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Forecasting long-term effects of climate change on urban weather comfortableness trend (case study: Quebec City, Canada)

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Abstract

In recent decades, the heat island effect due to rapid urbanization in major cities combined with the effects of the global climate warming has led to significant changes in the urban weather condition. The study of meteorological data and application in planning for residential and tourism centers is essential, and the climatic condition has a vital role in people's comfortability. This study aims to forecast the long-term effects of climate change on the comfortability of the Quebec City's climate, Canada. The second generation Canadian Earth System Model (CanESM2) was used under three Representative Concentration Pathway (RCP) scenarios including RCP2.6, RCP4.5 and RCP8.5 scenarios and by applying statistical downscaling model (SDSM) weather generator, minimum temperature (Tmin), maximum temperature (Tmax), average temperature (Tmean) variables and using the change factor method, relative humidity (RH) variable were projected for the periods 2027-2050 and 2057-2080. Then, using the projected variables and Mahani and Givoni indicators, the appropriate months for human physiological comfort were determined in the next two periods and compared with the baseline period (1982-2005). The results indicate that the city will be in a cold range in the autumn and winter in the following two periods at night and day. In addition, in April and September, it will be in comfort range at daytime with cold nights, and in June, July and August, it will be in comfort range at nighttime, with days in warm range.

Keywords: Climate Change, RCPs Scenarios, Comfortable Climate, Mahani, Quebec; Water resource management

1. INTRODUCTION

Human bioclimatic studies are the basis of urban, civil, residential, architecture and tourism planning. Comfortable climate is one of the most important factors affecting human life style and happiness (Durst, 1951). The variability of climatic components in a geographic context has different effects on of human health and comfort. Climate change, especially during the last century, is one of the current problems in human society and is a threat to the planet because of the action of human forces (Stocker et al., 1992). The advancement and industrialization of human societies over the last century ve intensified greenhouse gas concentrations and observed changes in the globe's climate. The symbol of these climate changes in changing the long-term value is meteorological variables. According to these major changes, it is not surprising that urban areas exhibit the most tangible signs of occurred changes and climatic adjustments (Targhi and Dessel, 2015). It is natural for human beings to provide themselves more comfortable to form human societies in appropriate environments. Climate change is one of the most important natural factors affecting human well-being and changing comfort conditions (Fanger, 1972). From the climatic perspective, four elements of temperature, humidity, wind, and radiation are involved in forming human comfort conditions (Tseliou et al., 2010). Among these elements, temperature and humidity have the greatest impact on human health and comfort, and therefore most human comfort models have been established on these two elements (Kunst et al., 1994). In this regard, many researchers around the world have done valuable research on hydrological parameters analysis and climate change, its variability and the projection of these changes in different periods of the future through data science and machine learning based models (Azari et al., 2021 ; Bonakdari et al., 2019a, 2019b ; Ebtehaj et al., 2019, 2020, 2021 ; Stajkowski et al., 2020, 2021 ; Soltani et al., 2021a, 2021b ; Zeynoddin et al., 2020, 2021). Hoswever, the social, economic and political views of climate change are being studied globally. Terjung (1986) defined climatic zones to determine the role of climate in human comfort based on temperature and wind speed. In 1971, Mahani introduced the Mahani table in which the comfort zone can be evaluated using averages (Joodaki and Tahmasbizadeh, 2018). Olgay (1973) scientifically proposed humidity and heat conditions concerning human needs and climatic design. Emmanuel (2005) examined the effect of land cover changes on thermal comfort in Columbuserilanka City and concluded that the trend of increased thermal comfort was due to land cover changes, especially buildings and roads. Bouden and Ghrab (2005) also studied thermal comfort in five Tunisian cities from two climatic zones. In their study, 200 people were questioned from their normal working and living conditions per month for a year and compared their results with thermal comfort indices. The results of their study showed a significant relationship between the declared thermal comfort conditions and the thermal comfort indices. Toy et al. (2007) studied the bioclimatic comfort in Erzurum in three urban, rural and forest-urban areas of Turkey and concluded that forest-urban areas are more compatible with the thermal comfort index used. Deb and Ramachandriah (2010) studied thermal comfort at the Indian Railway Terminal and stated that one of the most important aspects of passenger satisfaction in these locations is the existence of an acceptable heat environment. Hence, using the PET index, measured passenger satisfaction at the south Indian station in June. Cheng et al. (2012) studied the thermal comfort of Hong Kong using physiologically equivalent temperature indices and the mean of the observations obtained from the questionnaire. In this study, they investigated the effect of changing wind conditions and solar radiation on people's temperature sensation in the region. The results were presented as mathematical relationships to investigate these factors. Yahia et al. (2013) compared the results of different thermal indices in urban environments and in the warm and dry air of the Syrian city, which estimated the climatic comfort value due to the high and low thresholds of each of the indices. Fang and Yin (2015), studying the tourism climate index in China, found that the number of good months for tourism across China varied from zero (Tibetan Plateau region) to 15 (Yunnan province) per year. Mihăilă and Bistricean (2018) used the Tourism Climate Index (TCI) to study the role of climate in tourism in the Moldavan region of Romania. Their research results showed that September was the best time to develop tourism services in the study area. In addition, considering that their research was one of the first researches on the impact of climate on tourism in the region, they suggested that this research in the Moldovan region be used in tourism planning. Recent studies have also examined the effect of climate change on various variables such as precipitation (Alexanderand Arblaster, 2017; Ishida et al., 2017), temperature (Mathukumalli et al., 2016), runoff (Su et al., 2016), evaporation and transpiration (Peng et al., 2017). Therefore, the purpose of this study is to investigate the effect of climate change on the comfortable climate of Quebec, Canada, using the CMIP5 series model under RCPs scenarios, which the proposed methodology is presented in Fig.1.

