Wasit Journal of Engineering Sciences

Journal homepage: https://ejuow.uowasit.edu.iq

Using the LARS-WG Model to Predict the Maximum Temperature in Zakho City, Iraq

Sura M. Abdulsahib[1], Salah L. Zubaidi[1], and Nadheer S. Ayoob[1]

Affiliations
[1] Civil Engineering Department, Wasit University, Kut, Iraq

Correspondence
Sura M. Abdulsahib
Email: Std2022203.S.M@uowasit.edu.iq

Received
23-May-2024
Revised
25-June-2024
Accepted
25-June-2024
Doi: https://doi.org/10.31185/ejuow.Vol12.Iss4.563

Abstract

Climate change has significantly impacted residential environments in many parts of the world. Scientists are nowadays more motivated to study and predict future changes in essential climatic elements, including temperature, to provide helpful reference results for future planning and managing. This study aims to estimate the impact of global warming on Zakho City, northern Iraq. The daily maximum temperatures are downscaled using the Long Ashton Research Station Weather Generator (LARS-WG) model based on the SSP585 scenario. Five General Circulation Models (GCMs) outputs are used for the selected period (2021-2040). The results exhibit that the statistical analysis validated the LARS-WG model's ability and dependability to downscale maximum temperature time series, and the average of five GCMs showed a rise in the monthly data of the studied period compared to the reference period (1985-2015). The predicted increase for the maximum temperature ranges between 1.4 to 2.7 ºC. The obtained results of the current research have the chance to improve comprehension of how the urban environment is affected by climate change and motivate stakeholders and planners to identify the most effective means of reducing these effects.

Keywords: LARS-WG, GCMs, Downscaling, Maximum temperature, Zakho.

الخلاصة: يؤثّر التغيّر المناخي بشكلٍ كبيرٍ على بيئة المراكز الحضريّة في مناطق مختلفة من العالم. أصبح الباحثون في هذه الأيام أكثر تحفّزاً لدراسة وتنبؤ التغيّرات المُستقبليّة في العناصر المُناخيّة الأساسيّة، مثل درجات الحرارة، من أجل توفير نتائج مرجعيّة مُفيدة للتخطيط والإدارة المستقبلية. تهدف هذه الدراسة لتخمين تأثير الاحتباس الحراري على مدينة زاخو في شمال العراق. تمَّ تخفيض درجات الحرارة العظمى اليوميّة بواسطة نموذج LARS-WG اعتمادًا على سيناريو SSP585. تم استخدام مُخرجات خمسة نماذج دوران عالميّة (GCMs) لفترة الدراسة التي تمتد من 2021 ولغاية 2040. أظهرت نتائج الدراسة أن التحليل الإحصائي أكّد قُدرة وموثوقيّة نموذج LARS-WG على تخفيض سلسلة بيانات درجات الحرارة العظمى بشكل جيّد، كما أن مُعدّل نماذج الدوران العالمي الخمسة أظهر ارتفاعًا في البيانات الشهرية لدرجات الحرارة خلال فترة الدراسة بالمقارنة مع الفترة المرجعية (1985-2015). يتراوح الارتفاع المتوقّع بدرجات الحرارة العظمى بين 1.4 و 2.7 درجة مئوية. تمتلك نتائج الدراسة الحاليّة القدرة على تحسين فهم تأثير التغير المناخي على البيئة الحضرية كما وتحفّز المُخططين وأصحاب العلاقة على تحديد الوسائل الأكثر فاعلية في الحد من هذه التأثيرات.

1. INTRODUCTION

Globally, climate change affects every urban region. Many catastrophic weather and climate occurrences have been related to human activities due to the Intergovernmental Panel on Climate Change (IPCC) [1]. The frequency, regional extent, intensity, timing and length of extreme weather and climate incidents alter due to climate change [2]. Climate change makes flooding and drought more severe and frequent [3-8]. Temperature is considered the most critical climate parameter, and many researchers have revealed that temperature governs water consumption [9-11].

