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MODELING THE CHANGE IN MAXIMUM TEMPERATURE IN ZUWARA WEATHER STATION FOR THE PERIOD (1961-2099) USING SDSM TECHNIQUE

Abstract: The research aims to use climate models to identify how the climate has changed over time in the Zuwara region of Libya, especially the change in the maximum temperature during the twenty-first century. It is based on the technique of the Statistical Downscaling Model "SDSM", where it will depend on the maximum temperature data of a weather station, and Zuwara for the period from (1961-1990), and forecasting the monthly, quarterly and annual rate of future increase or decrease during the period (2019-2099) according to the two climate change scenarios, which are approved by the Intergovernmental Panel on Climate Change The (IPCC) in a report known as Special Report Emissions Scenarios (SRES) in 2000 to make projections of the climate and the environment based on the amount of greenhouse gas emissions. The results proved that the annual average maximum temperature in the Zuwara region will take an upward trend during the modelling periods compared to the base period (1961-1990). This is consistent with all IPCC scenarios, especially during the second period (2046-2072) with an increase of 1.3°C over the base period, and this rate maintains its trend of increasing by about 1°C during the period (2073-2099). The results also indicated an increase in the average maximum seasonal temperature according to the two scenarios H3A2a and H3B2a during the winter season in the second period (2046-2072) at a rate of 8°C. In the spring, the rate of change will reach 2°C. It is expected that the summer will witness a decrease in the maximum average temperature by 5°C, and the same will be the case in the autumn by a rate of 3.3°C in the second period compared to the base period, which threatens the inability of the countries of the world to control and mitigate emissions of greenhouse gases.

Key words: climate change, maximum temperature, climate model, climate scenarios, statistical minimization

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Introduction

The climate system is a complex system and is the result of the interaction of a group of intertwined natural elements in regular natural processes and cycles, each of which interacts and overlaps with the other. Therefore, any change and fluctuation in its natural characteristics will lead to a change in the climate system itself, which is what actually happens. The Earth's climate is fickle, unstable and changeable. It has changed many times in the distant and recent past, and is expected to remain so in the future (Sharaf, 2001). Human activities upset the balance of this system, especially the excessive use of fossil fuels, which led to an increase in the concentration of greenhouse gases, which contributed to climate change and extremism, especially the increase in the temperature of the Earth's atmosphere and oceans by 3 degrees Celsius until the year 2100 (Siama, 2015).

Today, global climate change has become inevitable, and will lead to changes in the entire planet, including the occurrence of more effective natural disasters. This necessitates changing our lifestyle, production and consumption, especially since controlling the magnitude of these changes is still within our reach.

Recent studies interested in understanding climate and predicting climate change have shown that through the general air circulation, it is possible to predict the future climate by means of global models, which are digital models that combine physical interaction on the surface of the earth, in the ocean, atmosphere and cryosphere, including the General Atmosphere Circulation Model (GCM General). Circulation Model and Regional Climate Models (RCM) as inputs in analysing and determining the strength of relationships between different climatic elements, and therefore it is one of the most famous models that are used in creating global databases and preparing climate change reports at the world level (United Nations Economic and Social Commission for Western Asia (ESCWA) et al., 2018).

For many decades, scientists have been interested in the possibility of modifying the Earth's climate through human activities such as burning fossil fuels, agriculture, and deforestation. During the twentieth century, the Earth's surface temperature increased by more than half a degree Celsius, and the 1990s were, on average, the hottest decade of the past thousand years (IPCC Working Group III, 2001).

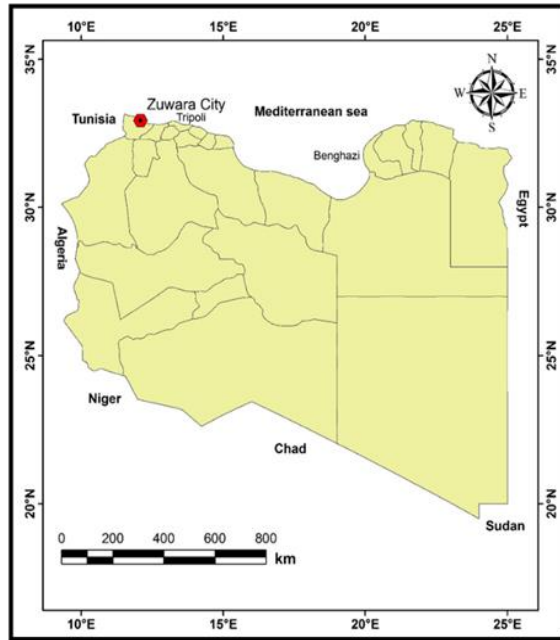


Fig. 1. Zuwara Region (Source: *The National Atlas, 1978*)

