



The effect of climate change on groundwater resources availability: a case study in the city of Brescia, northern Italy

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Abstract

The impact of climate change on water availability is alarming, both globally and locally. The city of Brescia has a large reserve of water deriving from the aquifer, the presence of springs and numerous streams, for a water supply system serving 200,000 inhabitants. The aim of this study was to project Brescia's spring discharge for two future periods 2040–2060 and 2080–2100. Observed climate components of precipitation and temperature for 20 years 2000–2020 with future data from regional climate model RCM runs on CORDEX database for three Representative Concentration Pathway RCP (RCP2.6, RCP4.5, RCP8.5) were analyzed. The future scenarios show an increment of temperature with an increment of winter's precipitation and a decrement for summer's precipitation. This future change in climate components will impact the water balance that impacts the runoff, evapotranspiration, and groundwater recharge. The two main springs of the city of Brescia are Mompiano and Cogozzo used to supply 50% of the water demand of the city in the past while it is occupied about 14% now. This drop was due to the growth of water needs, urbanization that affects the groundwater recharge and climate change. In the future, based on the study carried out, the results show a few impacts on water discharge from Mompiano and Cogozzo springs for the two periods and its clearer under RCP4.5 for period 2040–2060 that shows a decrease of about 7.8% and 3.94% respectively. This shows the importance of having a proper water resources management system to satisfy the water demand.

Keywords Brescia Springs · Water supply · Water management · Climate changes

Abbreviations

AET	Actual evapotranspiration	MOD	Modeling data
C_t	Coefficient of evapotranspiration	S_t	Moisture content
P_i	Corrective coefficient depending on the latitude	T_i	Monthly mean value of temperature
α	Degree day factor	NRC	National Research Council
EEA	European Environment Agency	OBS	Observed data
\emptyset	Fraction of infiltration	PET	Potential evapotranspiration
I	Heat Index	P	Precipitation
S_{if}	Maximum amount of saturation	P_t	Rainfall and actual snow melt
S_{max}	Maximum water content of the soil	RCM	Regional climate model
MAE	Mean absolute error	RCP	Representative concentration pathway
t_j	Mean monthly temperature	RMSD	Root Mean Square Deviation
		SWE	Snow water equivalent
		T	Temperature
		WFD	Water Framework Directive

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Introduction

Climate change has a direct impact on water consumption as well as on the water cycle and consequently groundwater and springs (NRC 2008). Humans' activities are impactful for climate change, because of the evidenced increase in the

concentration of the anthropogenic greenhouse gases which may lead to a global change in climate. Climate change is linked to the temperature, humidity, precipitation, and other climate characteristics that affect the water resources availability and water demand for different uses. Water resources are constantly renewed, but they are not available in unlimited quantities and cannot be reproduced or replaced. The main recourse to meet the needs of water is by using the surface water which can be indicated in lacks or artificial reservoirs, and the groundwater that goes to the earth through the porosity of the soil. The need for water is linked to various sectors: civil uses, to generate and support economic activities and agriculture, commercial fishing, energy production, the manufacturing industry, transport, and tourism (Kumar et al. 2016). Over the last century, world consumption of fresh water has increased by almost 10 times, and about 70% of water consumed on Earth is used for agricultural use, 20% for industrial uses and 10% for domestic uses (EEA 2003). In Italy the volume of total water withdrawn for civil use was 9.5 billion m³ which estimates a growth of 3.8% compared to the figure recorded in 2008 (Istat 2014). Given competing pressures, global water demand is estimated to exceed by 2030 the actual availability by forty percent (Water Resources Group 2009).

Water resources in Italy are 53% located in the north, 19% in the central and 28% in the southern and the islands. The protection of water resources in Italy follows the new setting of the water management policy of the European Union—EU, introduced by the Water Framework Directive (WFD 2000). The effect of climate change is clear in Italy, especially in the northern part. In the Alpine region, the rising temperatures have resulted in the loss of more than half of the glaciers' volume since 1900. With a global temperature shifted by 2–4°, 50–90% of the ice's mass coming from mountain glaciers could disappear by the end of this century (Beniston 2012). Italy is the European country that holds the record for the consumption of drinking water: it starts from about 150 L/day to even reach 240 L/day per person. Half of the water consumption of the province of Brescia is attributable to agriculture, the other half satisfies civil uses domestic and industrial, starting from the losses of the aqueduct networks 40% in the province, 29% in the city. The city of Brescia located at the foot of the Alps in northern Italy within the Po River basin, in region Lombardia, providing 16,000,000 m³ of water annually. It gets its supplies from 41 wells and 3 springs, one of which is in Mompiano and two in Cogozzo (Prato and Siviano), consists of 3 sub-networks (Cogozzo-Nord, Fossa, Montagnola) albeit interconnected with each other. Plenty of studies on the effect of climate change have been carried out in different locations with the Po River watershed. Climate perimeters in Po River catchment area are changing, an increase of the annual mean temperature of about 2 °C has been observed, and it is expected

to reach 3–4 °C at the end of the century (Pedro-Monzonis et al. 2016). The decrease of precipitation is not so evident, a decrease of the annual mean precipitation of about 20% observed during the last thirty years (Pedro-Monzonis et al. 2016). The effect of climate change is less clear on groundwater compared to surface water (Holman 2005). Surface water flowing to springs and wells of groundwater is connected through hyporheic exchange (Bencala et al. 2011; Daniluk et al. 2013).

The city of Brescia has demonstrated an increment of domestic water use for the past ten years, with an increase in the water demand for the agriculture use and other human activities in the city. Mompiano and Cogozzo sources provided around 50% of the city's water needs in the 1960s. Its contribution has significantly dropped over time, and as of right now, the sources account for roughly 14% of the total funds distributed in Brescia. This pressure of satisfying the water demand for different stakeholders shows the importance of studying the water availability for future periods. This study is based on a simplified water balance model that leads to evaluating the future water availability from the springs. Climate projections of temperature and precipitation of this study were based on the Representative Concentration Pathway (RCP) (Meinshausen et al. 2011; Li et al. 2010), which describes the concentration of greenhouse gases. The RCP2.6 scenario foresees those emissions will be halved from the year 2050; for RCP 4.5 this target will be reached in 2080; while according to RCP8.5 emissions will continue to increase with today's rate (Pachauri et al. 2014). Using the observed data from the methodological station for the period from 2000 to 2020 with the future scenarios, the specific objectives of this study are: (I) evaluate the precipitation and temperature regimes for the city of Brescia for the future and the past period; (II) Study the vulnerability of springs discharge to climate change and the limitation of the use of this resource for the water supply system for the two future periods of 2040–2060 and 2080–2100 using hydrological model balance. This study was the first study that focuses on the discharge of the spring of the city of Brescia under future climate change scenarios. These two springs of the city are considered as an important water resource in parallel with the groundwater wells which are supplying the water demand for different activities.

