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Using LARS –WG model for prediction of temperature in Columbia City, USA

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Abstract: Climate change has placed considerable pressure on the residential environment in different areas of the world. These issues have increased the motivation of researchers to analyse and forecast the changes in critical climatic factors, such as temperature, in order to offer valuable reference outcomes for management and planning in the future. This study set out to determine to what extent global warming would affect Columbia City, Missouri, USA. The Long Ashton Research Station Weather Generator (LARS-WG) model is used for downscaling daily maximum temperatures based on the SRA1B scenario. Seven General Circulation Models (GCMs) outputs are employed for three selected periods, 2011–2030, 2046–2065 and 2080–2099. The findings show that (1) statistical analysis confirmed the skill and reliability of the LARS-WG model to downscale maximum temperature time series; (2) the ensemble mean of seven GCMs exhibited an increasing based on yearly and monthly data for all periods compared with baseline period 1980-1999. The findings can contribute to a better understanding of the impacts of climate change on the urban environment and encourage planners and stakeholders to find the best solution for mitigation of these impacts.

Keywords: Climate change; Columbia City; LARS-WG; statistical downscaling.

1. Introduction

Humanity has faced uncommonly from global challenges, and one of the most critical issues is global warming. Global warming, which is often named climate change, is the phenomenon of rising in temperature of atmospheric that leads to modifications in the ecosystem. So, these changes are impacting, directly and indirectly, both people and their surrounding environment for short and long term [1, 2]. UNFCCC [3] stated that climate change has several harmful influences such as 1) shortages in quantity and quality of agricultural production; 2) spread many diseases, e.g. cholera and malaria; 3) depilation the freshwater resources which in turn exerts extra pressure on water and wastewater treatment facilities [4-14]. In addition, several researchers proved that temperature driven water consumption such as [15, 16, 17].

Many studies have applied downscale approaches to simulate future climate factors, such as Abdellatif, et al. [18], who investigated the spilling volume of urban drainage catchment in northwest England under

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different climate change scenarios and climate models using a generalised linear model and an ANN (hybrid GLM-ANN) model. In addition, Räisänen [19] used 12 regional model simulations (RCM) and baseline (1980–2010) monthly mean temperature to investigate the changes in snowfall in northern Europe. Moreover, Masanganise, et al. [20] utilised 10 global climate models (RCM) and monthly temperature and rainfall to describe climate changes by mid-century in Zimbabwe, 2040-2070 period, relative to the 1980-2010 baseline.

This study endeavours to achieve three aims include firstly, to evolve a downscaling model that has the capability to simulate current and future maximum temperature in Columbia City. Next, to employ the developed downscale model together with information about climate change to simulate maximum temperature for three future periods. Finally, to analyse the obtained outcomes to assess the future maximum temperature in the studied area.

2. Area of study and data set

Columbia City locates in northern mid-Missouri state that lay middle of the United States of America (Figure 1). Columbia City has an area of around 164.5 km², and its coordinates are 38.9517° N, 92.3341° W. The city has a growth in population from 62,061 to 108,500 capita between 1980-2010. The groundwater represents the primary source of the freshwater resource. The water company serve about 44,360 different customers inside the city, and 92% of them is residential customers [21].

The weather in the city is hot, muggy and wet in summer and the warmest period between 31st May to the 17th September, with an average daily high temperature above 26 °C. While winter is very cold with an average daily high temperature that reaches no higher than 10 °C and the coldest period is between 28th November to 26th February [22]. Historical daily maximum temperature data (°C) were gathered from Columbia City's council for the period from 1980-2010.