Zuwara is located in the northwest of Libya, and the far west of the Jafara Plain, which is predominantly equatorial. It extends along the Mediterranean Sea, which is bordered on the north, while on the east it is bordered by the Sabratha region, and from the south by the regions of Al-Jamil and Regdalin. Coordination of the location is the following- it is located at latitude 32.53 degrees north and longitude 12.04 east (Berry, 2005).

Study Methodology

This study relied on the statistical analytical approach of the daily averages of the maximum temperature of the Zuwara station issued by the Libyan National Centre of Meteorology for the period (1990-1961), to be used in simulations or future modelling for the period 2021-2099, using SDSM technology as a tool used to support decision-making. In the future prediction of temperatures based on emissions scenarios to understand climate change over time during the twenty-first century, HadCM3 issued by The Hadley Centre of the Met Office in the United Kingdom is used. Aspects of his performance in climate simulations are run by the Intergovernmental Panel on Climate Change (Johns et al., 2006), which is one of the most important scenarios in the study of climate change and this scenario is mainly based on Stabilization of greenhouse gas emissions rates recorded in the year 2000. As the climate system according to this scenario is subject to a certain amount of change based on the current concentrations of the various elements of the atmosphere, and in the field of climate, scenarios are used due to the great uncertainty of change at the regional level, which is represented in a subcontinent, the first town area (Kharfan, 2007). Its scenario (HadCM3) is:

Scenario A2a: Describes a highly diverse, heterogeneous, highly self-reliant world, in which economic development is regionally oriented and varies by region. It assumes that

fertility patterns vary across regions, implying a continuous growth in the world's population and an increase in population density.

Scenario B2a: This scenario is directed towards global solutions for economic, social and environmental sustainability and depends on alternative energy developments, achieving social and economic justice and a reduction in the intensity of resource exploitation. It also assumes that there is a continuous increase in the population but at a slower pace than the A2a scenario, and with an average rate of economic development, and with less rapid and more diverse technological change (Intergovernmental Panel on Climate Change, 2000).

SDSM Statistical Minimization Model and Methods of Using It in Prediction of Maximum Temperatures

The Statistical Downscaling Model (SDSM) technology is one of the techniques adopted by the International Panel on Climate Change (IPCC). Figure 1 show an example where it is used to deal with data of various climatic elements to assess the effects of regional climate change and support decision-making related to the future prediction of the state of climate and climate changes and what they will be, as well as to assess local statistics and their effects on climate change. Through this program, scenarios are used to help determine the daily, monthly and annual weather variables for the current and future state of the climate (Al-Malyan et al., 2021). This is based on simulations of global models, including the General Circulation Model (GCM) and Regional Climate Models (RCM) as inputs in analysing and determining the strength of the relationships between the different climatic elements to determine which of them has the strongest influence on the future projections of the maximum temperature in the Zuwara region (Wilby & Dawson, 2004). The variables affecting the climate were relied on according to the GCM model, which are related to the maximum temperature, as shown in Table 1.

The SDSM statistical minimization model is reliable for deriving a temperature data series from global models data for local representation (Gagnon et al., 2005).

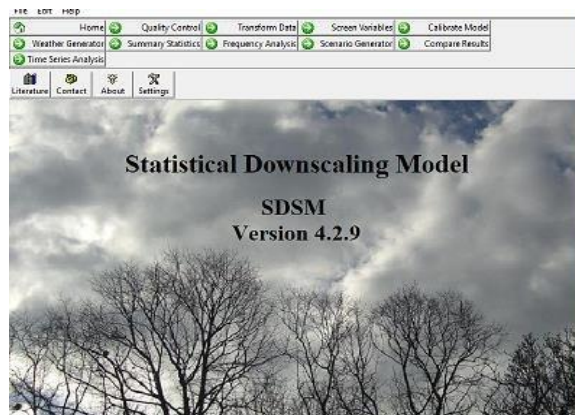


Fig. 2. The interface of the SDSM software (Wilby and Dawson, 2007)