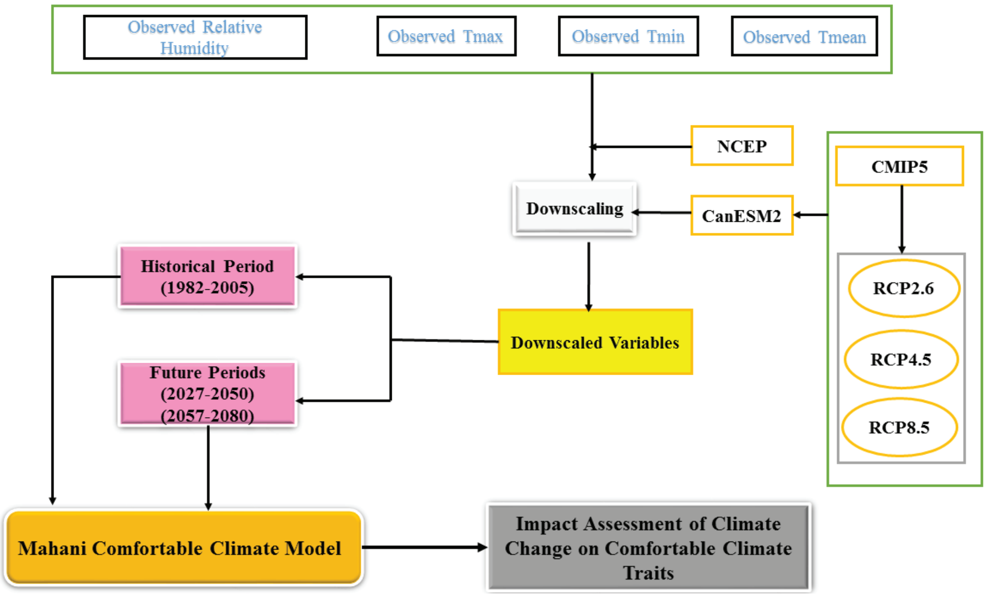


Figure 1. Flowchart of the proposed methodology

2. MATERIALS AND METHOD

2.1. Study Area

Quebec City, the capital of the province of Quebec, Canada, and the largest city in eastern Quebec, with an area of approximately 484 square kilometers, is located at 46 degrees 49 minutes north latitude and 71 degrees 13 minutes west longitude. The sea level is 98 meters from the banks of the St. Lawrence River, one of the largest rivers in Canada. Figure 2 shows the location of the study area across Canada and Quebec.

In this study to investigate the impact of climate change on the comfortable climate of Quebec City, daily meteorological data (1982-2005) were collected from the National Aeronautics and Space Administration (NASA) (https://power.larc.nasa.gov) including Tmin, Tmax and Tmean (2 m above the surface of the earth, in _C), RH (at 2 m high, in %).

Figure 2. The geographical location of Quebec City in Canada and Quebec Province

2.2. Methods

The outputs of AOGCM models require different downscaling techniques. In this study, the SDSM model for temperature variable was used to generate daily and downscaled climatic data, and change factor method was used for the relative humidity variable that models such as LARS-WG and SDSM are not capable of downscaling. Then climatic data for the next two periods (2027-2050 and 2057-2080) were generated using CanESM2 model under RCP2.6, RCP4.5 and RCP8.5 scenarios and then using projected climate variables, the comfortable climate of the city of Quebec was studied during the periods above.