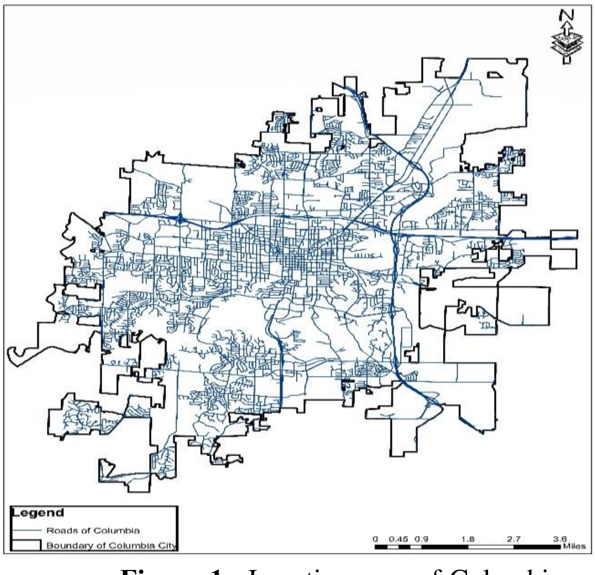

Figure 1. Location map of Columbia

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3. Downscaling Technique

Several approaches have been utilised to assess global climate simulations and to downscale different global climate scenarios, resulting from different emissions scenarios, for the evaluation of climate influences on hydrologic systems [18, 19, 23]. Daniels, et al. [24] mentioned that downscaling techniques could be divided into two main types: dynamic and statistical. In addition, downscaling methods are based on several General Circulation Models (GCMs) and the Intergovernmental Panel on Climate Change (IPCC) scenarios.

A GCM is the main tool applied to project the influences of emissions on climate in the future. It provides information at a scale of 100-500 kilometres for one grid size and temporal scales of monthly means and longer. Accordingly, it is considered too coarse for planning and assessment of impact for almost all decision makers. However, the downscaling technique has been used to obtain information on climate change at a scale more relevant to stakeholders. It is utilised spatially, with a resolution of 20 kilometres, or even a specific location, and temporally (e.g., daily temperature sequences from monthly or seasonal temperature amounts) [25]. Roy and Majumder [26] point out that the IPCC offers various climate change scenarios and attempts to forecast the result of that variation on different related natural phenomena. These scenarios are based on pollution and land use dynamics, population and the influence of climate change on these activities. These scenarios – such as A2 that depicts a very heterogeneous world, continuously growing global population and economic development – are oriented regionally. B1 describes a convergent world, where global population will peak mid-century and clean technologies will be introduced. A1B is balanced between using fossil and non-fossil energy across all sources. More details about IPCC scenarios can be found in [27].

Daniels, et al. [24] stated that the statistical downscaling method has advantages such as being efficient, computationally inexpensive and offering several various emissions scenarios and GCM pairings, while the dynamic downscaling method needs high computational resources and expertise and a high volume of data inputs. Accordingly, this study will apply the statistical downscaling method and, more precisely, The Long Ashton Research Station Weather Generator (LARS-WG) model.

3.1. The Long Ashton Research Station Weather Generator (LARS-WG)

LARS-WG is a stochastic weather generator utilised to generate a long series of synthetic data in three periods (2011-2030, 2046-2065 and 2080-2099). In addition, it has been designed to study the impact of climate change. Moreover, it has been tested for various sites across the world, and the results showed that the model is able to simulate climatic factors with reasonable skill [28]. Semenov [28] inspected and stated that the period from 1980-2010 is valid as a baseline period for generating future climatic factors. Additionally, several researchers have adopted this period in studies [19, 20].

For this research, version (5.5) of LARS-WG and 7 GCMs will be used to reduce the uncertainty for three different periods. Additionally, the A1B emissions scenario will be applied in the LARS-WG model. This scenario will be investigated to show its influence on residential complexes. Usage of more than one GCM and the A1B scenario is to eliminate the uncertainty that results from the assumption in each approach. More precisely, it is utilised for long-term period projection. More details about the seven GCMs that were selected from IPCC AR4 can be found in [29].

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4. Results and discussion

4.1. LARS-WG Calibration and Validation

The daily maximum temperature data for Columbia City for the period 1980-2010 (31 years) was employed for calibration and validation of the LARS-WG model. Graphic comparison of mean and standard deviation between observed and simulated data was used to assess the ability and reliability of the model to downscale future temperature data. Figure 2 shows the model had a very good performance in fitting mean and standard deviation in terms of maximum temperature.