Previous investigations have forecasted future climatic factors using global climate models (GCMs) and representative concentration pathways (RCPs). However, GCMs are improper for direct application to local-scale and sub-grid or effect assessments because they employ comparatively coarse computational cells. Thus, these GCMs must be either statistical downscaling (SD) or dynamic downscaling (DD) [12].

The statistical downscaling models are the most widespread because of their comparatively lower computer resource requirements, ease, and accuracy [13]. The Long Ashton Research Station Weather Generator (LARS-WG) represents an application of the SD models [14]. Many previous works have used the LARS-WG model and confirmed that, with appropriate skill, LARS-WG is able to anticipate future climate successfully [15-18]. The LARS-WG model has been efficiently used in many studies to downscale climate variables. For instance, Osman, Al-Ansari [19] estimated the influence of climate change on the stream flow of the Great Zab River in Iraq using predicted temperature and precipitation from the LARS-WG. The obtained results revealed that stream flow tends to drop by 25-60% throughout the present century. Furthermore, utilising the LARS-WG, Mohammed, Scholz [20] studied possible impacts of climate change on an area in Northern Iraq within the basin of Lower Zab River. Their research indicated that, compared to the reference period, there is a chance that the minimum temperature will increase from 3.02 to 3.33 °C and the maximum temperature will rise from 3.17 to 3.70 °C during the period of 2046-2065.

Although the significance of Zakho for Iraq in many aspects, including agriculture and tourism, a comprehensive study on climate forecast is not available in the literature. This work applies the weather generator LARS-WG, the newest software version 8.0, which involves models from the Coupled Model Intercomparison Project Phase 6 (CMIP6), to predict the maximum temperature for the Zakho station in northern Iraq during a chosen period between 2021 and 2040. Five GCMS models are employed and implemented under new scenarios of Shared Socioeconomic Pathways (SSP585). These findings will aid the decision-makers in local environmental planning and risk reduction.

2. METHODOLOGY

2.1 Area of study and data set

Zakho is a big city in Duhok province, Kurdistan Region, Iraq. It extends from 37°22' to 37°00′ N and 43°11′ to 42°22′ E. Its area is about 1454 km^2, and has elevations ranging from 350 to 2250 m (see Figure 1) [21]. The region has a diverse topography, including plains, valleys, hills, and rolling areas. The location of Zakho City is strategic; it is located near the border junction between Turkey, Syria, and Iraq. One river (Khabour), 166.8 km long, flows across the region. The weather in the city is sunny and dry in summer and rainy and cold in winter.

Zakho meteorological station was selected to study climate change. The station's coordinates are 42.69, 37.14 and 444, represented by Longitude, Latitude and elevation, respectively. In the current study, historical daily data of climate variables were collected using satellites for the period from January 1, 1985, to December 31, 2015 (30 years). The data involves the rainfall (mm/day), the maximum temperature (T_{max}), and the minimum temperature (T_{min}).

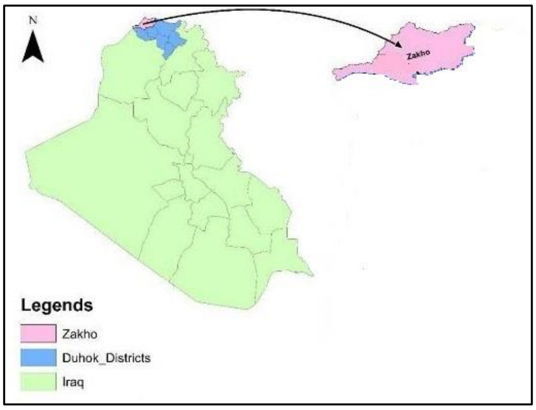

Figure 1 A Map Represents the Area of Study.

2.2 Downscaling technique

In assessing climate impacts on hydrologic systems, several methods were applied to estimate climate simulations and downscale various scenarios of global climate, which are the outcome of various emissions scenarios [22-27]. As aforementioned, Daniels et al. [28] mentioned that two primary methods of downscaling are available they are dynamic and statistical downscaling. In addition, downscaling techniques are based on GCMs and scenarios from the Intergovernmental Panel on Climate Change (IPCC).