2.3. SDSM downscaling model

Wilby et al. (2002) first proposed this model to downscaling the temperature and precipitation data using statistical methods. In this study, version 5.1 was used to downscaling the studied variables. The basis of this model is a combination of regression models and the random generator of climatic data (Wilby and Dawson, 2007). A period is used as the baseline or current climate condition in climate studies. Station observation data and National Center for Environmental Prediction (NCEP) data will also be used to calibrate and validate the model. One of the most critical steps of the downscaling model is the selection of observational predictive variables. Selection of variables that are reasonably well suited to the selected climatic variables. NCEP variables include 26 atmospheric variables and selection of the most appropriate NCEP variable is based on the highest correlation coefficient and the lowest value of PR index. In this study, the SDSM model was used to calculate the correlation coefficient and the following equation was used to calculate the PR index:

$$PR = \frac{R_a - R_p}{R_a} \qquad [1]$$

This equationThis equation is the absolute correlation coefficient and the partial correlation coefficient. After certifying and evaluating the model's ability to simulate climate variables in the base period in the study area, the climate variables based on CanESM2 output under the new RCPs scenarios that the Intergovernmental Panel on Climate Change (IPCC) compiled in its Fifth Assessment Report (AR5) used to represent the different concentrations of greenhouse gases is projected. The CanESM2 general circulation model is the fourth generation of climatic models developed by the Canadian Center for Modeling and Analysis (cccma) under the Environmental Protection Agency (EPA). In this model, the entire surface of the Earth is mapped to 128*64 cells, with the dimension of 2.7906 ° latitude and 2.8128 ° longitude (Chaumont, 2014).

2.4. Change factor downscaling method

The SDSM model is unable to generate daily RH data. Hence, RH changes in future periods should be obtained to assess comfortable climate. Therefore, in this study, the change factor method was used to downscale the RH data. In this method, to calculate the climate change scenario in the CanESM2 model, the values of the difference for RH (equation 2) between the 24-year averages in future periods (2027-2050 and 2057-2080) and the base period (1982-2005) by the same model for each cell is computed from the computational network (Wilby & Harris, 2006). These values represent the 24-year average of climate change compared to the baseline period.

$$\Delta RH_i = (\overline{RH}AOGCM, fut_i - \overline{RH}AOGCM, base_i) \qquad [2]$$

where ΔRH_i represent the climate change scenario of RH for the long-term 24-year average for each month ($1 \leq i \leq 12$), $\overline{RHAOGCM}, fut_i$ the 24-year average RH projected by the CanESM2 model for the next period, and

$\overline{RH}AOGCM, base_i$ the 24-year average RH simulated by the model in the same period with the observation period for each month. Climate change scenarios are added to the observed values in the change factor method to obtain future climate scenario time series (1982-2005).

$$RH = RH_{obs} + \Delta RH_i \qquad [3]$$

where RH_{obs} represents the observed RH time series (daily) in the base period, the RH time series derived from the RH climate scenario in future periods (2027-2050) and (2057-2080) and ΔRH is the downscaled climate change scenario.

2.5. Mahani Comfortable Climate Model

Mahani et al. (1970) proposed a method in which human comfort was taken into account. The Mahani table (Table 1) first determines the comfort zone according to the annual Tmean of the study area and the RH average of each month (United Nation, 1976). The method is to compare the monthly Tmean and the RH of the month with the table values to determine what temperature range is considering. Now, to check the day temperature, the Tmax of one month with the table values are compared, if this value is higher than the table values, it is in the warm range and if lower than the values, it is in the cold range and between these values is in the comfort zone and to evaluate the thermal state of the night, the Tmin was used for comparison.

Table 1. Mahani table for day and night comfort zone

Climate Group	Average relative humidity (%)	Average annual temperature					
		More than 20		15 to 20		Less than 15	
		day	night	day	night	day	night
1	0-30	34	25	32	23	30	21
		26	17	23	14	21	12
2	30-50	31	24	30	22	27	20
		25	17	22	14	20	12
3	50-70	29	23	28	21	26	19
		23	17	21	14	19	12
4	70-100	27	21	25	20	24	18
		22	17	20	14	18	12

3. RESULTS AND DISCUSSIONS

3.1. Selection of independent variables to simulate and calibrate the SDSM model

In transfer function models such as the SDSM model, before calibrating the model, it is necessary to determine the climatic variables that have the highest correlation with the desired variables. In the present study, first, using the significant variables of the NCEP and SDSM software, the selected predictors of the required climatic variables were investigated. For this purpose, among the 26 NCEP large scale variables, the final large scale variables were chosen for the climatic variables that the results of the last selected predictors are presented in Table 2.