Study area

Brescia is the capital of the province of Brescia which is one of the largest in Italy and the largest province in the Lombardy region, it is located between the two rivers of Mella and the Naviglio. The administrative commune covers a total area of 90.3 square kilometers; the map of the city of Brescia is represented in Fig. 1. Brescia has a population

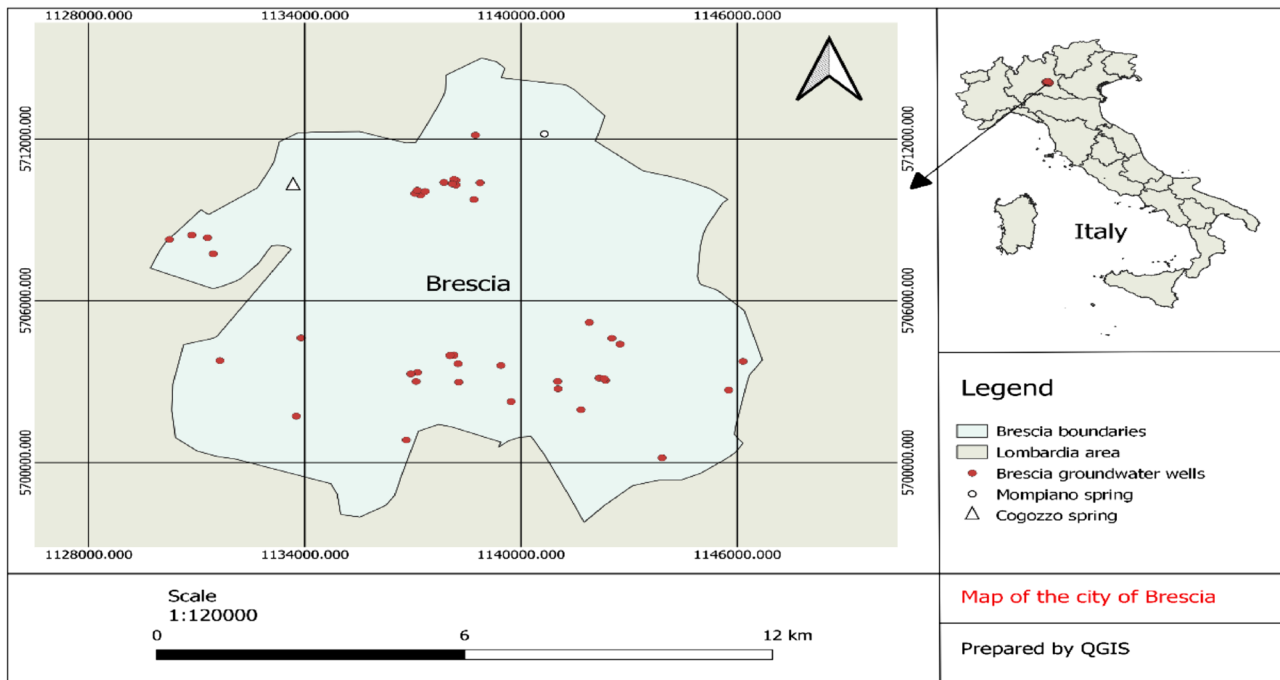


Fig. 1 The map of the city of Brescia includes springs and groundwater wells

of 200,000 inhabitants according to the population census in January 2019. The population of Brescia grew by 3.9%, while Italy grew by 2.1%. There are different activities and importance of the city, it is classified as the industrial area in Italy. Moreover, there are different agriculture activities that are carried out especially in the south part of it. These different activities are looking for the availability of water. The climate of Brescia is reasonably continental, with cold, damp winters and hot, muggy summers. It is considered as a mid-latitude humid subtropical climate according to the Köppen–Geiger system (Peel et al. 2007). The average temperature is 13.1 °C during the year and the coldest month of the year is January while the warmest is July. The city has a widespread quantity of rainfall for the duration of the year with an annual rainfall of 900 mm. The city has a system for supplying water that draws from 41 groundwater wells and three main springs, two of which are in Cogozzo, and one is in Mompiano. The southern area of the city was supplied by the Mompiano aqueduct, while Cogozzo supplied water to the higher parts of the city. Water gushed copiously from Mount San Giuseppe’s limestone rock, coming from the Mompiano Spring. The spring’s annual average flow rate, which varies depending on the season, is 10 million cubic meters. Cogozzo, which consists of the two independent capitations Prato and Siviano, is situated in the Villa Carcina municipality in the lower Val Trompia, about 10 km north of Brescia. A special adductor connects the two springs to the city network. The importance of studying the availability

of water resources in the city is warming up due to climate change and population growth. This study will focus on the variation of the springs discharge under climate change.

Methodology

Data

The data that were used for this study derived from different resources and it represents different variables. The observed daily precipitation and temperature time series (2000–2020) were downloaded from the Regional Agency for the environment, especially the meteorological station of Brescia ITAS Shepherds. The data for past and expected precipitation and temperature for the time series of (2000–2100) were downloaded from RCMs runs of the CORDEX database which mainly came from the Earth System Grid Federation ESGF. The data for spring discharge (m^3) in the city were provided by the help of the municipality of Brescia. These data are provided for the three springs, one in Mompiano and the other two in Cogozzo which are considered as one for this study. The data downloaded from three different RCM and for three different emission pathways (RCP2.6 RCP4.5, and RCP8.5). All the models were corrected by the Swedish Meteorological and Hydrological Institute (SMHI) using different scaling modeling (Yang et al. 2010). Table 1

Table 1 Climate models and data sources used from CORDEX database

Model Number	Driving climate model	Regional climate model
Model 1	ICHEC-EC-EARTH (27050)	RCA4 (59366)
Model 2	MOHC-HadGEM2-ES	RCA4 (59366)
Model 3	MPI-M-MPI-ESM-LR	RCA4 (59366)

shows the different driving climate models that have been used in this study under the same RCM from the CORDEX database.

Climate models evaluation

Climate model evaluation is carried out in two steps based on the available data and the observed data. The RCPs models represent the data in a model way starting from 2006 while the past data are available in the historical baton of each climate model. For this research, the comparison will be divided into two main parts, the first will represent the years starting from 2000 to 2005 which shows the modeled historical data depending on each regional climate model before the representative concentration pathways. The second will show the modeled data for each of the different three models for the 3 RCPs, so in total we have 9 combinations, and each combination has data of precipitation and temperature. The climate model's evaluation is based on the comparison between the observed values of the monthly precipitation (mm) and temperature (°C) received from the meteorological station and the expected data received from the CORDEX. The aim of this evaluation is to find the closest model and RCP for the observed data, and this result will lead to finding the correction values of temperature and precipitation. The two steps of this comparison were carried out in the same way of evaluation, which was mainly based on two indices. First is Root Mean Square Deviation (RMSD) (Jain and Singh 2003) represented in Eq. (1), the most used index in climate and modeling, which aggregates the error of prediction for different values in different models to a single observed date. The model with the lowest RMSD is the best and as much as the RMSD has a lower value, it will be close to the real. The second index is Mean Absolute Error (MAE) represented in Eq. (2), which mainly depends on the RMSD on the absolute value of the difference. MAE is a common measure of forecast error in time series analysis (Coban et al. 2021). These two indices are mainly dependent on the Observed Data (OBS) for the period of 2000–2020 and on the Modeling Data (MOD) for both the historical modeled data and the RCPs.