Among the several approaches for creating future climate scenarios, the CMIP suggested by the WGCM was used in this work. SSP126, SSP245, and SSP585, the three most recent SSPs in CMIP6, were employed as climate change scenarios. The SSP126 and SSP245 represent positive and moderate climate policy-controlled worlds, respectively. On the other hand, SSP58.5 depicts an uncontrollably chaotic world with disastrous climate policies and high greenhouse gas emissions. Here, future climate change was evaluated in the context of SSP585, and the results were incorporated into the LARS-WG model parameters.

General Circulation Models (GCMs) and scenarios are the primary sources of knowledge on regional and global climate change IPCC 2007. However, GCMs use coarse-grained computational cells, so they do not help study effects on a sub-grid or local scale [29]. These GCMs have to be downscaled. According to [30], the statistical downscaling approach offers several different emissions scenarios and GCM pairings, is efficient, and is computationally inexpensive; on the other hand, the dynamic downscaling approach requires a large volume of data inputs, high computational resources, and experience. Thus, The LARS-WG model, which depends on the statistical downscaling, will be used in this work.

2.2.1 The LARS-WG model

It is an example of a system that uses the SD technique [14]. To simulate meteorological conditions at a single location, researchers employ LARS-WG [31], obtaining the present and future climatic conditions. The weather generator needs each day's time-series data for the variables, such as precipitation and minimum and maximum temperature. As a computationally inexpensive tool, LARS-WG can produce weather data appropriate for risk assessment in hydrological and agricultural investigations, extend weather data simulation to unstudied regions, and generate daily scenarios of climate change depending on outputs from GCMs. LARS-WG can also simulate daily weather data at a specific region that "statistically" matches the observed data. Daily temperature and precipitation time series can be synthetically generated by LARS-WG [32].

The current work uses five GCMs and the newest version of LARS-WG (8.0) to minimise uncertainty for the future. Furthermore, the model of LARS-WG was used with the SSP585 emissions scenario. Several GCMs and the SSP585 scenario are utilised to remove the uncertainty arising from the assumptions in each GCM.

3. RESULTS AND DISCUSSION

3.1 Valiation and calibration of LARS-WG

The model was validated and calibrated in this study depending on daily maximum temperature data for Zakho City for thirty years (from 1985 to 2015). The reliability and capability of the LARS-WG to project future temperature values were evaluated by a graphical comparison of the standard deviation and the mean of the simulated and observed data. As seen in Figure 2, the model fits the maximum temperature's mean and standard deviation very well. The calibration results clearly show that the LARS-WG model is suitable for this region because it performs well in simulating the maximum temperature recorded in this study. Furthermore, the ability of the model to downscale GCMs in the research area was examined using a statistical test. Table 1 illustrates the K-S test for distributions of the seasonal wet and dry series, and Table 2 shows the K-S test for daily maximum temperature distributions. The Kolmogorov-Smirnov (K-S) test was used to examine if the seasonal wet and dry (WD) series and daily maximum ($D.T_{max}$) temperature distributions fit well. The LARS-WG (8.0) performs well when the K-S value approaches zero. It can be concluded that Zakho station responded excellently according to the results. Similar consistent results for generating the maximum temperature were obtained for the LARS-WG technique in different parts of the globe, as reported in [33]. Thus, reliability in using the downscaling model in this work was consequently raised.

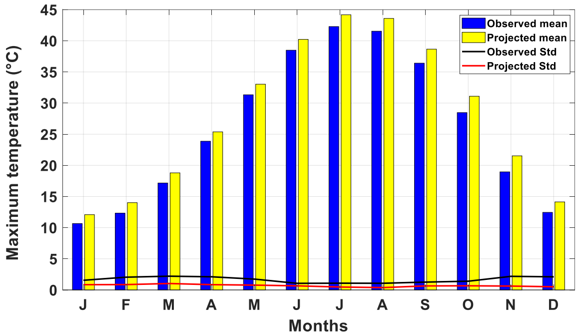

Figure 2 Observed and Projected standard deviation and mean of the maximum temperature at the area of study.