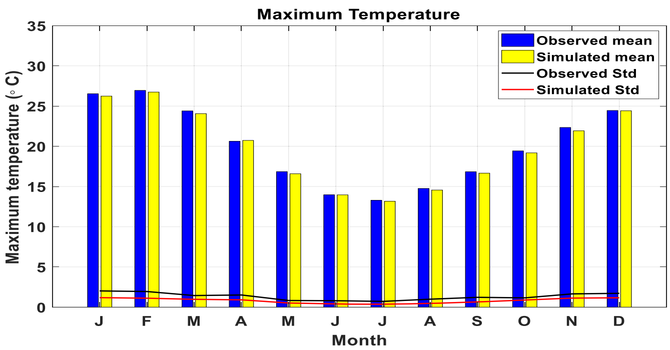

Figure 2. Measured and simulated mean and standard deviation of Tmax at study area

The LARS-WG model reveals an adequate performance in replicating the observed maximum temperature in this study, which obviously emphasises that the model is appropriate for this region. Similar reliable performances in generating maximum temperature have been found for the LARS-WG model in various locations around the world, as mentioned in [29]. Accordingly, confidence was increased to employ the downscaling model in this study.

4.2. Projection of Future Temperature

The developed and calibrated LARS-WG model for Columbia City was then employed to forecast maximum temperature for three periods, 2011-2030, 2046-2065 and 2080-2099, dependent on the SRA1B scenarios generated from seven GCMs. The results of the yearly maximum temperature forecasting data for all GCMs and their ensemble mean for the three periods are plotted in Figure 3. This figure shows that all the GCMs' projected data over the period 2011-2030, in general, have little variation. The pattern of HADCM3 and NCCCSM models are closer to each other, while GFCM21 and MPEH5 models have the same pattern but are not close to each other. INCM3 and IPCM4 models have an irregular pattern in some years. The limitation of ensemble projected between around 18.4-19.6 (i.e. it means the maximum and minimum values over the 20 years). The results for the second period, 2046-2065, present that all GCMs show approximately the same pattern, except the IPCM4 and MPEH5 models, which have considerable variation. In addition, the GCMs exhibit anomalous behaviour in the end quarter of the period. The limitation of ensemble projected approximately 20.3-21.3. The third period, 2080-2099, shows that the variation between the GCMs has increased, compared with the previous two periods. HADCM3 and IPCM4 models have almost the same pattern and offer highest temperature predictions degree compared with the other models, which demonstrate approximately the same trend, except for MPEH5, which shows the lowest one. The limitation of ensemble projected around 21.4-22.4.

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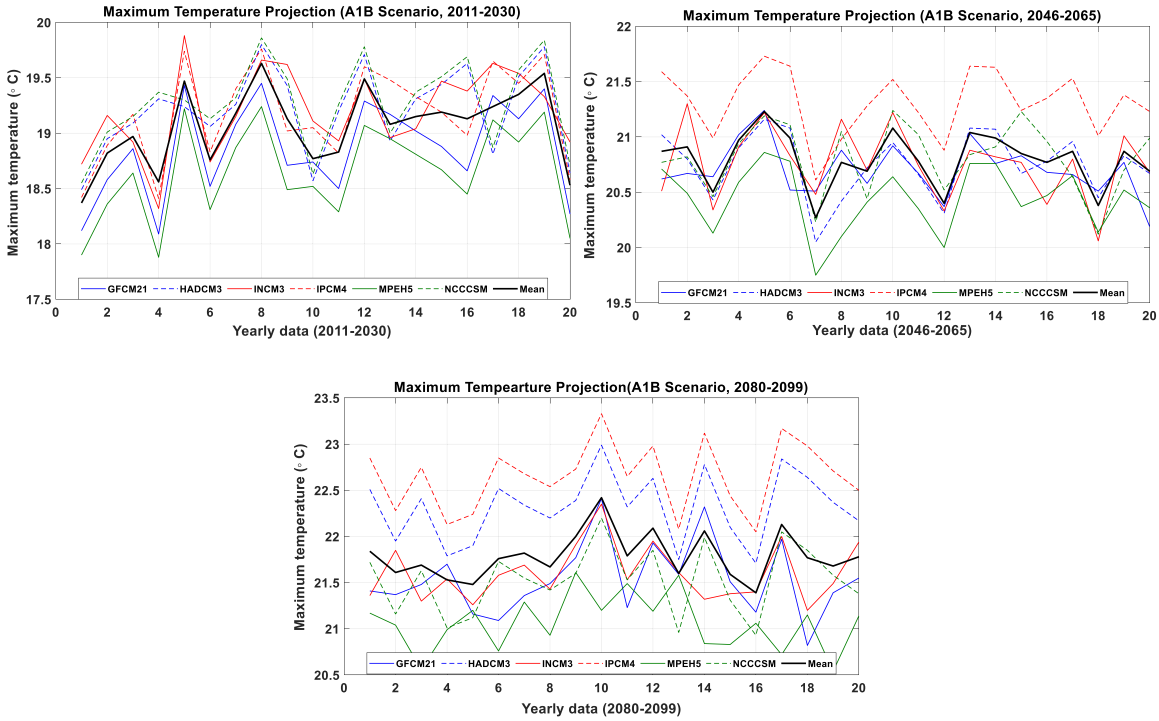