Table 1. Prediction variables for climate scenarios

No	Predictor variables	Predictor description	No	Predictor variables	Predictor description
1	Mslpaf	mean sea level pressure	14	p5zhaf	500hpa divergence
2	p_faf	surface air flow strength	15	p8_faf	850hpa air flow strength
3	p_uaf	surface zonal velocity	16	p8_uaf	850hpa zonal velocity
4	p_vaf	Surface meridional velocity	17	p8_vaf	850hpa meridional velocity
5	p_zaf	surface vorticity	18	p8_zaf	850 hpa vorticity
6	p_thaf	surface wind direction	19	p850af	850 hpa geopotential height
7	p_zhaf	surface divergent	20	p8thaf	850hpa wind direction
8	p5_faf	500hpa airflow strength	21	p8zhaf	850hpa divergence
9	p5_uaf	500hpa zonal velocity	22	pr500af	Relative humidity at 500hpa
10	p5_vaf	500hpa meridional velocity	23	pr850af	Relative humidity at 850hpa
11	p5_zaf	500hpa vorticity	24	rhumaf	Near surface relative humidity
12	p500af	500hpa geopotential height	25	shumaf	Surface specific humidity
13	P5thaf	500hpa wind direction	26	tempaf	Mean temperature at 2 m

Source: Wilby & Dawson (2007)

The program includes work in six stages, starting from verifying the validity of the data through the Quality Control icon to the Summary Statistics, which is the last stage that summarizes the data, predicting statistically (Wilby & Dawson, 2007). The are the stages in the following order: 1-Data Quality Control; 2-Screen variables; 3-Calibrate Model; 4-Weather Generation; 5-Scenario Generation; 6-Summary Statistics.

In the quality control stage, the daily data of the maximum temperature rates were verified, and they matched with the numerical values for the base period 1961 -1990 representing 10957 days, and the missing and incomplete values were checked and processed, as well as the outliers were adjusted. In the second stage, the strength of the prediction variables is examined, such as the height at sea level and the atmospheric pressure values, which differ in terms of place and time, and in which the value of the correlation between the maximum temperature in Zuwara and the twenty-six variables mentioned in Table 1 is identified. Eight out of 26 variables are closely related to the simulation of the maximum temperature of Zuwara station (Table 2). The relationship between the average temperature at a height of 2 meters above ground level and the maximum temperature of Zuwara station represented the highest correlation value of 0.779 (Figure 3).

Table 2. Eight variables of the GCM model that are related to the maximum temperature in the Zuwara region

Ranking	Code	N	R-NCCCSM
26	tempaf	Mean temperature at 2 meters	0.779
12	p500af	hpa geopotential height500	0.726
25	shumaf	Surface specific humidity	0.522
4	p_vaf	Surface meridional velocity	0.468
19	p850af	hpa geopotential850	0.352
17	p8_vaf	hpa meridional velocity850	0.208
6	p_thaf	surface wind direction	0.151
13	P5thaf	hpa wind direction500	0.120

Source: Researchers' work based on SDSM4.2.9.

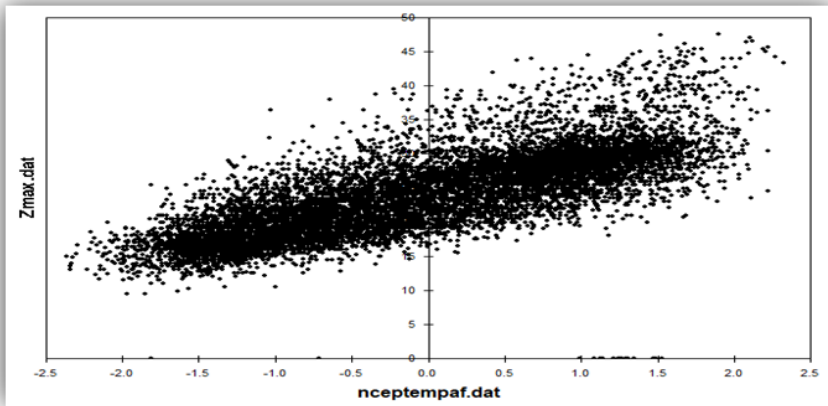


Fig. 3. Correlation between the maximum temperature of Zuwara with variable number 26 (Researchers' work based on SDSM4.2.9.)