Table 1 K-S test for distributions of the seasonal wet and dry series

Season	Wet/Dry	N	K-S	P-value	Assessment
DJF	Wet	11.5	0.080	1.000	Perfect
	Dry	11.5	0.084	1.000	Perfect
MAM	Wet	11.5	0.059	0.984	Very good
	Dry	11.5	0.130	1.000	Perfect
JJA	Wet	11.5	0.079	1.000	Perfect
	Dry	11.5	0.070	1.000	Perfect
SON	Wet	11.5	0.059	1.000	Perfect
	Dry	11.5	0.065	1.000	Perfect

Table 2 KS-test for daily maximum temperature distributions

Month	N	K-S	P-value	Assessment
J	11.5	0.053	1.000	Perfect
F	11.5	0.053	1.000	Perfect
M	11.5	0.053	1.000	Perfect
A	11.5	0.053	1.000	Perfect
M	11.5	0.053	1.000	Perfect
J	11.5	0.053	1.000	Perfect
J	11.5	0.053	1.000	Perfect
A	11.5	0.105	0.999	Very good
S	11.5	0.053	1.000	Perfect
O	11.5	0.053	1.000	Perfect

N	11.5	0.053	1.000	Perfect
D	11.5	0.105	0.999	Very good

3.2 Future temperature prediction

Depending on the SSP585 scenario generated by the five GCMs, the maximum temperature for the selected period (2021-2040) was projected using the calibrated and validated LARS-WG (8.0) technique for the Zakho station. Figure 3 illustrates the predicted yearly maximum temperature for each GCM together with their assembled mean for the studied period. As shown in this figure, every GCM exhibits almost the same pattern. The HadGEM3-GC31-LL and ACCESS-ESM1-5 models show analogous patterns and give forecasted temperatures approximately similar to the mean of all GCMs. On the other hand, the MPI-ESM1-2-LR and MRI-ESM2-0 models are relatively close to each other and offer the lowest temperature projection. In contrast, the CNRM-CM6-1 model provides the highest temperature forecasts among the other models. The limit of the projected maximum temperature is between 27 and 29 ºC.

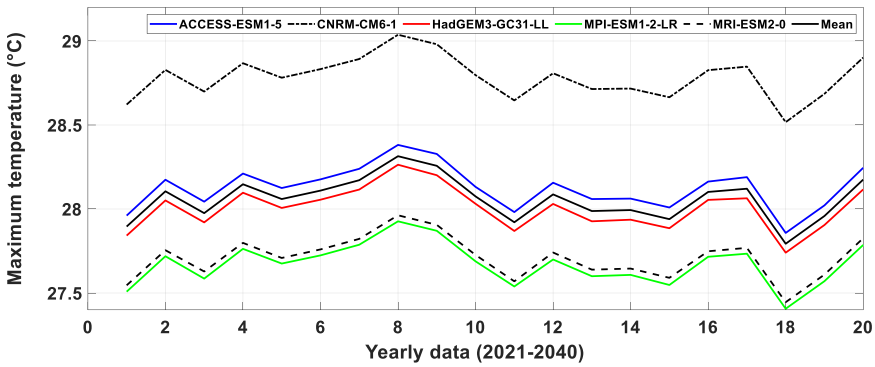

Figure 3 Predicted Yearly Data of the Maximum Temperature for the Selected Period.

Additionally, the monthly results can help to understand climate change better. Therefore, the mean of the predicted maximum temperature obtained by the five GCMs were considered, and the differences between the mean of the monthly predicted temperature during the chosen period and the monthly mean temperature of the baseline (1980-1999) were plotted in Figure 4. The monthly temperature will rise for the studied period, and the maximum temperature will increase between 1.4 to 2.7 ºC.

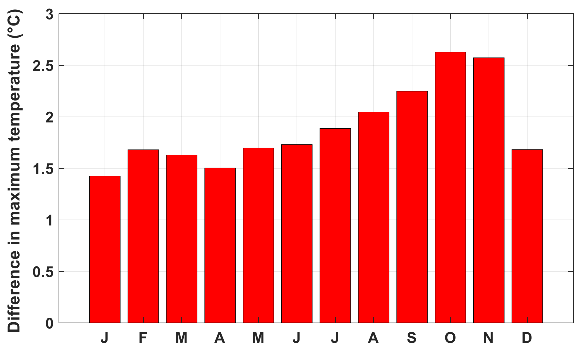

Figure 4 The differences in maximum temperature between the selected period (2021-2040) and the baseline (1985-2025).