Table 2. Selection of predictor variables to simulate local temperature variables at the Station

Variable	Selected Predictors	Absolute Correlation	Correlation Partial	PR	P-value
Tmean	Surface temperature at a height of 2 meters (Nceptempgl.dat)	0.863	0.501	0.42	0.00
	Surface specific humidity (Ncepshumgl.dat)	0.813	0.057	0.92	0.00
Tmax	Surface temperature at a height of 2 meters (Nceptempgl.dat)	0.856	0.509	0.40	0.00
	Surface specific humidity (Ncepshumgl.dat)	0.80	0.023	0.97	0.051
Tmin	Surface temperature at a height of 2 meters (Nceptempgl.dat)	0.856	0.481	0.43	0.00
	Surface specific humidity (Ncepshumgl.dat)	0.809	0.069	0.91	0.00

3.2. Results of radiative forcing scenarios in future periods

The average results of temperature and relative humidity changes under the three scenarios RCP2.6, RCP4.5, and RCP8.5 are listed in Table 3. The RH changes relative to the base period are given in terms of percentage and changes in Tmean, Tmax and Tmin in degrees Celsius.

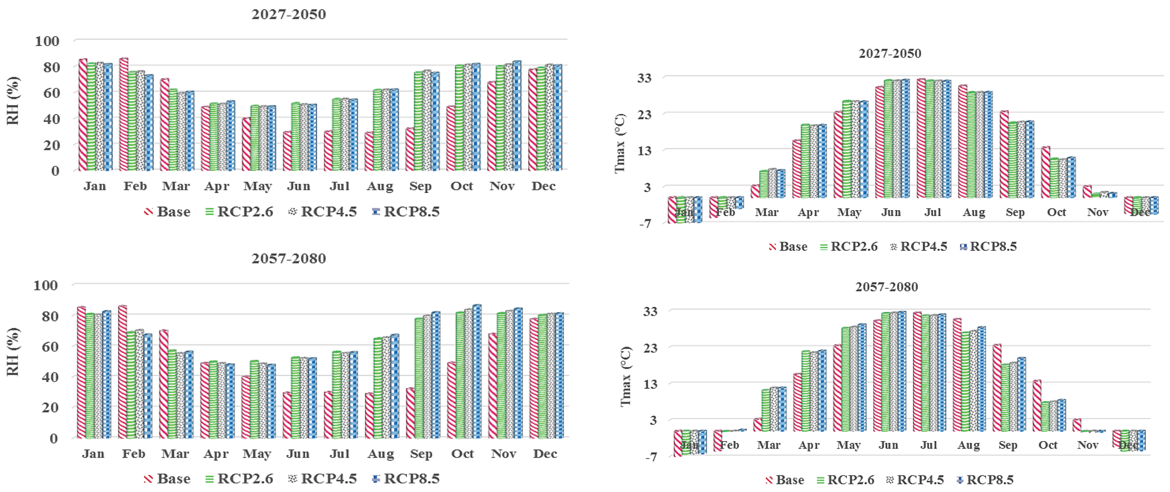
Table 3. Mean change of variables studied in future periods compared to baseline

