse, M. J., and Rietveld, P. (2009). The impact of climate change and weather on transport: An overview of empirical findings. Transportation Research Part D: Transport and Environment, 14(3), 205-221.

[5] Mackay, A. (2008). Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Journal of Environmental Quality, 37(6), 2407.

[6] Oreskes, N. (2018). The scientific consensus on climate change: How do we know we're not wrong?. In Joseph F. C., The Climate Change: What It Means for Us, Our Children and Our Grandchildren (pp. 31-64). MIT Press: Springer.

[7] Zhang, J., and Rothrock, D. (2003). Modeling global sea ice with a thickness and enthalpy distribution model in generalized curvilinear coordinates. Monthly Weather Review, 131(5), 845-861.

[8] Peñuelas, J., and Filella, I. (2009). Phenology feedbacks on climate change. Science, 324(5929), 887-888.

[9] Griffiths, J. A., Zhu, F. F., Chan, F. K. S., and Higgitt, D. L. (2018). Modelling the impact of sea-level rise on urban flood probability in SE China. Geoscience Frontiers, 10(2), 363-372.

[10] Hallegatte, S., Green, C., Nicholls, R. J., and Corfee-Morlot, J. (2013). Future flood losses in major coastal cities. Nature climate change, 3(9), 802-806.

[11] What Climate Change Means for Guan. Climate change (2016). Climate Change and Coral Loss. Retrieved on August, 2016 from http://www.epa.gov/climatechange

[12] Meng, J., Fan, J., Ashkenazy, Y., Bunde, A., and Havlin, S. (2018). Forecasting the magnitude and onset of El Nino based on climate network. New Journal of Physics, 20(4), 1367-2630.

[13] Yeh, S. W., Kug, J. S., Dewitte, B., Kwon, M. H., Kirtman, B. P., and Jin, F. F. (2009). El Niño in a changing climate. Nature, 461(7263), 511-515.

[14] Allen, J. T., Molina, M. J., and Gensini, V. A. (2018). Modulation of annual cycle of tornadoes by El Niño–Southern Oscillation. Geophysical Research Letters, 45(11), 5708-5717.

[15] Ashok, K., and Yamagata, T. (2009). Climate change: The El Niño with a difference. Nature, 461(7263), 481-484.

[16] Gadgil, S., Rajeevan, M., and Francis, P. (2007). Monsoon variability: Links to major oscillations over the equatorial Pacific and Indian oceans. Current Science, 93(2), 182-194.

[17] Philander, S. G. H. (2004). On El Nino and the uncertain science of global warming. Earth Science, 133(2), 105-108.

[18] Dore, M. H. (2005). Climate change and changes in global precipitation patterns: what do we know?. Environment international, 31(8), 1167-1181.

[19] Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., and Dasgupta, P. (2014). Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change: IPCC.

[20] Yusof, F., Hui-Mean, F., Suhaila, J., Yusop, Z., and Ching-Yee, K. (2014). Rainfall characterisation by application of standardised precipitation index (SPI) in Peninsular Malaysia. Theoretical and Applied Climatology, 115(3-4), 503-516.

[21] Wang, Z., Zhong, R., Lai, C., Zeng, Z., Lian, Y., and Bai, X. (2018). Climate change enhances the severity and variability of drought in the Pearl River Basin in South China in the 21st century. Agricultural and Forest Meteorology, 249, 149-162.

[22] Hughes, L. (2003). Climate change and Australia: Trends, projections and impacts. Austral Ecology, 28(4), 423-443.

[23] Murphy, B. F., and Timbal, B. (2008). A review of recent climate variability and climate change in southeastern Australia. International Journal of Climatology: A Journal of the Royal Meteorological Society, 28(7), 859-879.

[24] Amirabadizadeh, M., Ghazali, A. H., Huang, Y. F., and Wayayok, A. (2016). Downscaling daily precipitation and temperatures over the Langat River Basin in Malaysia: A comparison of two statistical downscaling approaches. International Journal of Water Resources and Environmental Engineering, 8(10), 120-136.