4. CONCLUSION

This paper investigated the LARS-WG suitability to project the daily maximum temperature (T_{max}) (°C) in Zakho station. The LARS-WG technique uses historical daily minimum and maximum temperatures and rainfall data, which are produced from the five GCMs and the SSP585 scenario, to downscale maximum temperatures for the studied period (2021-2040). The downscaling model was calibrated by comparing the future scenarios with the historical data (1985-2015). Based on the results of this research, the following can be concluded:

- The used LARS-WG downscales the daily data of maximum temperature with exceptional accuracy in the area of study.

- There are apparent differences in the trends of the projected maximum temperature resulting from each of the five GCMs. This represents the importance of using more than one GCM to reduce the uncertainty in climate change research.
- During the selected period, the monthly temperature will rise, and the predicted increase for the maximum temperature is in the range between 1.4 to 2.7 ºC.

The obtained results provide a basis for more studies and can improve our knowledge about climate change in several ways. They also enhance the legislators' understanding of choosing the best options to lessen the effects of global warming in residential areas and promote sustainability.

REFERENCES

1. Rhodes, C.J.J.S.p., *Only 12 years left to readjust for the 1.5-degree climate change option–Says International Panel on Climate Change report: Current commentary.* 2019. **102**(1): p. 73-87.
2. Naqi, N.M., et al., *Statistical analysis of extreme weather events in the Diyala River basin, Iraq.* Journal of Water and Climate Change,, 2021. **12**(8): p. 3770-3785.
3. Yu, T., et al., *East Asia dust storms in spring 2021: Transport mechanisms and impacts on China.* Atmospheric Research, 2023. **290**: p. 106773.
4. Rami, A., et al., *Atmospheric analysis of dust storms in Sistan region.* Journal of Atmospheric and Solar-Terrestrial Physics, 2022. **227**: p. 105800.
5. Ledari, D.G., M. Hamidi, and Y.J.J.o.A.E. Shao, *Numerical simulation of the 18 February 2017 frontal dust storm over southwest of Iran using WRF-Chem, satellite imagery, and PM10 concentrations.* Journal of Arid Environments, 2022. **196**: p. 104637.
6. Hamidi, M.J.C., *The key role of water resources management in the Middle East dust events.* Catena, 2020. **187**: p. 104337.
7. Khazaei, B., et al., *Climatic or regionally induced by humans? Tracing hydro-climatic and land-use changes to better understand the Lake Urmia tragedy.* Journal of hydrology, 2019. **569**: p. 203-217.
8. Khazaei, B., et al., *Climatic or regionally induced by humans? Tracing hydro-climatic and land-use changes to better understand the Lake Urmia tragedy.* ournal of hydrology, 2019. **569**: p. 203-217.
9. Zubaidi, S.L., et al., *A Novel approach for predicting monthly water demand by combining singular spectrum analysis with neural networks.* Journal of hydrology, 2018. **561**: p. 136-145.
10. Zubaidi, S.L., et al. *Short-term water demand prediction in residential complexes: Case study in Columbia city, USA.* in *2018 11th International Conference on Developments in eSystems Engineering (DeSE)*. 2018. IEEE.
11. Zubaidi, S.L., et al., *Short-term urban water demand prediction considering weather factors.* Water resources management,, 2018. **32**: p. 4527-4542.
12. Fowler, H.J., S. Blenkinsop, and C.J.I.J.o.C.A.J.o.t.R.M.S. Tebaldi, *Linking climate change modelling to impacts studies: recent advances in downscaling techniques for hydrological modelling.* nternational Journal of Climatology, 2007. **27**(12): p. 1547-1578.
13. Trzaska, S. and E.J.U.S.A.f.I.D.b.T.T.A. Schnarr, *A review of downscaling methods for climate change projections.* International Development, 2014. **45**(05): p. 45-2621.
14. Semenov, M.A., E.M. Barrow, and A.J.U.M.H.U. Lars-Wg, *A stochastic weather generator for use in climate impact studies.* resources.rothamsted.ac.uk, 2002: p. 1-27.
15. Khoi, D.N., et al., *Impact of climate change on hydro-meteorological drought over the Be River Basin, Vietnam.* Journal of Water and Climate Change, 2021. **12**(7): p. 3159-3169.