$$RMSD = \sqrt{\frac{\sum_{t=1}^N (OBS(t) - MOD(t))^2}{N}} \quad (1)$$

$$MAE = \frac{1}{N} \sum_{t=1}^N (OBS(t) + MOD(t)) \quad (2)$$

Temperature and precipitation regimes

Climate classification for a specific region can be mainly defined by the precipitation and temperature regimes (Polo et al. 2011). These regimes are mainly based on historical records data. Precipitation regime of the observed data of precipitation 2000–2020, it is based on the accumulated precipitation during each month for each year of the study period, then the average values of each month will be calculated for the whole period of study. This evaluation will be carried out by using the Microsoft Excel program, with a special command of (sum of is) that will evaluate the accumulated precipitation for each month for each year. Secondly, the temperature regime analyzed and evaluated for the observed data under the same period of study, this regime is mainly based on the evaluation of the average monthly temperature for each month by using the Microsoft Excel program with its special command of (average if is) then a final calculation for the average temperature for the whole year (Bajni et al. 2021). Moreover, a comparison of these two climate regimes was carried out based on the observed data and on the historical modeled data for the three regional climate models under the period of 2000–2005. Finally, these regimes also evaluated for the modeled data under the period of 2006–2020 for the three regional climate models under the different RCPs and this evaluation used for the next step by selecting the best model to deal with for data downscaling.

Date statistical downscaling

Data downscaling is defined as the process of using the past historical observed data to create a prediction for future values and data (Wang et al. 2022). The data downscaling applied depending on the correction factors that were evaluated for the different models by considering the modeled data for the past and for the future. The correction factor for the precipitation and temperature is evaluated based on the best modeled data and the new modeled data for the period of 2006–2100. These correction factors are evaluated on a monthly scale for all the climate models and RCPs and applied symmetrically for the whole day in the month. These corrections are calculated by applying equations (3) and (4). The data downscaling applied for the best climate model within the three models

evaluated and for the three RCPs for that model for two periods (2040–2060) and (2080–2100). Precipitation correction factor applied for the past data in terms of a multiplication factor that would increase or decrease the precipitation while the temperature correction factor applied in terms of increment or decrement. The new data were evaluated based on Eqs. (5) and (6).

$$\Delta P = \frac{P_{\text{new modeled}}}{P_{\text{past modeled}}} \quad (3)$$

$$\Delta T = T_{\text{new modeled}} - T_{\text{past modeled}} \quad (4)$$

$$P_{\text{predicted}} = P_{\text{past}} + \Delta P \quad (5)$$

$$T_{\text{predicted}} = T_{\text{past}} + \Delta T \quad (6)$$

Hydrological modeling and analysis

Precipitation and actual snow melt analysis

Precipitation falls on the ground in different phases of the water, it can be rainfall when it is liquid and snowfall when it is solid. A transformation of the water from one phase to another can occur based on the temperature of the threshold (Tournier 2020). Total amount of water in the liquid phase which mainly consists of the rainfall and the snow melt has been calculated starting with the separation of the precipitation to rainfall and snowfall based on the threshold temperature T (threshold) which is considered as 1°C for the study. The snow fall will face a melting phase but not all the snow will melt, this leads to use of Degree Day Equation (Anderson 2006) to find the actual snow melt, the degree day factor is considered as 2 for this study. This amount of actual snowmelt and rainfall is the main part of the analysis of the water availability. Degree day equation evaluates the potential snow melt based on the average daily temperature in degree Celsius as indicated in the Eq. (7). Potential snow melt represents the maximum snow that can melt but, the actual snow melt is calculated based on the accumulated snow and potential one. The actual snow melt is calculated based on the compression between the potential snow melt and the accumulated snow by considering that the original accumulated snow is zero. If the potential snow melt is greater than the accumulated snow, the actual snow melt will be equal to accumulated. On the other hand, if the accumulation is greater than the potential, the actual snow melt will be the potential (Cline 1997).

$$SWE = \alpha(T - T(\text{threshold})) \quad (7)$$

Evapotranspiration analysis

Evapotranspiration is defined as the amount of water that evaporates from the surface and the water that transpiration from the plants (Katul and Novick 2009). This is one of the main components that affect the water availability, and this amount of water is considered as a loss from the precipitation amount. The calculation of the amount of evapotranspiration went in two steps for the two periods of the study, starting with evaluating the Potential Evapotranspiration (PET) which is affected mainly by surface and air temperatures, insulation, and wind. PET has been calculated using the Thornthwaite method (Stanhill 2005) represented in Eqs. (8) and (9). The values of the corrective coefficient depending on the latitude have been found for the city of Brescia in Table 2. The second step was evaluating the Actual Evapotranspiration (AET) which evaluated through the mass balance which applied to the soil considering the soil moisture content (Jain and Singh 2019). It had been evaluated based on Eqs. (10), (11), (12) and (13). Where \varnothing considered for Brescia as 50% which means that half of the water will infiltrate to the soil, S_{max} considered for Brescia as 100 mm.

$$PET = 16 \cdot P_i \cdot (10 \cdot T_i / I)^{0.5 + 0.0161I} \quad (8)$$

$$I = \sum_{j=1}^{12} \left(\frac{t_j}{5} \right)^{1.514} \quad (9)$$

$$AET_t = C_t + PET_t \quad (10)$$

$$C_t = \frac{S_t}{S_{\text{max}}} \quad (11)$$

$$S_{t+1} = S_t + \Delta S \quad (12)$$

$$\Delta S = S_t + \varnothing \cdot P_t \quad (13)$$

Surface runoff

The runoff is the flow of water happening at the ground surface whilst extra rainwater, storm water, meltwater, or different

Table 2 Monthly correction factors for the city of Brescia

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEB	OCT	NOV	DEC
P_i	0.8	0.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	0.94	0.79	0.75

sources, can now no longer sufficiently swiftly infiltrate withinside the soil (Allegra and David 2007). This can arise whilst the soil is saturated through water to its complete capacity, and that the rain arrives greater faster than the soil can take in it. Surface runoff regularly takes place due to the fact impervious areas (which includes roofs and pavement) no longer permit water to soak into the floor. Furthermore, runoff can arise both through herbal and man-made processes. Surface runoff is a major thing of the water cycle but not for the city of Brescia. This amount had been calculated based on the soil moisture content and the actual evapotranspiration as indicated in the equation (14).

$$\text{Surface Runoff} = S_{if(t-1)} + P - AET - S_{if(t)} \quad (14)$$

Inflow

A step of the hydrological analysis is evaluating the amount of water that infiltrated into the soil, this value can be negative when the actual evapotranspiration is greater than the rainfall and actual snow melt. On the other hand, it can be positive when the water is higher than what is evaporated and transmitted. A comparison was carried out for this value under the three RCPs to check the effect of climate change scenarios on this amount of water. The inflow has been calculated using the water balance represented in Eq. (15).