	Scenario		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2027-2050	RCP2.6	$\Delta\overline{RH}(\%)$	-3.05	-10.4	-7.93	2.54	9.57	22.11	24.87	32.72	43.12	31.62	12.24	1.38
		$\Delta\overline{T}_{max}(^{\circ}C)$	0.48	2.23	3.52	4.01	2.75	1.6	-0.31	-1.59	-2.88	-2.8	-1.81	-0.12
		$\Delta\overline{T}_{min}(^{\circ}C)$	0.13	1.96	2.37	3.92	2.68	1.92	0.03	-1.55	-2.35	-2.02	-1.46	-0.12
	RCP4.5	$\Delta\overline{RH}(\%)$	-2.55	-9.73	-10.57	2.25	9.24	21.32	25.15	33.14	44.45	32.13	13.61	3.62
		$\Delta\overline{T}_{max}(^{\circ}C)$	0.5	2.35	4.07	3.8	2.69	1.54	-0.34	-1.55	-2.66	-2.97	-1.31	-0.06
		$\Delta\overline{T}_{min}(^{\circ}C)$	0.23	2.1	2.7	3.67	2.59	1.9	0.02	-1.52	-2.19	-2.05	-1.08	-0.04
	RCP8.5	$\Delta\overline{RH}(\%)$	-3.43	-12.76	-9.53	4.25	9.22	20.99	24.49	33.24	42.83	32.82	15.91	3.25
		$\Delta\overline{T}_{max}(^{\circ}C)$	0.51	2.31	3.77	3.92	2.6	1.71	-0.37	-1.53	-2.57	-2.52	-1.58	-0.1
		$\Delta\overline{T}_{min}(^{\circ}C)$	0.17	2.06	2.52	3.78	2.54	2.01	0.00	-1.5	-2.07	-1.66	-1.37	-0.05
2057-2080	RCP2.6	$\Delta\overline{RH}(\%)$	-4.31	-16.8	-13	0.93	10.13	23.03	26.33	35.93	45.59	32.66	13.46	2.65
		$\Delta\overline{T}_{max}(^{\circ}C)$	1	5.1	7.52	5.88	4.52	1.76	-0.71	-3.45	-5.25	-5.6	-3.15	-1.03
		$\Delta\overline{T}_{min}(^{\circ}C)$	0.2	4.26	5.29	5.66	4.53	2.57	-0.52	-3.45	-4.35	-3.65	-2.65	-1.1
	RCP4.5	$\Delta\overline{RH}(\%)$	-4.65	-15.58	-14.72	-0.1	8.47	22.66	25.5	36.66	47.53	34.68	14.93	3.34
		$\Delta\overline{T}_{max}(^{\circ}C)$	1.01	5.3	8.14	5.61	4.83	1.88	-0.65	-3.05	-4.74	-5.37	-3.17	-1.01
		$\Delta\overline{T}_{min}(^{\circ}C)$	0.29	4.46	5.92	5.32	4.76	2.82	-0.44	-3.11	-3.9	-3.62	-2.67	-1.07
	RCP8.5	$\Delta\overline{RH}(\%)$	-2.59	-18.46	-13.74	-0.91	7.68	22.47	26.03	38.26	49.72	37.43	16.46	3.7
		$\Delta\overline{T}_{max}(^{\circ}C)$	1.11	5.61	8.16	6.05	5.51	2.1	-0.44	-2.02	-3.42	-4.96	-3.09	-0.93
		$\Delta\overline{T}_{min}(^{\circ}C)$	0.37	4.68	5.92	5.84	5.51	3.25	-0.05	-2.18	-2.58	-3.23	-2.57	-0.91

According to Table 3 and Fig. 3a, RH will decrease in the first and second periods and under all three scenarios in January, February, and March. Also, in April's second period under the RCP4.5 and RCP8.5 scenarios, the RH will decrease. In the first and second periods, the highest RH decrease in February under the RCP8.5 scenario will be 12.76% and 18.46%, respectively. According to Table 3, RH will increase in the rest of the year, with the highest increase in the first and second periods under all three scenarios for September. The maximum increase under the RCP8.5 scenario will be 49.72% in the second period.

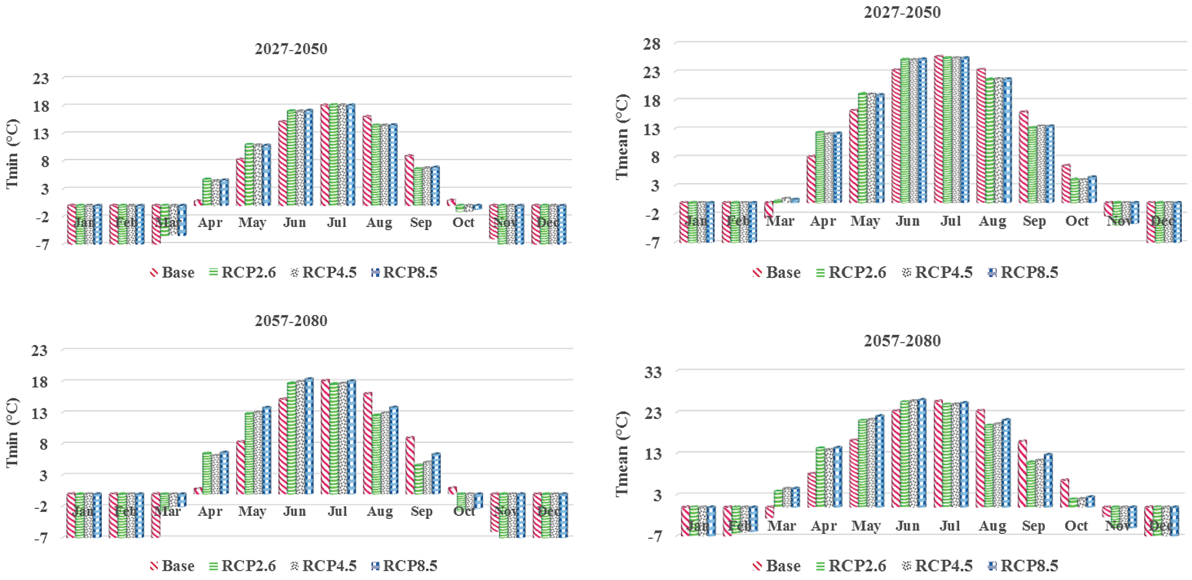
In addition, according to Table 3 and Fig. 3b, it is observed that in the first and second periods, under all three scenarios, the Tmax will rise in the first six months of the year and decrease in the second six months of the year. The maximum of this increase will be in March in the second period under the RCP8.5 scenario, which is 8.18 °C. Moreover, the maximum decrease in this variable will be in October in the second period under the RCP2.6 scenario, equal to 5.60 °C.