16. Javan, K., A. Movaghari, and J.-S. Park, *Projected changes in extreme precipitation indices over the Lake Urmia basin in Iran.* Journal of Water and Climate Change, 2023. **14**(8): p. 2564-2582.
17. Hosseini Baghanam, A., et al., *Policy-Making toward Integrated Water Resources Management of Zarrine River Basin via System Dynamics Approach under Climate Change Impact.* Sustainability, 2022. **14**(6).
18. Moghadam, S.H., P.-S. Ashofteh, and H.A. Loáiciga, *Investigating the performance of data mining, lumped, and distributed models in runoff projected under climate change.* Journal of Hydrology, 2023. **617**.
19. Osman, Y., et al., *Climate change model as a decision support tool for water resources management in northern Iraq: a case study of Greater Zab River.* Journal of Water and Climate Change, 2019. **10**(1): p. 197-209.
20. Mohammed, R., M.J.T. Scholz, and a. climatology, *Climate change and water resources in arid regions: uncertainty of the baseline time period.* Theoretical and applied climatology, 2019. **137**(1): p. 1365-1376.
21. Yaseen T. Mustafa, D.R.I., *Land Use Land Cover Change in Zakho District, Kurdistan Region, Iraq: Past, Current and Future.* International Conference, 2019.
22. Abdellatif, M., et al., *Quantitative assessment of sewer overflow performance with climate change in northwest England.* Hydrological Sciences Journal, 2015. **60**(4): p. 636-650.
23. Räisänen, J.J.C.d., *Twenty-first century changes in snowfall climate in Northern Europe in ENSEMBLES regional climate models.* Climate dynamics, 2016. **46**: p. 339-353.
24. Zamani, M.G., et al., *Developing sustainable strategies by LID optimization in response to annual climate change impacts.* Journal of Cleaner Production, 2023. **416**.
25. Tikuye, B.G., et al., *Modelling the impacts of changing land use and climate on sediment and nutrient retention in Lake Tana Basin, Upper Blue Nile River Basin, Ethiopia.* Ecological Modelling, 2023. **482**.
26. Soltani, S., et al., *Climate change and energy use efficiency in arid and semiarid agricultural areas: A case study of Hamadan-Bahar plain in Iran.* Energy, 2023. **268**.
27. Morid, R., Y. Shimatani, and T. Sato, *An integrated framework for prediction of climate change impact on habitat suitability of a river in terms of water temperature, hydrological and hydraulic parameters.* Journal of Hydrology, 2020. **587**.
28. Daniels, A.E., et al., *Climate projections FAQ*. 2012: United States Department of Agriculture, Forest Service, Rocky Mountain ….
29. Khan, S.F. and U.A. Naeem, *Future climate projections using the LARS-WG6 downscaling model over Upper Indus Basin, Pakistan.* Environ Monit Assess, 2023. **195**(7): p. 810.
30. Khalaf, R.M., et al., *Projections of precipitation and temperature in Southern Iraq using a LARS-WG Stochastic weather generator.* Physics and Chemistry of the Earth, Parts A/B/C, 2022. **128**.
31. Hassan, Z., et al., *Application of SDSM and LARS-WG for simulating and downscaling of rainfall and temperature.* Theoretical and applied climatology, 2014. **116**: p. 243-257.
32. Willis, J.C., et al., *Use of an individual-based model to forecast the effect of climate change on the dynamics, abundance and geographical range of the pest slug Deroceras reticulatum in the UK.* Global Change, 2006. **12**(9): p. 1643-1657.
33. Osman, Y., et al., *Climate change and future precipitation in an arid environment of the MIDDLE EAST: CASE study of Iraq.* 2017. **25**(3).