$$\text{Inflow} = \text{Rainfall \& actual snow melt}_t - AET_t \quad (15)$$

Correlation analysis between precipitation and flow data of springs

The relationship between precipitation and spring flow is analyzed on a monthly and seasonal scale for the three springs of the city of Brescia, one in Mompiano spring and the other two springs in Cogozzo considered as one spring. The analysis is based on the Statistical Package for the Social Sciences SPSS software. This program considered Pearson's correlation coefficient (Warren 1971) which is the test statistics that measures the statistical relationship between 2 continuous variables. This analysis made it easier to evaluate the relation between the precipitation and the discharge of the springs. The value of it is going between ± 1 and it gives the indication about the strength of the relation and based on it. The correlations between precipitation and spring flow will be determined using the precipitation and flow data for the years 2000–2019. These relationships will be utilized to determine the anticipated spring flow for the two research periods of 2040–2060 and 2080–2100. It is possible to determine the impact of climate change, which is reflected in this case by the variation in precipitation on the

Table 3 Climate models evaluation results for the period 2000–2005

Climate models	P (mm)		T (°C)	
	MAE	RMSD	MAE	RMSD
Model 1	55.67	71.76	2.35	2.87
Model 2	56.62	82.42	1.97	2.52
Model 3	70.42	95.75	2.07	2.59

Table 4 Climate models evaluation results for the period 2006–2020

Climate scenarios	RCPs	P (mm)		T (°C)	
		MAE	RMSD	MAE	RMSD
Model 1	RCP2.6	55.90	72.48	2.35	2.87
	RCP4.5	58.25	76.97	2.19	2.71
	RCP8.5	55.77	71.71	2.07	2.63
Model 2	RCP2.6	59.30	77.45	1.97	2.52
	RCP4.5	63.00	82.60	1.95	2.50
	RCP8.5	62.86	81.83	1.99	2.51
Model 3	RCP2.6	72.02	92.77	2.07	2.59
	RCP4.5	62.25	78.59	1.81	2.22
	RCP8.5	68.34	90.37	1.89	2.32

spring's flow discharge, based on the correlation between precipitation and spring discharge.

Results

Climate models evaluation

Climate models evaluation had been carried out for the discussed three climate models under the two steps of evaluation, The ICHEC-EC-EARTH regional climate model showed the most accurate model for both precipitation and temperature under the historical evaluation among the others with lowest value of mean average error MAE for precipitation and temperature. The same model showed the best evaluation under the other index of Root Mean Square Deviation (RMSD). As a conclusion, the three models showed the same evaluation under the temperature while the differences were so clear in the models under the evolution of the precipitation. The best model under precipitation considered for both and the result of this part of the analysis presented in Tables 3 and 4. Talking about the precipitation, ICHEC-EC-EARTH (27050) global circulation model with RCA4_v1 regional climate model is the best response under the 3 Representative Concentration Pathways. RCP8.5 shows the minimum value under the two used indices in comparison with the whole models

and RCPs. For this study, the ICHEC-EC-EARTH (27050) global circulation model with RCA4_v1 regional climate model with the RCP8.5 had been used in both precipitation and temperature.

Temperature and precipitation regimes

A monthly analysis of the observed data of precipitation (2000–2020) had been carried out, as an average, the maximum precipitation is perceived in May with an average amount of 107.74 mm of the yearly precipitation, while the minimum amount is in January. The same analysis has been carried out for the temperature, the temperature showing a gradually increasing trend for the city. The coldest month was January with an average temperature of 2.67 °C while the hottest one was July with an average of 25.2167 °C. These results are presented Figs. 2 and 3. The two regimes were also calculated for the 3 regional climate models under the same period 2000 to 2005. As an average, the ICHEC-EC-EARTH regional climate model showed the closest value for the observed. This comparison can't be taken in consideration and calculations because the period is just for 5 years. The modeled data for the period 2006–2020 has been also analyzed as well, the representative concentration pathways start to

be available in 2006. For each model, there is 3 RCPs (RCP2.6, RCP4.5, RCP 8.5) and the regime for all of them has been calculated in which will be used for the evaluation of the correction factors that will be used for data downscaling for future results.

Date statistical downscaling

Data downscaling results are based on the correction factors for precipitation and temperature; these factors have been evaluated for the city of Brescia for the three mentioned climate models under the three RCPs for different periods of time. Based on the past step of climate models evaluation, the ICHEC-EC-EARTH climate model shows the best model with respect to the past data. On the other hand, the same model showed the lowest correction factors for the whole period from 2020 to 2100. The downscaling has been considered as linear and constant for each month along the period and it has been carried out for this model under the three RCPs and it has been analyzed for the period of 2040–2060 and 2080–2100. The results of this step can be better presented in Tables 5 and 6.

For the low emission scenario RCP2.6 under the first period of study, it shows a small decrease in monthly precipitation in September and October while an increment for the rest of the

Fig. 2 Pluviometric regime of the city of Brescia for the period 2000–2020

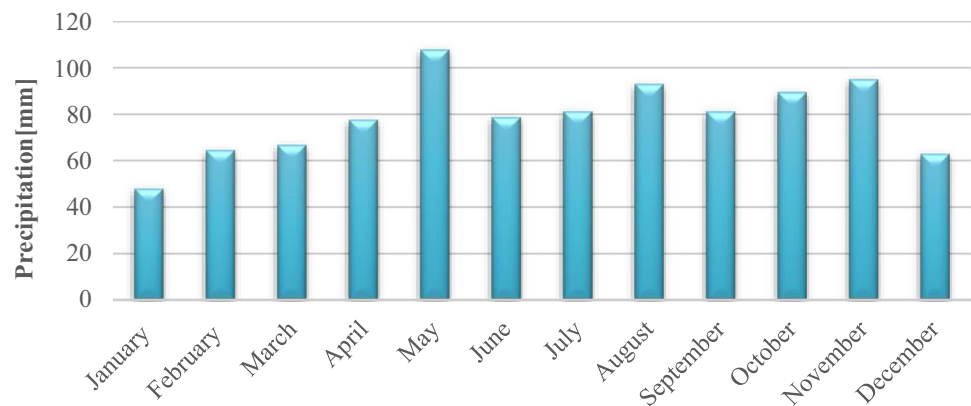


Fig. 3 Thermometric regime of the city of Brescia for the period 2000–2020

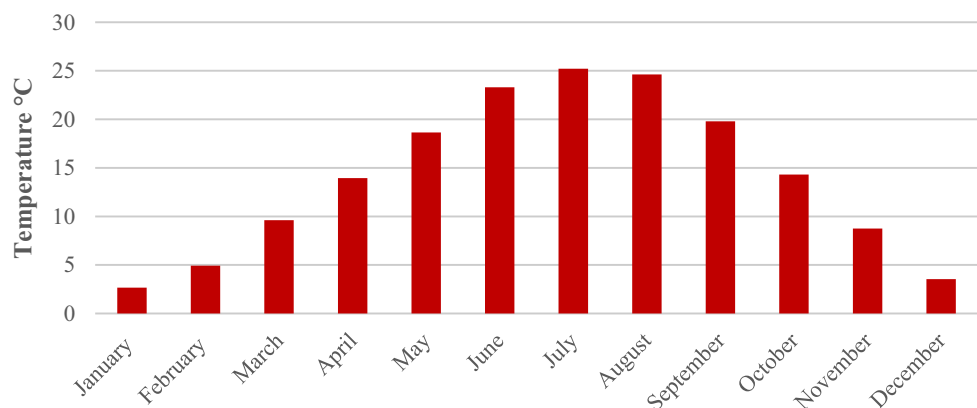


Table 5 Brescia precipitation and temperature regimes observed 2000–2020 and predicted for the period 2040–2060