According to Table 3 and Fig. 4a, it is observed that in the first and second periods, under all three scenarios, the Tmin will rise in the first six months of the year and decrease in the second six months of the year. The maximum increase will be 5.92°C in March for the second period under the RCP8.5 and RCP4.5 scenario. The maximum decrease for this variable will be 4.35 °C in September and in the second period under the RCP2.6 scenario. In addition, according to Table 3 and Fig .4b, the average annual temperature in the first period will increase by 0.52°C compared to the base period and will increase by 0.84 °C in the second period.



a) b)

Figure 3. Relative humidity and Tmax changes changes in future periods compared to baseline under RCPs scenarios



a) b)

Figure 4. Tmin changes and Mean temperature in future periods compared to baseline under RCPs scenarios

3.3. Comfortable climate results of Quebec City by Mahani method

According to Table 4, it can be seen that the city of Quebec is in the climate group 4 (70-100% humidity) from December to March, and except in November, it is in the climate group 3 (50-70% relative humidity). The rest of the year is in climatic group 2 (30 – 50 %). The table also shows the values of all three climatic factors as well as the comfort of day and night according to these values.

Table 4. Comfortable range for different months using Mahani modle in the base period (1982-2005)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	c
$\overline{RH}(\%)$	85.23	85.95	70.06	48.92	40.05	29.49	29.94	29.01	32.27	49.13	67.95	77.64
$\overline{T}\,°_{max}$	-7.36	-5.34	3.67	15.89	23.65	30.47	32.31	30.38	23.36	13.38	2.75	-4.48
Upper limit of comfort at day	24	24	26	27	27	30	30	30	27	27	26	24
Lower limit of comfort at day	18	18	19	20	20	21	21	21	20	20	19	18
$\overline{T}\,°_{min}$	-15.7	-15.7	-7.97	0.82	8.33	15.16	18.14	16.05	8.97	0.95	-6.04	-12.4
Upper limit of comfort at night	18	18	19	20	20	21	21	21	20	20	19	18
Lower limit of comfort at night	12	12	12	12	12	12	12	12	12	12	12	12

According to Table 5, it is observed that Quebec City under all three scenarios in December, January, and February in climatic group 4 (70-100% humidity) in periods (2027-2050) and is similar to the baseline period. Also in May, under all three scenarios will be in climate group 2 (relative humidity 30-50) and identical to the baseline. In March from climate group 4 to 3, April from climate group 2 to 3, June, July and August from climate group1 to 3, September and October from climate group 2 to 4 and November from climate 3 to 4 under all three scenarios will change from baseline. The table also shows the values of all three-climate factors as well as the day and night comfort levels.

Table 5. Comfortable range for different months using Mahani comfortable table in 2027-2050

Scenario		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RCP2.6	$\overline{RH}(\%)$	82.18	75.55	62.13	51.46	49.62	51.60	54.81	61.73	75.39	80.75	80.19	79.02
	$\overline{T}\circ_{max}$	-6.88	-3.11	7.19	19.90	26.40	32.07	32.00	28.79	20.48	10.58	0.94	-4.60
	Upper limit of comfort at day	24	24	26	26	27	26	26	26	24	24	24	24
	Lower limit of comfort at day	18	18	19	19	20	19	19	19	18	18	18	18
	$\overline{T}\circ_{min}$	-15.63	-13.81	-5.60	4.74	11.01	17.08	18.17	14.50	6.62	-1.07	-7.50	-12.56
	Upper limit of comfort at day	18	18	19	19	20	19	19	19	18	18	18	18
	Lower limit of comfort at night	12	12	12	12	12	12	12	12	12	12	12	12
RCP4.5	$\overline{RH}(\%)$	82.68	76.22	59.49	51.17	49.29	50.81	55.09	62.15	76.72	81.26	81.56	81.26
	$\overline{T}\circ_{max}$	-6.86	-2.99	7.74	19.69	26.34	32.01	31.97	28.83	20.70	10.41	1.44	-4.54
	Upper limit of comfort at day	24	24	26	26	27	26	26	26	24	24	24	24
	Lower limit of comfort at day	18	18	19	19	20	19	19	19	18	18	18	18
	$\overline{T}\circ_{min}$	-15.53	-13.67	-5.27	4.49	10.92	17.06	18.16	14.53	6.78	-1.10	-7.12	-12.48
	Upper limit of comfort at night	18	18	19	19	20	19	19	19	18	18	18	18
	Lower limit of comfort at night	12	12	12	12	12	12	12	12	12	12	12	12
RCP8.5	$\overline{RH}(\%)$	81.80	73.19	60.53	53.17	49.27	50.48	54.43	62.25	75.10	81.95	83.86	80.89
	$\overline{T}\circ_{max}$	-6.85	-3.03	7.44	19.81	26.25	32.18	31.94	28.85	20.79	10.86	1.17	-4.58
	Upper limit of comfort at day	24	24	26	26	27	26	26	26	24	24	24	24
	Lower limit of comfort at day	18	18	19	19	20	19	19	19	18	18	18	18
	$\overline{T}\circ_{min}$	-15.59	-13.71	-5.45	4.60	10.87	17.17	18.14	14.55	6.90	-0.71	-7.41	-12.49
	Upper limit of comfort at night	18	18	19	19	20	19	19	19	18	18	18	18
	LowerUpper limit of comfort at day	12	12	12	12	12	12	12	12	12	12	12	12