Before starting to model the future maximum temperature for the study periods 2019-2045, 2046-2072 and 2073-2099 for the Zuwara station, in the third stage, the simulation model was calibrated with the comparison of the observed Zuwara station data during the period 1991-2010. The statement of the National Centre of Meteorology with the result of the modelling process by SDSM technology for the same period, as it was clear that the data recorded during the months of April, May, June and December matched. This is evidence of the accuracy of the modelling, even if it was identical in only four months, while the reason for the mismatch in the rest of the months is due to the inaccuracy of the measurement or the lack of data recording in the remaining months by the observers at the station and its dependence on personal estimates (see Figure 4).

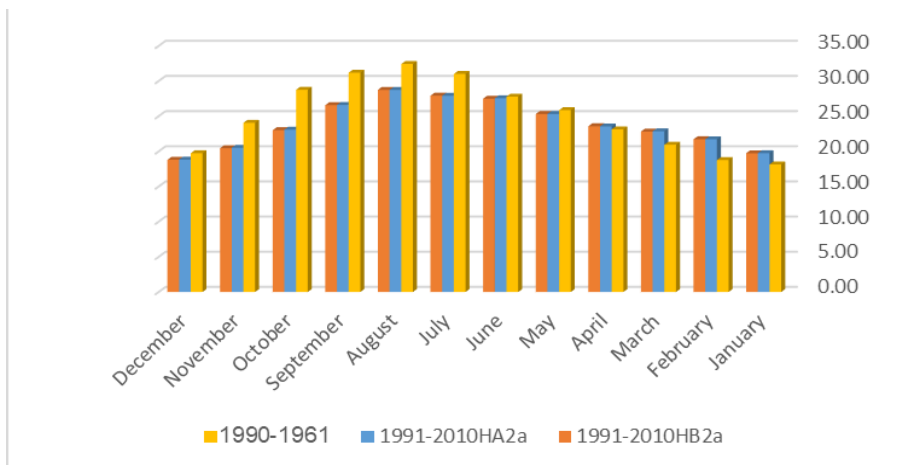


Fig. 4. Calibration of the model for temperature at Zuwara station for the period (1991-2010) (Researchers' work based on meteorological data and SDSM4.2.9.)

Change in maximum temperature in Zuwara region during the period (1961-2099)

The change in the monthly and annual maximum temperatures according to the H3A2a scenario

The results of Table 3 show a comparison of the average maximum temperature for the base period (1961-1990) with the maximum temperature during the modelling periods that extend between 2019-2099 depending on the H3A2a scenario. It is noted that there is no clear change in the annual average of the maximum temperature in Zuwara station during the first modelling period (2019-2045), which is estimated at 24.01°C, with a difference of -0.02°C from the base period. Still, it will rise in the second period (2046-2072) at a rate of 1.22°C with an estimated increase of about 5% compared to the base period, recording an annual rate of 25.25°C, and in the third period (2073-2099) the maximum temperature will reach 24.95°C with an estimated increase of approximately one degree Celsius its average in the base period.

Table 3. Projections of the monthly and annual maximum temperature in Zuwara station according to the H3A2a scenario

Month	1960-1990	2019-2045		2046-2072		2073-2099	
	Monthly Average	Monthly Average	Change amount	Monthly Average	Change amount	Monthly Average	Change amount
January	17.68	20.74	3.06	25.75	8.07	19.56	1.88
February	18.44	23.03	4.59	25.00	6.56	20.37	1.93
March	19.92	23.87	3.95	22.62	2.70	21.41	1.49
April	22.23	23.85	1.62	20.40	-1.83	22.81	0.58
May	24.76	25.21	0.45	21.04	-3.72	25.05	0.29
June	27.27	26.54	-0.73	20.98	-6.29	27.45	0.18
July	29.70	26.89	-2.81	24.48	-5.22	28.78	-0.92
August	30.97	28.08	-2.89	27.95	-3.02	30.21	-0.76
September	29.83	26.01	-3.82	28.38	-1.45	29.77	-0.06
October	26.98	22.77	-4.21	28.75	1.77	28.32	1.34
November	23.08	21.25	-1.83	30.23	7.15	24.49	1.41
December	19.22	19.84	0.62	27.32	8.10	20.92	1.70
Average	24.03	24.01	-0.02	25.25	1.22	24.95	0.92

Source: Researchers' work based on SDSM4.2.9.