ICHEC-EC-EARTH								
RCPs	Observed		RCP 2.6		RCP 4.5		RCP 8.5	
Parameter	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)
January	47.86	2.67	82.02	3.31	34.43	2.50	35.26	3.45
February	64.46	4.92	83.92	5.42	63.49	5.86	67.87	5.89
March	66.78	9.61	90.15	10.81	68.57	9.85	82.52	10.83
April	77.60	13.95	89.24	14.53	76.27	13.99	103.71	13.98
May	107.74	18.65	128.21	19.16	104.55	19.76	87.17	20.21
June	78.74	23.30	117.32	22.97	71.17	24.92	57.25	26.68
July	81.20	25.21	111.24	24.87	1.25	25.24	0.01	25.22
August	92.92	24.63	144.02	25.01	40.23	27.32	73.62	26.58
September	81.16	19.79	77.92	20.75	53.60	21.21	139.40	20.73
October	89.50	14.32	82.34	15.23	95.66	15.50	148.63	15.12
November	94.96	8.74	124.39	9.72	103.00	9.72	198.88	10.44
December	62.93	3.54	85.58	3.29	42.88	4.19	71.98	5.36
Yearly	945.83	–	1216.36	–	755.11	–	1066.27	–

Table 6 Brescia precipitation and temperature regimes observed 2000–2020 and predicted for the period 2080–2100

ICHEC-EC-EARTH								
RCPs	Observed		RCP 2.6		RCP 4.5		RCP 8.5	
Parameter	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)
January	47.86	2.67	65.92	2.80	38.93	3.57	64.46	5.59
February	64.46	4.92	82.14	5.64	98.53	6.84	58.70	7.61
March	66.78	9.61	82.26	10.64	82.88	10.84	67.62	12.44
April	77.60	13.95	103.56	13.96	73.59	13.98	94.08	14.01
May	107.74	18.65	110.13	19.52	100.72	19.73	83.49	22.65
June	78.74	23.30	73.43	24.54	87.93	25.13	47.08	28.88
July	81.20	25.21	0.02	25.21	0.01	25.22	0.01	25.25
August	92.92	24.63	102.45	24.74	85.13	27.19	67.60	29.99
September	81.16	19.79	75.04	20.93	71.09	21.78	94.70	24.40
October	89.50	14.32	105.45	14.74	127.76	16.11	148.52	17.80
November	94.96	8.74	104.14	9.53	122.14	10.20	143.37	12.47
December	62.93	3.54	78.99	3.61	38.92	4.29	54.34	6.47
Yearly	945.83	–	983.53	–	927.64	–	923.96	–

year. For the same period, the temperature shows an increase during the whole year except June and July with a decrease of 0.33 °C. For the second period of study under the same RCP, both the precipitation and temperature show a small increment of 20% for precipitation and about 0.5 °C. This scenario of emission is considered the most optimistic scenario among the others. For the intermediate scenario of emission RCP4.5, which is considered as less optimistic than the past scenario. Under the two periods of study, the amount of precipitation shows a decrease in its amount along the year in parallel with an increment of the temperature which puts more pressure. The precipitation regime for the most pessimistic scenario with the highest emission shows the largest difference in the

amount of precipitation and temperature compared with the past observed data and the two other scenarios under the same climate model. It shows a high increment in winter precipitation while a decrease for summer. At the same time, temperature is constantly increasing from the first period till the second one. The results of this step show that the city will face a decrease in precipitation for the future period in the period 2040–2060, and this decrease will reach its maximum by the end of this century 2080–2100. On the other hand, the temperature of each month will have an increment that will lead to an increase in the amount of evapotranspiration and affect the amount of runoff water. This will impact the water that comes from springs and wells.

Hydrological modeling and analysis

Precipitation and actual snow melt analysis

Precipitation data showed an expected decrease in summer while an increment in winter rainfall and actual snow melt are considered as the main components for the recharge of the different water resources like springs and groundwater. For the period 2040–2060, the actual snow melt will increase compared with the past years due to increment of the temperature and this will lead to more water coming from solid state. The RCP4.5 which was the best representative for this period shows a decrease of this amount of rainfall and actual snow melt due to the decrease of rainfall amount. At the same time, RCP2.6 shows an increment for the whole year while RCP8.5 shows the great differences as increment in winter and decrement in summer. For the period of 2080–2100, the effect of global warming became clearer with the evidence of the increment of the snow melt. At the same period, the amount of precipitation showed an increase for the winter session and decrease for the summer one. RCP8.5 was the best representative concentration pathway for this time and its analysis shows a growth for September, October, and November while decreasing for

the other months of the year. This major decrease in the rainfall and actual snow melt will have a great impact on the recharge of the groundwater in the city; these results are displayed in the Fig. 4a, b.

Evapotranspiration analysis

The analysis that was carried out for the city of Brescia using Thornthwaite method for evaluating the potential evapotranspiration shows that this amount has a direct relationship with the temperature. This value shows an increment for the future period of 2040–2060 and 2080–2100 as a yearly value; it gives it maximum under the analysis for RCP8.5 for the two periods. This increment has a negative impact on the water availability because this amount of water will be considered as a loss from the rainfall and actual snow melt. Carrying out the soil water balance for the city of Brescia to evaluate the actual evapotranspiration with the consideration of the maximum saturation is 50 mm for evaluating the actual evapotranspiration. This value shows a decrease due to the decrease of the precipitation, and it shows it is minimum under the RCP8.5. This amount is less than the potential one and it shows the actual and real value of water that evaporates and transpires by the plants. The results of

Fig. 4 **a** Rainfall and actual snow melt of the city of Brescia for the period 2000–2020 and predicted for the period 2040–2060. **b** Rainfall and actual snow melt of the city of Brescia for the period 2000–2020 and predicted for the period 2080–2100



the actual evapotranspiration for the two-study period are represented in Fig. 5a, b.

Surface runoff

In general, surface runoff is considered one of the main components of the water resources, but this amount of water is not so reliable for Brescia, and it is a very small amount. The evaluation of this amount of water is very useful to avoid some issues and phenomena like floods and its useful for the design of the infrastructure and stormwater analysis and design.