According to Table 6, it is observed that Quebec City at the period (2057-2080) under all three scenarios are in December and January in climatic group 4 (70-100% humidity) similar to baseline. In April, under all three scenarios, it will be in climate group 2 (relative humidity 30-50) and is similar to the baseline. In February, it will be under climate group 4 of the RCP4.5 scenario, similar to the baseline period, and under the other two scenarios in climate group 3. It will be in climate group 2 under RCP4.5 and RCP8.5 in May and is similar to the base period and under climate group 3 in RCP2.6. In March from climate groups, 4 to 3 and in June, July and August from climate groups 1 to 3, in September and October from climate groups 2 to 4 and in November from climate groups 3 to 4 under all three scenarios will change to the baseline. The table also shows the values of all three-climate factors as well as the day and night comfort levels.

Table 6. Comfortable range for different months using Mahani comfortable table in 2057-2080

Scenario		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RCP2.6	$\overline{RH}(\%)$	80.92	69.15	57.06	49.85	50.18	52.52	56.27	64.94	77.86	81.79	81.41	80.29
	$\overline{T}\circ_{max}$	-6.36	-0.24	11.19	21.77	28.17	32.23	31.60	26.93	18.11	7.78	-0.40	-5.51
	Upper limit of comfort at day	24	26	26	27	26	26	26	26	24	24	24	24
	Lower limit of comfort at day	18	19	19	20	19	19	19	19	18	18	18	18
	$\overline{T}\circ_{min}$	-15.56	-11.51	-2.68	6.48	12.86	17.73	17.62	12.60	4.62	-2.70	-8.69	-13.54
	Upper limit of comfort at night	18	19	19	20	19	19	19	19	18	18	18	18
	Lower limit of comfort at night	12	12	12	12	12	12	12	12	12	12	12	12
RCP4.5	$\overline{RH}(\%)$	80.58	70.37	55.34	48.82	48.52	52.15	55.44	65.67	79.80	83.81	82.88	80.98
	$\overline{T}\circ_{max}$	-6.35	-0.04	11.81	21.50	28.48	32.35	31.66	27.33	18.62	8.01	-0.42	-5.49
	Upper limit of comfort at day	24	24	26	27	27	26	26	26	24	24	24	24
	Lower limit of comfort at day	18	18	19	20	20	19	19	19	18	18	18	18
	$\overline{T}\circ_{min}$	-15.47	-11.31	-2.05	6.14	13.09	17.98	17.70	12.94	5.07	-2.67	-8.71	-13.51
	Upper limit of comfort at night	18	18	19	20	20	19	19	19	18	18	18	18
	Lower limit of comfort at night	12	12	12	12	12	12	12	12	12	12	12	12
RCP8.5	$\overline{RH}(\%)$	82.64	67.49	56.32	48.01	47.73	51.96	55.97	67.27	81.99	86.56	84.41	81.34
	$\overline{T}\circ_{max}$	-6.25	0.27	11.83	21.94	29.16	32.57	31.87	28.36	19.94	8.42	-0.34	-5.41
	Upper limit of comfort at day	24	26	26	27	27	26	26	26	24	24	24	24
	Lower limit of comfort at day	18	19	19	20	20	19	19	19	18	18	18	18
	$\overline{T}\circ_{min}$	-15.39	-11.09	-2.05	6.66	13.84	18.41	18.09	13.87	6.39	-2.28	-8.61	-13.35
	Upper limit of comfort at night	18	19	19	20	20	19	19	19	18	18	18	18
	Lower limit of comfort at night	12	12	12	12	12	12	12	12	12	12	12	12