The modelling results show that the increase in the monthly average maximum temperature will be greater in January and December during the period 2046-2072, which will be more than 8°C and an increase of more than 45% over its rates in the base period, which will reach 25.75°C and 27.32°C, respectively. During the same period, as well as in the month of December, where the modelling results indicate that it will witness an increase in its rate by more than 7°C and an increase of approximately 31%, which is also evident in the average month of February, which will record an increase of more than 2.3°C and an increase of 35.5%. While the monthly averages of maximum temperature in the period 2046-2072 will take a downward trend from April to September, and the largest decrease in these rates was in June and July, which is expected to exceed 5°C compared to their rates in the base period.

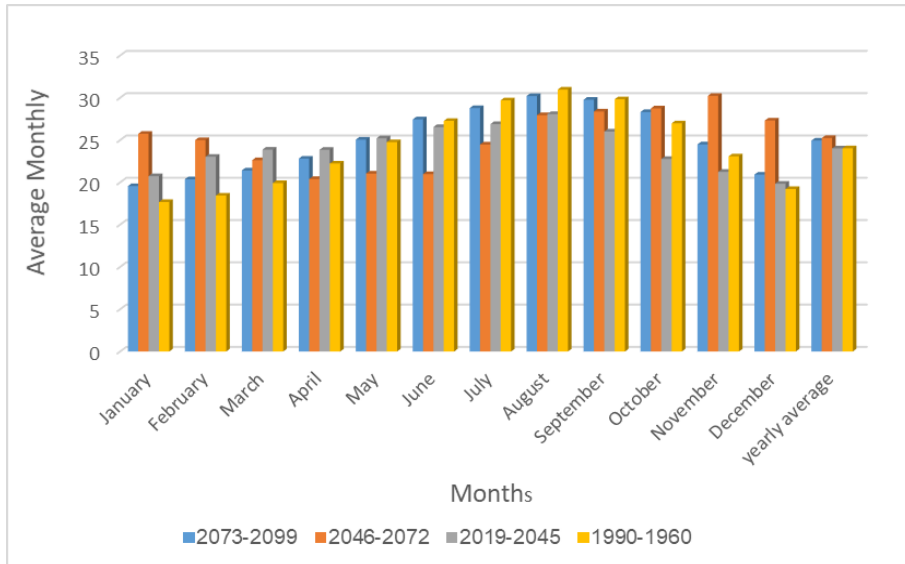


Fig. 5. Maximum temperature averages at Zuwara station for the three modelling periods according to the H3A2a scenario (Researchers' work based on SDSM4.2.9.)

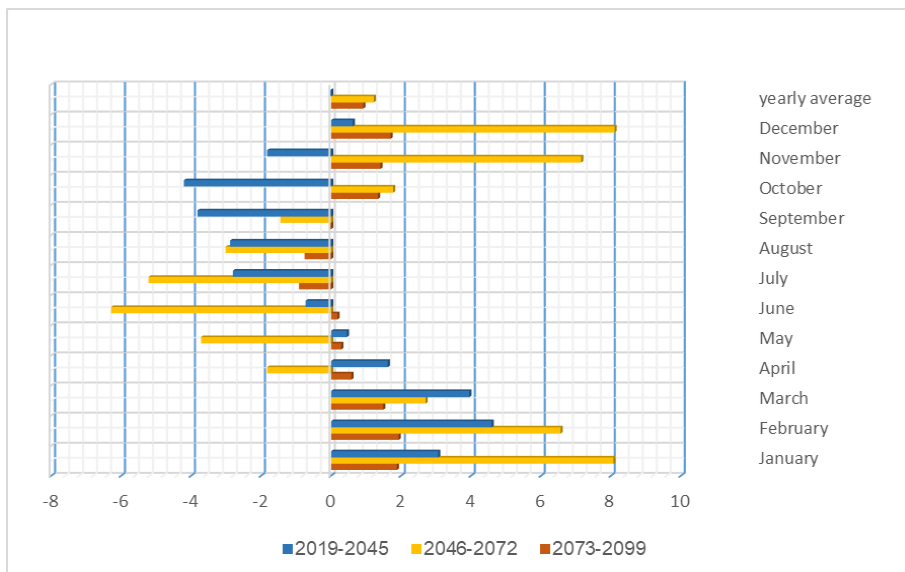


Fig. 6. Trends of change in the monthly average maximum temperature at Zuwara Station in the modelling periods according to the H3A2a scenario (Researchers' work based on SDSM4.2.9.)