Inflow

This section shows the amount of water that will go into and infiltrate the soil that will go directly to the lower part of the soil and may reach to the ground water. It shows the whole amount of water infiltrates while in the next section, it will mainly focus on spring recharge. RCP4.5 was the closest pathway for the future expectation of climate components for the period of 2040–2060, while RCP8.5 was the best representative concentration pathway for the future climate

component under the period 2080–2100. Starting with the period on study of 2040–2060, the RCP2.6 and RCP8.5 showed a small increment of this amount of inflow in the yearly scale, while RCP4, 5 shows a decrement of the inflow in monthly and yearly scale, this will affect the amount of water that can be extracted and used for water supply system for the city of Brescia. The same analysis had been carried out for the period 2080–2100, the scenario of high emission RCP8.5 shows a decrease of this amount of water, while RCP4.5 and RCP2.6 shows a constant and a small increment respectively. These results show that there will be extra pressure on the water resources. Figure 6a, b present the average monthly variation of the inflow.

Correlation analysis between precipitation and flow data for prediction future springs discharge

- Mompiano spring: for the period 2040–2060, the spring flow will increase for all months of the year, except for June and October, according to the lowest emission scenario RCP2.6. According to RCP4.5, the spring flow will decrease in January, February, April, May, June, August, and December while slightly increasing in the

Fig. 5 a Actual Evapotranspiration of the city of Brescia for the period 2000–2020 and predicted for the period 2040–2060. b Actual Evapotranspiration of the city of Brescia for the period 2000–2020 and predicted for the period 2080–2100

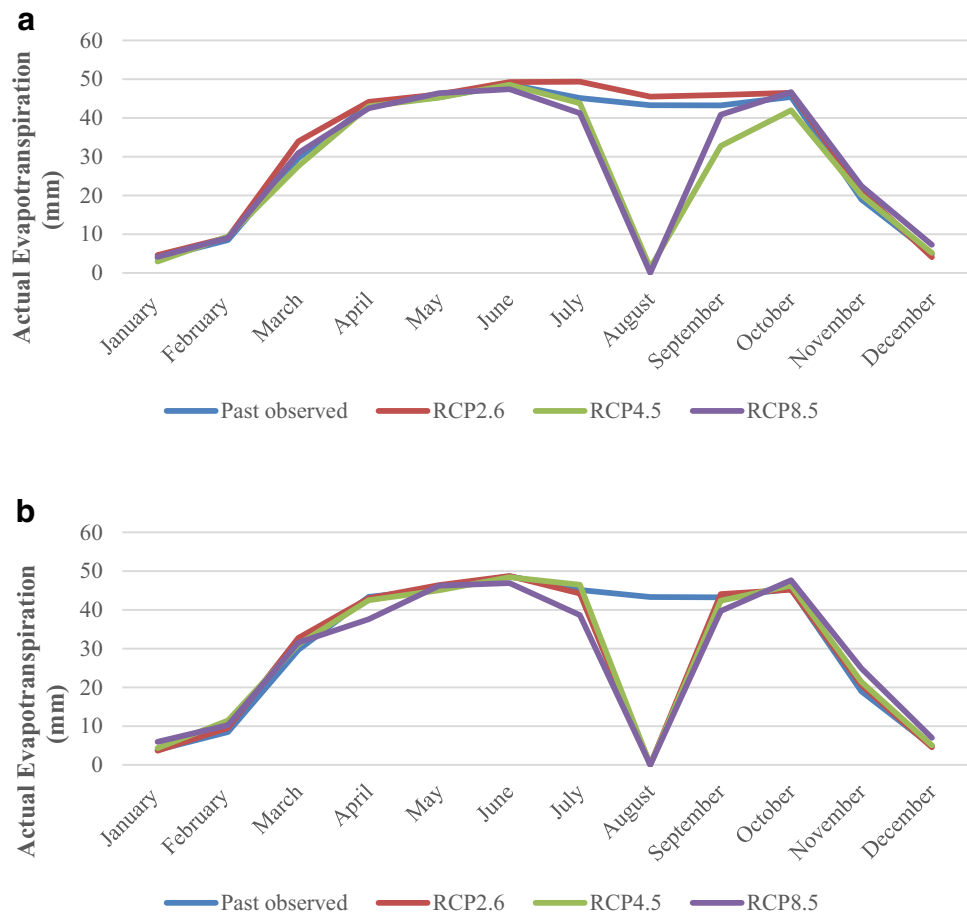
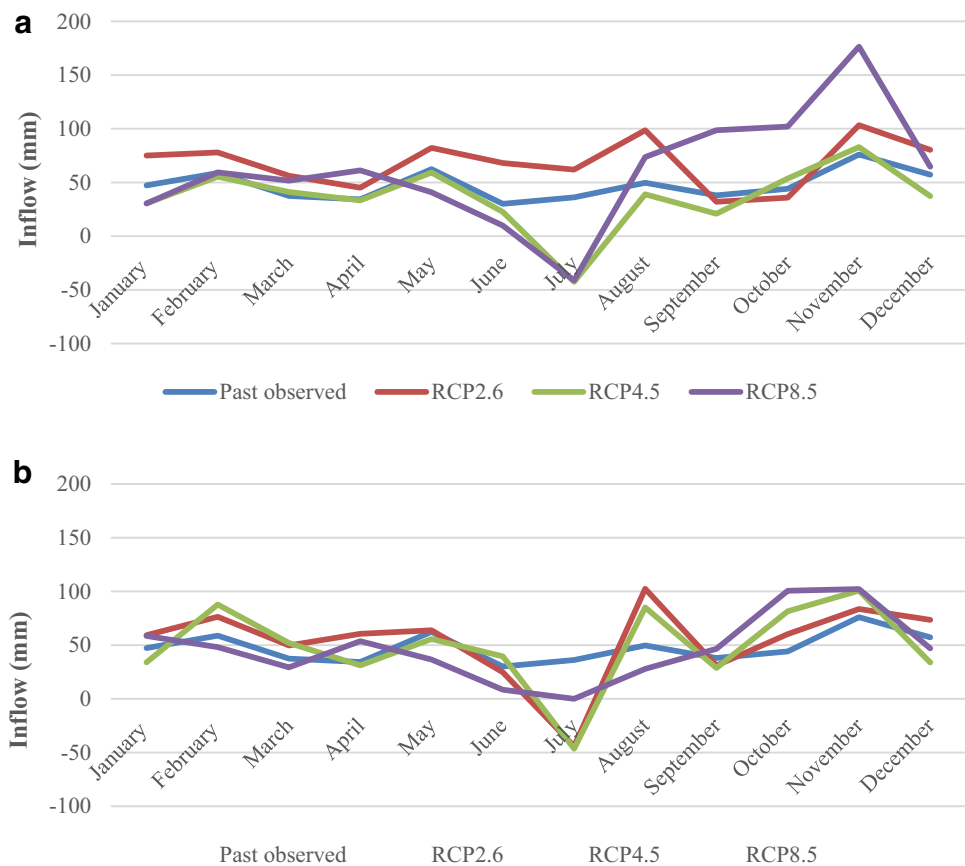


Fig. 6 **a** Inflow of city of Brescia for period 2000–2020 and predicted for the period 2040–2060. **b** Inflow of city of Brescia for period 2000–2020 and predicted for the period 2080–2100