3.4. Night comfortable climate in the basic and future Periods

In the study of the night comfortable climate, for the base period and the next two periods in Quebec, the following points were derived according to Table 7, that in the base period in the autumn, winter, and in April and May, the city is in cold range, and the spring and summer is in the comfortable zone. There has been no warm range for the city. This trend is the same for the first period under all three scenarios. In the second period in the autumn, winter and April, from the spring, city will be in the cold, and the summer will be in the comfortable zone. Moreover, in this period under all three scenarios from May to spring will be in the comfortable zone, which is due to an increase of 5.66 °C the Tmin under the RCP2.6 scenario, 5.32 °C the Tmin under the RCP4.5 scenario and 5.84 °C the Tmin under the RCP8.5 scenario in this month.

Table 7. Night thermal condition for different months of Quebec station using Mahani comfortable table in base period and two future periods

Period	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Base	--------	C	C	C	C	C	O	O	O	C	C	C	C
2027-2050	RCP2.6	C	C	C	C	C	O	O	O	C	C	C	C
	Rcp4.5	C	C	C	C	C	O	O	O	C	C	C	C
	RCP8.5	C	C	C	C	C	O	O	O	C	C	C	C
2057-2080	RCP2.6	C	C	C	C	O	O	O	O	C	C	C	C
	Rcp4.5	C	C	C	C	O	O	O	O	C	C	C	C
	RCP8.5	C	C	C	C	O	O	O	O	C	C	C	C

C= Cold, H= Hot, O= Comfort

3.5. Daily comfortable climate in base and future periods

In the study of daily comfortable climate conditions, for the base period and the two following periods in Quebec, according to Table 8, it was concluded that in the base period in spring and autumn and April from spring, the city was in cold range. The city is warm range in June, July and August and in May and September, the city was within comfortable range. Except for April, the rest of the months will have the same base period in the first period. April will transition from cold to comfortable under all three scenarios, resulting from an increase of 4.01 °C under the RCP2.6 scenario and 3.80 °C under the scenario. RCP4.5 and 3.92 °C are the Tmax under the RCP8.5 scenario in this month. Except for April and May, the rest of the months will have the same base period in the second period. April will transfer from the cold to the comfortable zone under all three scenarios. This change in range is due to the increase of 5.88 °C under RCP2.6 scenario, 5.61 °C under RCP4.5 scenario and 6.05 °C under RCP8.5 scenario in this month. May will switch from comfortable to warm in all three scenarios during this period, resulting in a 4.5 °C increase in the Tmax under the RCP2.6 scenario, a 4.83 ° Tmax under the scenario RCP4.5 and 5.51 °C the Tmax under the RCP8.5 scenario in this month.

Table 8. Day thermal condition for different months of Quebec Station using Mahani comfortable table in base period and two future periods

Period	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Base	--------	C	C	C	C	O	H	H	H	O	C	C	C
2027-2050	RCP2.6	C	C	C	O	O	H	H	H	O	C	C	C
	Rcp4.5	C	C	C	O	O	H	H	H	O	C	C	C
	RCP8.5	C	C	C	O	O	H	H	H	O	C	C	C
2057-2080	RCP2.6	C	C	C	O	H	H	H	H	O	C	C	C
	Rcp4.5	C	C	C	O	H	H	H	H	O	C	C	C
	RCP8.5	C	C	C	O	H	H	H	H	O	C	C	C

C= Cold, H= Hot, O= Comfort

4. CONCLUSIONS

Understanding the attractions and hidden potentials in the atmospheric, climatic, and geographic features at different seasons of the year are essential for considering them in different planning at the provincial and national scales, such as tourism development, under the convenience of human health (Tourists) are affected by the weather and climate. This study was conducted to investigate the effects of climate change on the comfortable climate of Quebec City. For this purpose, mean and maximum and minimum temperature data were downscaled using the SDSM model and relative humidity variable using the change factor method under RCPs scenarios for two future periods. The results showed that relative humidity would decrease in the first and second periods under all three scenarios in January, February and March and relative humidity will increase in the rest of the year. In addition, during the first and second periods, under all three scenarios, the maximum and minimum temperatures will increase in the first six months of the year and decrease in the second six months of the year. In addition, the average annual temperature in the first period will increase by 0.52 °C compared to the base period and in the second period, it will increase by 0.84 °C compared to the base period. A study of the city's comfortable climate indicates that the city will be in a cold range in the autumn and winter for the following two periods at night and day. Furthermore, in April and September, it will be in comfort range at daytime with cold nights and in June, July and August it will be in comfort range at nighttime with hot days.

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