Figure 3. Projected yearly maximum temperature data for all periods

Additional results based on a monthly basis can increase our knowledge about climate change. Therefore, the ensemble means of maximum temperature forecasting from the seven GCMs were considered and the variations between baseline (1980-1999) and ensemble means for all periods were plotted, as shown in Figure 4. It can be seen that temperature will increase based on a monthly basis for all periods except June, July, August and September in the first period. The temperature will increase more as the prediction moves into the future (i.e., 2080-2099 is the hottest period).

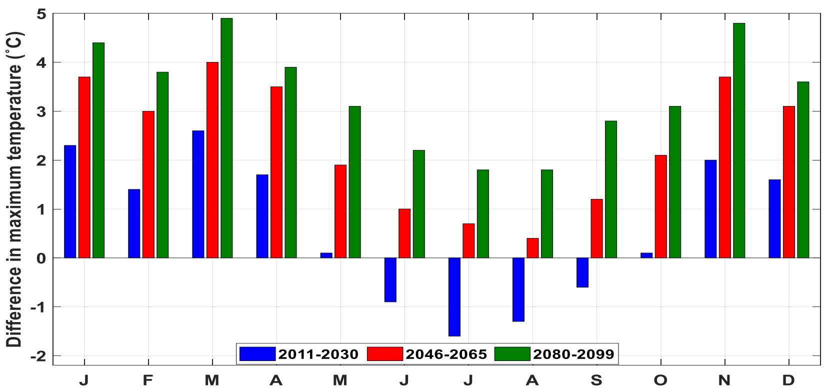

Figure 4. The differences in maximum temperature between the periods (2011-2030, 2046-265 and 2080-2099) and the current

5. Conclusions

In this study, the applicability of the LARS-WG model in downscaling daily maximum temperature was tested in Columbia City. Historical daily maximum temperature data, seven GCMs and SRA1B scenario were employed in the LARS-WG model to downscale maximum temperature in three periods of 2011-2030, 2046-2065 and 2080-2099. Historical data for the period of 1980-2010 were utilised to calibrate the downscaling model and to compare with future scenarios. From the study, it is concluded that:

- The LARS-WG model has the ability to perform excellently in downscaling daily maximum temperature data in the study area.
- The downscaled maximum temperature from a simulation of seven GCMs has various changing oscillating trends in all future periods. This also clarifies that more GCMs should be utilised in climate change research to minimise the models' uncertainty.
- The monthly differences between the baseline value and the ensemble means for all future periods show that maximum temperature was increased in all months except June, July, August and September. In addition, maximum temperature value increased as the prediction moved into the future.

These findings contribute in several ways to our understanding of climate change and provide a basis for further research. Additionally, they enhance the knowledge of policymakers to select the right solutions – those which mitigate the impacts of global warming in residential complexes and support sustainability.

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