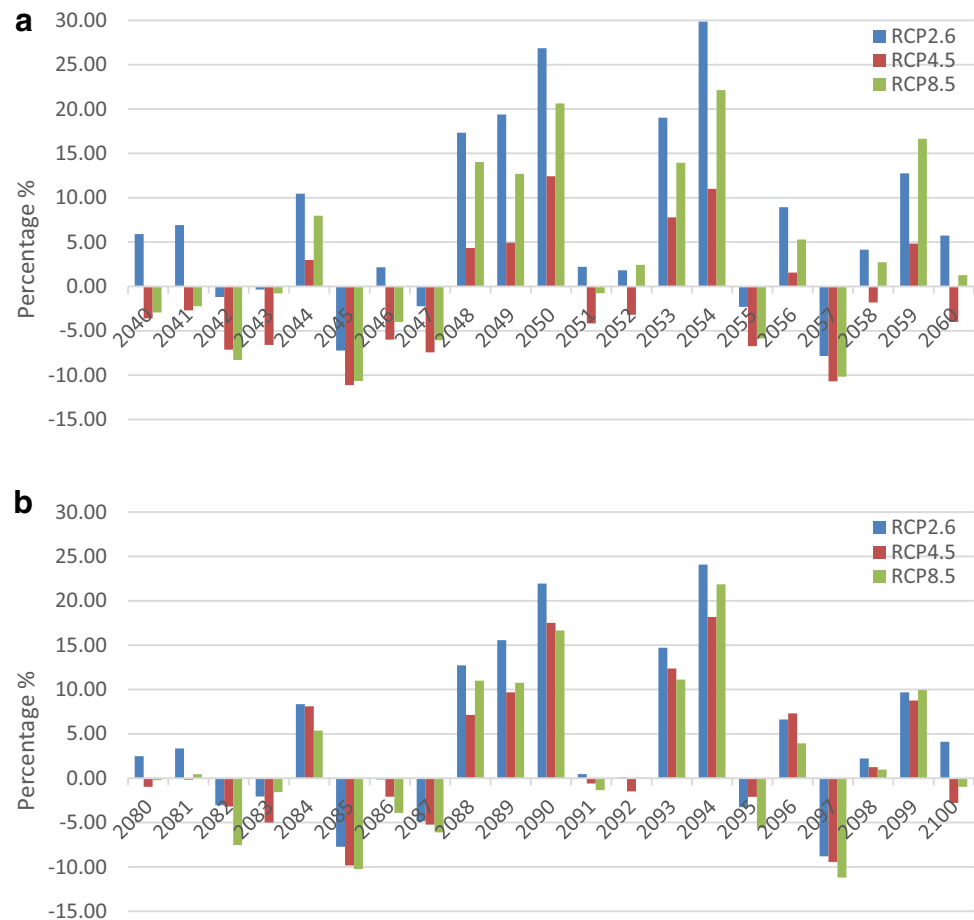


other months. According to the high emission scenario RCP8.5, the flow under the months of January, June, August, and September will decrease while the flow under the other months will be slightly increased. On a seasonal scale, RCP2.6 depicts an increase in the flow for all four seasons, but RCP4.5 and RCP8.5 depict an increase in the Autumn and a decrease in the flow for the other seasons. For this period of study, Fig. 7a represents the future annual percentage of variation of the spring's flow based on the average flow. For the period 2080–2100, RCP2.6 predicts that the volume of flow will increase, except for June which predicts a significant fall in spring flow. RCP4.5 shows a decrement for the other months and an increment for the months of February, March, June, July, September, October, and November. During the months of February, March, May, June, August, and September, the decrement under RCP8.5 was so obvious, but the other months of the year had a clear increase. In a seasonal scale, RCP2.6 and RCP4.5 shows an increment for the whole seasons, while RCP8.5 shows an increment for Winter and Autumn and a decrease for Spring and Summer. For this period of study, Fig. 7b represents the future annual percentage of variation of the spring's flow based on the average flow.

- Cogozzo spring: for the period of study of 2040–2060. RCP2.6 shows an increase in summer months as well as in January and March while a decrease for the other months of the year. RCP4.5 shows an increase for the months of February, March, May, October, November, and December while a decrease for the other months of the year. RCP8.5 shows an increase for the months of April, May, and Autumn months, while a decrease for the other months of the year. On a seasonal scale, RCP2.6 shows an increment of the amount for the whole season while RCP4.5 and RCP8.5 show an increment for winter and summer. For this period of study, Fig. 8a represents the future annual percentage of variation of the spring's flow based on the average flow.

For the period of study of 2080–2100, RCP8.5 shows a great decrease for the summer months while a slight increment for the other months. RCP2.6 shows an increment for most of the year, for January, March, April, August, October, and November while a decrement for the rest. RCP4.5 shows a decrease for summer months and January and February months. On a seasonal scale, the results show that almost all the RCPs have the same trend; they show a decrease for the summer season and only RCP4.5 shows a decrease in winter,

Fig. 7 **a** Future annual percentage of variation of the Mompiano spring's flow for period 2040–2060. **b** Future annual percentage of variation of the Mompiano spring's flow for period 2080–2100



while an increase for the other seasons. For this period of study, Fig. 8b represents the future annual percentage of variation of the spring's flow based on the average flow.

Discussion

Since the late eighteenth century, the Earth's mean surface temperature has been continuously increasing because of human activities on the climate (Pachauri et al. 2014). Predicting how hydrogeological systems will respond to climate change becomes important, particularly if used to supply drinking water or ensure the sustainability of ecosystems that depend on groundwater (Kløve et al. 2014). Unfortunately, due to altered temperatures, precipitation patterns, and water flow regimes, climate change has affected freshwater ecosystems on both the supply and demand sides (Carpenter et al. 2011; Däll and Zhang 2010). This study focused on analysis of the impact of climate change with different scenarios on the water availability from the two main springs of the city of Brescia that are used for the water supply system. The relation between the precipitation and the spring flow was found

and then applied to project water availability under the three emissions scenarios. RCP8.5 shows the highest impact on the availability of the water resources on the two springs for the two periods of study. RCP4.5 impact was close to RCP8.5 for Mompiano spring while the effect of it on Cogozzo is weaker than Mompiano. RCP2.6 shows a general increment of the flow for the two springs of the city under the two periods of study. The average of springs flow of 20 years in a seasonal scale were evaluated and used to show the impact of climate change on the availability of springs flow under the three representative pathways for the two periods of study. The results show that we will experience water scarcity by the middle of the century, according to the results, which demonstrate that the influence of RCP4.5 is clearer. This study demonstrates that summertime water availability in Brescia will constantly decline due to warming caused by climate change. On the other hand, we will have an increase of the evapotranspiration due to temperature increase. The source of Mompiano, whose daily production is strongly influenced by meteoric precipitation, in "normal" climatic conditions, delivers about 100 L/s. The two sources of Cogozzo,

Fig. 8 a Future annual percentage of variation of the Cogozzo spring’s flow for period 2040–2060. **b** Future annual percentage of variation of the Cogozzo spring’s flow for period 2080–2100