[25] Feyissa, G., Zeleke, G., Bewket, W., and Gebremariam, E. (2018). Downscaling of future temperature and precipitation extremes in Addis Ababa under climate change. Climate, 6(3), 1-19.

[26] Hashmi, M. Z., Shamseldin, A. Y., and Melville, B. W. (2011). Comparison of SDSM and LARS-WG for simulation and downscaling of extreme precipitation events in a watershed. Stochastic Environmental Research and Risk Assessment, 25(4), 475-484.

[27] Haylock, M. R., Cawley, G. C., Harpham, C., Wilby, R. L., and Goodess, C. M. (2006). Downscaling heavy precipitation over the United Kingdom: A comparison of dynamical and statistical methods and their future scenarios. International Journal of Climatology, 26(10), 1397-1415.
[28] Maraun, D., Wetterhall, F., Ireson, A., Chandler, R., Kendon, E., Widmann, M., and Themeßl, M. (2010). Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user. Reviews of Geophysics, 4*8*(3), 8755-1209.
[29] Sa'adi, Z., Shahid, S., Chung, E. S., and bin Ismail, T. (2017). Projection of spatial and temporal changes of rainfall in Sarawak of Borneo Island using statistical downscaling of CMIP5 models. Atmospheric Research, 197, 446-460.
[30] Wilby, R. L., and Dawson, C. W. (2013). The statistical downscaling model: insights from one decade of application. International Journal of Climatology, 33(7), 1707-1719.
[31] Brown, C., Greene, A. M., Block, P., and Giannini, A. (2008). Review of downscaling methodologies for Africa climate applications. IRI Technical Report 08-05: IRI Downscaling Report, International Research Institute for Climate and Society, Columbia University.
[32] Alamdari, N., Sample, D. J., Liu, J., and Ross, A. (2018). Assessing climate change impacts on the reliability of rainwater harvesting systems. Resources, Conservation and Recycling, 132, 178-189.
[33] Ayanlade, A., Radeny, M., Morton, J. F., and Muchaba, T. (2018). Rainfall variability and drought characteristics in two agro-climatic zones: An assessment of climate change challenges in Africa. Science of the Total Environment, 630, 728-737.
[34] Musayev, S., Burgess, E., and Mellor, J. (2018). A global performance assessment of rainwater harvesting under climate change. Resources Conservation And Recycling, 132(1), 62-70.
[35] Endris, H. S., Lennard, C., Hewitson, B., Dosio, A., Nikulin, G., and Artan, G. A. (2018). Future changes in rainfall associated with ENSO, IOD and changes in the mean state over Eastern Africa. Climate dynamics, 52(3), 2029-2053.
[36] Dunning, C., Black, E., and Allan, R. (2018). Later wet seasons with more intense rainfall over Africa under future climate change. Journal of Climate, 18(102), 1-50.
[37] Zhao, Y., Yu, X., Yao, J., and Dong, X. (2018). Evaluation of the subtropical westerly jet and its effects on the projected summer rainfall over central Asia using multi‐CMIP5 models. International Journal of Climatology, 38, 1176-1189.
[38] Hassan, Z., and Harun, S. (2012). Application of statistical downscaling model for long lead rainfall prediction in Kurau River catchment of Malaysia. Malaysian Journal of Civil Engineering, 24(1), 1-12.
[39] Tukimat, N. N. A., and Harun, S. (2011). The projection of future rainfall change over Kedah, Malaysia with the statistical downscaling model. Malaysian Journal of Civil Engineering, 23(2), 67-79.
[40] Othman, A. S., and Tukimat, N. N. A. (2018). Assessment of the Potential Occurrence of Dry Period in the Long Term for Pahang State, Malaysia. Paper presented at the MATEC Web of Conferences, 150(3004), 1500-3004.