It is also noted from Figure 6 that the Zuwara station will witness a rise in temperature during the period (2073-2099), as most of the monthly maximum temperatures during the H3A2a scenario take a general trend to rise in most months of the year except for the months of July, August and September compared to the base period. By an amount ranging between 0.18°C in June and 1.93°C in February, and the change will reach its

maximum in January and February, with an increase of more than 10%, and with a monthly average of maximum temperature of 19.56°C and 20.37°C, respectively.

The change in maximum seasonal temperatures according to the scenario H3B2a

The results of Table 4 proved that there was an increase in the average maximum temperature in winter during the first modelling period (2019-2045) at a rate of 8°C, and in the second period (2046-2099) and the third (2073-2099), at a rate of 3°C, compared to base period (1961-1990).

Table 4. Projections of the monthly and annual maximum temperature in Zuwara station according to the H3B2a scenario

Month	1960-1990	2019-2045		2046-2072		2073-2099	
	Monthly Average	Monthly Average	Change amount	Monthly Average	Change amount	Monthly Average	Change amount
January	17.68	20.71	3.03	25.44	7.76	19.80	2.12
February	18.44	23.01	4.57	24.79	6.35	20.50	2.06
March	19.92	23.84	3.92	22.54	2.62	21.14	1.22
April	22.23	23.86	1.63	20.12	-2.11	22.20	-0.03
May	24.76	25.26	0.50	21.34	-3.42	24.89	0.13
June	27.27	26.63	-0.64	21.36	-5.91	27.05	-0.22
July	29.70	26.85	-2.85	24.66	-5.04	29.06	-0.64
August	30.97	28.08	-2.89	27.99	-2.98	30.52	-0.45
September	29.83	26.00	-3.83	28.63	-1.20	30.14	0.31
October	26.98	22.79	-4.19	28.93	1.95	28.31	1.33
November	23.08	21.22	-1.86	30.20	7.12	24.44	1.36
December	19.22	19.85	0.63	27.77	8.55	21.81	2.59
Average	24.03	24.01	-0.02	25.32	1.29	25.01	0.98

Source: Researchers' work based on SDSM4.2.9.

Figure 7 indicates the results of modelling the change in the monthly average maximum temperature in the Zuwara region according to the H3B2a scenario and the trends of change in these rates during the modelling periods compared to the base period (1961-1990) (see Figure 8). In the first modelling period (2019-2045), it is noted that the maximum temperature will rise in some months of the year above its rates in the base period by more than 4.5°C, in February, which will reach 23°C, with an increase of more than 24%, followed by the month of March with an increase of 3.9°C, with an increase of nearly 20%. Still, the modelling results show that it will take a different direction. Therefore, during the period from June to November, with a maximum in October, the amount of change will be -4.2°C, with a change rate of 18.4% compared to its average during the period 1961-1990.

For the second period (2046-2072), the scenario H3B2a indicates that the amount of change in the monthly rates of maximum temperature will be more pronounced, whether towards increase or decrease compared to the rest of the periods. The amount of increase will exceed 8.5°C in December, with a change rate of 44 % compared to its rates in the base period, which can also be observed in the months of January, February and November, with an increase in the monthly averages of maximum temperature that ranged between 6.35°C and 7.76°C during the mentioned months. As for the change towards a de-

crease, it is evident in the rates of the months of June and July, which in the last month is close to 6°C as it was in the period 1961-1990.