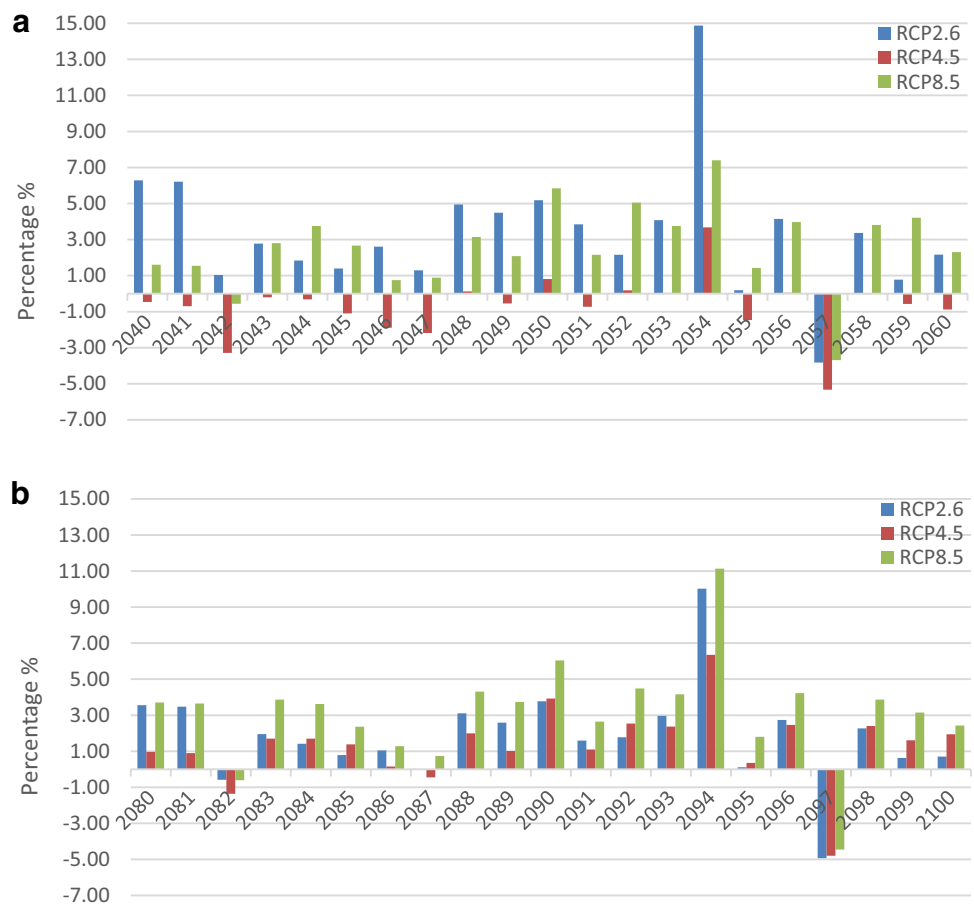


Table 7 Future seasonal percentage of variation of the Mompiano springs flow

Period	RCPs	Winter	Spring	Summer	Autumn
2040–2060	RCP2.6	19.70	5.61	1.65	5.48
	RCP4.5	− 8.37	− 0.26	− 1.01	5.63
	RCP8.5	− 1.17	− 0.34	0.08	17.69
2080–2100	RCP2.6	13.02	2.70	1.16	3.94
	RCP4.5	0.57	0.73	0.64	9.85
	RCP8.5	1.97	− 2.72	− 0.18	12.71

Table 8 Future seasonal percentage of variation of the Cogozzo springs flow

Period	RCPs	Winter	Spring	Summer	Autumn
2040–2060	RCP2.6	5.55	0.54	3.91	− 0.06
	RCP4.5	− 2.02	0.05	− 4.44	0.29
	RCP8.5	− 2.43	1.16	− 3.43	13.03
2080–2100	RCP2.6	2.8	0.88	− 1.79	2.25
	RCP4.5	− 1.45	0.37	− 2.15	5.71
	RCP8.5	3.19	0.66	− 3.94	9.87

which are less affected by meteoric precipitation, maintain a constant production equal to about 35/40 L/s. The flow of the springs shows a positive and negative variation in a monthly and yearly scale. The negative variation means a decrease of the flow of the springs which means less water for the water supply system, this will create the issue of water scarcity in the city. The decrease of the flow from the springs is more evident in summer seasons due to the decrease of summer precipitation and the temperature rise. Tables 7 and 8 show the percentage of variation of the

average future seasonal flow with respect to the average past flow.

Conclusion

The application of traditional groundwater flow models for the prediction of fractured media is complicated due to the duality of the flow systems (Pedretti et al. 2016). As a result of population growth and climate change, the water demand is expected to increase, and this creates the importance of studying the effect of climate change on

water availability. This study focused on studying the variation of the flow of the springs of the city of Brescia under the effect of three climate change scenarios for future periods of 2040–2060 and 2080–2100 under three RCPs. Future climate models for the city of Brescia predict that although temperatures continue to rise through the end of this century, summer precipitation will decline, and winter precipitation will rise. The hydrological analysis shows a minor decline in the inflow, which impacts the feed of the groundwater wells and springs, as well as annual increases in evapotranspiration which is considered as a loss from the precipitation. The effect of climate change shows a negative variation in the flow of the springs, this is clearer in the summer season that will put a pressure on the availability of the water. Mompiano spring is more affected with climate change compared with the other springs, under the scenarios of RCP2.6, RCP4.5 and RCP8.5, the spring shows an average variation of the flow with 7.43%, – 7.82% and 4.45% respectively for the period 2040–2060, while a variation of 4.72%, – 2.02% and –0.28% for the period 2080–2100. Cogozzo springs show less variation of the average flow of 2.55%, – 3.95% and 3.35% for the period 2040–2060, while 1.09%, – 0.59% and 1.85%. The results show that the effect of RCP4.5 is clearer for the two periods of study, this means that we will face water scarcity by the middle of the century. The results of this study match other past studies that show that the Po River basin will consistently have less water available in the summer due to climate change-induced warming (Ravazzani et al. 2015; Vezzoli et al. 2015). This study demonstrates the importance of taking action to adapt to and prevent climate change as well as to have a more sustainable management of water resources. The governance and institutional framework of the water resources management sector in the Po basin are quite complicated, which is one of its key limitations. With this in mind, we suggest that the water manager may occasionally use integrated management to carry out joint spatial and intertemporal interventions. To achieve the goal of adaptation to climate change, all stakeholders must participate in the management of water resources. To deal with the more erratic weather, a more effective water management system that is integrated throughout the watershed is required. We concentrated our study on spring discharge since it is particularly vulnerable to the effects of climate change.

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Data availability The datasets generated and analyzed during the current study are available in the [ARPA Lombardia] repository, [<https://www.arpalombardia.it/Pages/Meteorologia/Richiesta-dati-misurati.aspx>]. As well as some data are available in the [CORDEX] repository [<https://esgdn1.nsc.liu.se/search/cordex/>].

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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