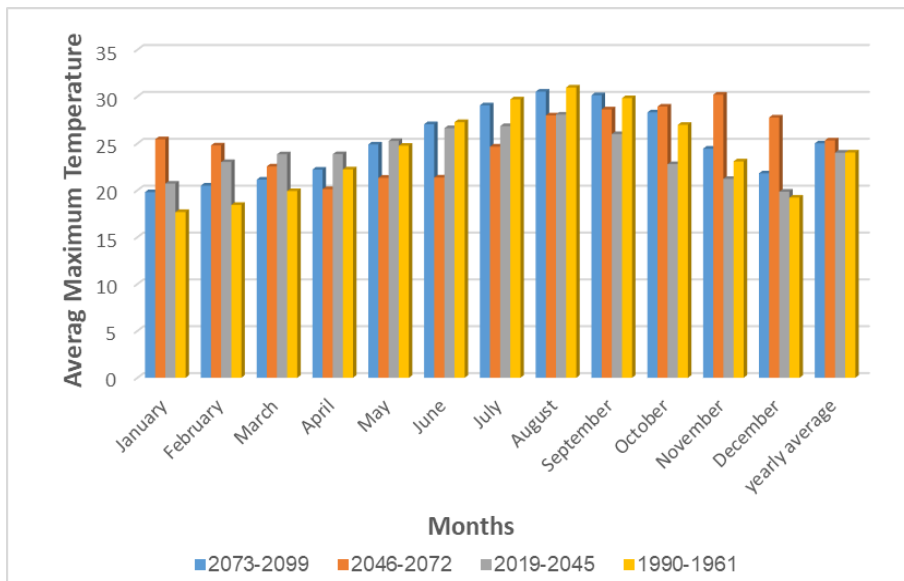


Fig. 7. Maximum temperature projections for the four periods according to the H3B2a scenario (Researchers' work based on SDSM4.2.9.)

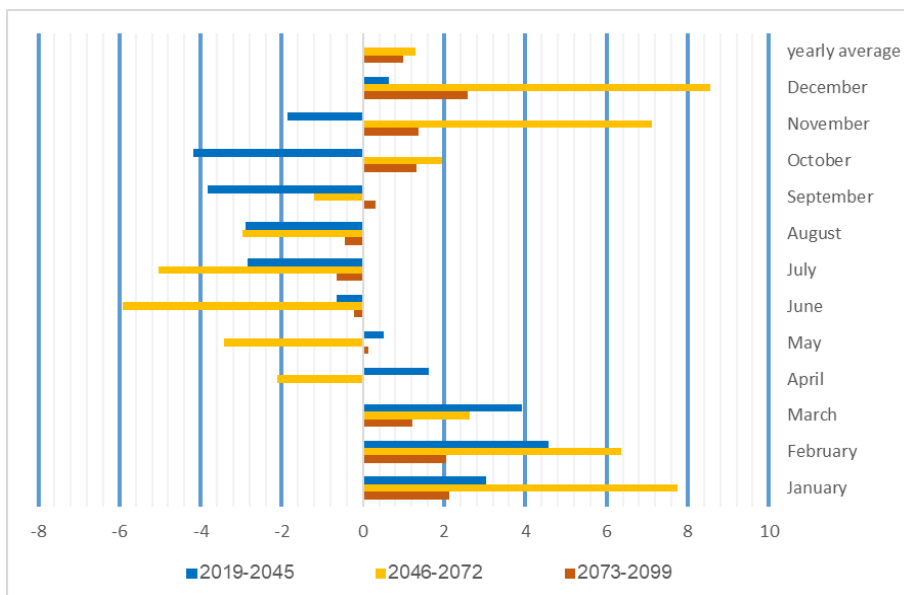


Fig. 8. Trends of change in monthly rates in the modeling periods according to the H3B2a scenario (Researchers' work based on SDSM4.2.9.)

For the third period (2073-2099), the results of maximum temperature modelling according to the scenario H3B2a for Zuwara station indicate that the change will be less

than the previous period, according to the trend assumed by this scenario towards reducing the rate of emissions and heading towards environmental, economic and social sustainability, which will have an impact on the rates of change in temperatures. Temperature, where the amount of increase will range between 2.5°C for the average month of December and 0.13°C for the average month of May, while the amount of decrease will range between 0.03°C for the month of April and 0.64°C for the month of July compared to its rates in the base period.

The change in maximum seasonal temperatures according to the scenario H3A2a, H3B2a

The results of Table 5 proved that there was an increase in the average maximum temperature in winter during the first modelling period (2019-2045) at a rate of 8°C, and in the second period (2046-2099) and the third (2073-2099), at a rate of 3°C, compared to base period (1961-1990).

Table 5. Projections of the seasonal maximum tractor degree according to the H3A2a/H3B2a scenario

Season	1960-1990	2019-2045		2046-2072		2073-2099	
		A2a	B2a	A2a	B2a	A2a	B2a
Winter	18.44	21.15	21.13	26.05	26.04	20.28	20.71
Spring	22.31	24.32	24.32	21.37	21.35	23.09	22.75
Summer	29.32	27.18	27.19	24.50	24.71	28.83	28.90
Autumn	26.63	23.34	23.33	29.12	29.25	27.54	27.64

Source: Researchers' work based on SDSM4.2.9.

As for the spring season, the results indicated that the seasonal average maximum temperature rise in Zuwara will reach about 2°C in the period (2019-2045). The results also indicated that the temperature in the summer tends to decrease from its average in the base period, so the rate of decrease in the first period was 2.14°C. In the second period at a rate of 5°C, and in the third period, the rate of decrease will be 0.5°C. In the fall, the average maximum temperature in the period 2019-2045 will decrease by about 3.3°C, then return to a rise in the period 2046-2072 compared to the base period at a rate of 2.5°C, and will rise in the period 2073-2099 at a rate of 1°C (see Figure 9).

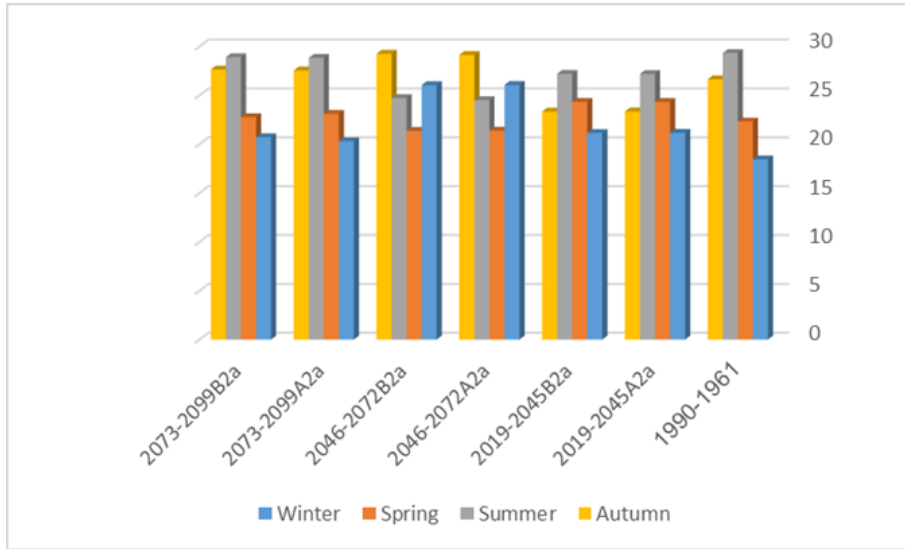


Fig. 9. Projections of the seasonal maximum degree of drag according to the H3A2a/H3B2a scenario (Researchers' work based on SDSM4.2.9.)

Conclusion

The maximum temperature in the Zuwara region is related to eight elements of the General Dura Model (GCM), and the surface temperature at 2 meters is correlated with the effect of the elements, as the correlation rate was 0.779.

The maximum temperature is constantly rising during the three modelling periods compared to the base period. This is consistent with all IPCC scenarios, and we find that the average monthly, seasonal and annual maximum temperature increase is consistent with A2a - B2A scenarios. Which warns of the inability of the world's countries to control and reduce emissions of greenhouse gases.

During the first modelling period (2019-2045) according to the H3A2a scenario, the annual maximum temperature in Zuwara station will witness an estimated average of 24.01°C, with a difference of -0.02°C from the base period. While it will rise in the second period (2046-2072) by 1.22°C, recording an annual rate of 25.25°C, while in the third period (2073-2099) the maximum temperature will reach 24.95°C, with an estimated increase of approximately one degree Celsius over its average in the base period (1961-1990).

The results of modelling the maximum temperatures in the Zuwara station according to the H3B2a scenario indicate that its annual average will take an upward trend and will reach 25.32°C during the period 2046-2072 with an increase of 1.3°C over its annual average in the base period (1961-1990) of 24°C. This rate maintains its trend of increasing by about one degree Celsius during the period (2073-2099).

The modelling results showed that the increase in the monthly average maximum temperature according to the two scenarios H3A2a and H3B2a will be greater in the months of January, February, November and December during the period (2046-2072), which will be more than 6°C. While the monthly averages of maximum tem-

perature will take a downward trend in the same period from April to September, and the largest drop of these rates was in June and July, which exceeded 5°C compared to their rates in the base period.

The modelling results confirmed that there is a significant change in the winter season, during the two scenarios H3A2a and H3B2a towards an increase during the second period (2046-2072) compared to the base period at a rate of 8°C, and in the spring the increase will not exceed a rate of 2°C. As for the summer, the average maximum temperature in Zuwara will witness a decrease of 5°C in the second period, and the fall in the autumn season will reach about 3.3°C in the same period compared to the base period.

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Conflicts of Interest: The authors declare no conflict of interest.

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