Climate change impact on water supply demands: case study of the city of Skopje

Katerina Donevska and Angelco Panov

ABSTRACT

The aim of the paper is to present the climate change impact on drinking water supply, and to assess the availability of current water resources to meet the increasing demands in climate change conditions, for the city of Skopje. Series of monthly precipitation and temperature data are estimated up to 2050, using recorded data and data for predicted changes of air temperature and precipitation according to climate change scenarios. Climate change impact on drinking water supply is assessed using multi-regression models for the dependence of the water supply data on the main climate parameters: temperature and precipitation. Forecast of future water quantities includes implementation of multi-regression models defined with a set of independent variables: the number of the population for time sets (t, t-1, t-2, t-3), precipitation and air temperature including predicted changes of the data under climate change conditions for the same time sets. Two scenarios are analysed: the first predicts that the number of the population until 2050 remains nearly the same as nowadays, the second predicts an increase of the number of the population at an average annual rate of increase of 0.58%. Results indicate shortage of available water resources for population and industry in climate change scenarios (increase of temperatures and decrease of precipitation) and increase of population.

Key words | climate change, drinking water supply, water management

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INTRODUCTION

In recent decades more intense rainfall events have occurred in parts of Europe as well as extreme weather events like severe droughts, floods and heat waves. Climate change scenarios predict more intense changes in temperature and precipitation and increase of the possibility of occurrence of extreme weather events. Decrease of precipitation combined with increase of temperatures will impact both the quantity and quality of water resources. However, uncertainties persist regarding the magnitude of the climate change impacts on water resources, the timeframe of occurrence, as well as their interactions with human activities.

Changes in water resources' quantity and quality and the timing of the occurrence of flows affect water supply systems, making them vulnerable to climate change. Water supply systems are already facing various pressures due to aging infrastructure, population increase, competition between different water users, etc. Climate change is an additional factor in the existing water management challenges, contributing to the increased vulnerability of water supply systems. Brun (2007) reports that nearly 40% of the supplied water for the Mexico City water supply system is lost in pipelines and network leakages. Considering available water resources and climate change scenarios for Mexico City, Brun (2007) concludes that reductions in water availability may cause or prolong social conflicts between municipalities, people and authorities over future water use. Mukheibir & Ziervogel (2007) in their research present a framework for development of a Municipal Adaptation Plan for climate change for the city of

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Cape Town. Their work illustrates that the city is the first major urban region in South Africa where the water demand will exceed the total available water resources in the case of economic and population growth scenarios and projected climate change impacts. Regarding water supply and demand, Downing *et al.* (2003) concluded that in England, per capita domestic demand could rise additionally in the range from 2% to 5% for the next 20 to 50 years as a result of climate change. Al-Zubari *et al.* (2018) assess the vulnerability of the municipal water management system to the impact of climate change in the Kingdom of Bahrain. They use a dynamic mathematical model to forecast municipal water demands and their associated cost for two scenarios: without and with climate change impacts.

Climate change scenarios for the Republic of North Macedonia (Climate Change Scenarios 2012) suggest that there will be continuous increase in temperature in the period 2025–2100. The predicted changes of temperature will be most intense in the warmest part of the year. A decrease of precipitation is predicted in the period 2025–2100, in all seasons and at an annual level, with the maximal decrease in the summer season, and with the expectation that in July and August there may be no precipitation at all. In the winter season, decreases of precipitation of up to 40% of the average monthly quantities are foreseen (*Third National Communication on Climate Change* 2014).

Regarding surface water resources, analyses of the variations and trend lines of the minimal, average and maximal annual discharges for all river basins in the country show that there is a general trend of reduction of all discharges, most expressed in the central and south-eastern part of the country (Donevska & Gorsevski 2011). Water resources in the country are highly vulnerable to climate change with regard to both their quantity and quality. The annual water resources per capita are about 3,150 m^3/year, classifying the country in the middle category of European countries based upon the available water resources per capita (*Second National Communication on Climate Change* 2008). However, these data are close to the threshold of water resources needed for sustainable development.

The objective of this research is to assess the vulnerability of the water supply to climate change impact for the city of Skopje, the capital of the country. The research presents a part of the project Climate Change Strategy for the City of Skopje (Resilient Skopje Climate Change Strategy 2017). The analyses include generation of series of monthly and annual temperature and precipitation data in compliance with the official climate change scenarios prepared for the *Third National Communication on Climate Change* (2014) and analysis of the dependence of the water supply on the generated climate parameters in climate change conditions. The research also links the demand to the supply of drinking water for the forthcoming period in climate change conditions for two scenarios: without and with increase of population.

MATERIALS AND METHODS

Background and study area

The city of Skopje is situated in the central part of the Skopje valley (Figure 1), covering an area of 571 km^2. The total number of residents in all municipalities within the region is 578,144 (Spatial Plan of Skopje region 2005–2020 – draft 2009). The region relief is complex, comprised of a valley and surrounding mountains on the north-west and on the south and east. The main direction of the valley is from the north-west to the south-east, being shaped by the action of the river Vardar.

The spring Rasce, the dominant water source for the domestic water supply of Skopje, is sited in the karst mountains of Zeden, located outside the west border of the valley. The spring has very favorable characteristics, it meets the needs of the water supply of the population, and it also provides water of good quality for human consumption by gravitation. The average capacity of the spring is $Q_{ave} = 4.0\ m^3/sec$, while the coefficient capacity ($Q_{max}/Q_{min} < 3$) is small compared with the typical karst springs (Realization of the Programme Activities for Monitoring of Quantitative and Qualitative Characteristics of the Water Resources Supplying Zeden Aquifer and Rasce Spring 2010).

The valley geology is represented by Neogene and Quaternary sediments. There are two main groundwater aquifers: the first one is a high-yield semi-confined aquifer of superficial sand and gravel with clay horizons and the second is a low-yield aquifer in underlying marls. The superficial aquifer is in a direct continuity with the river Vardar, while the depth of the groundwater level varies depending

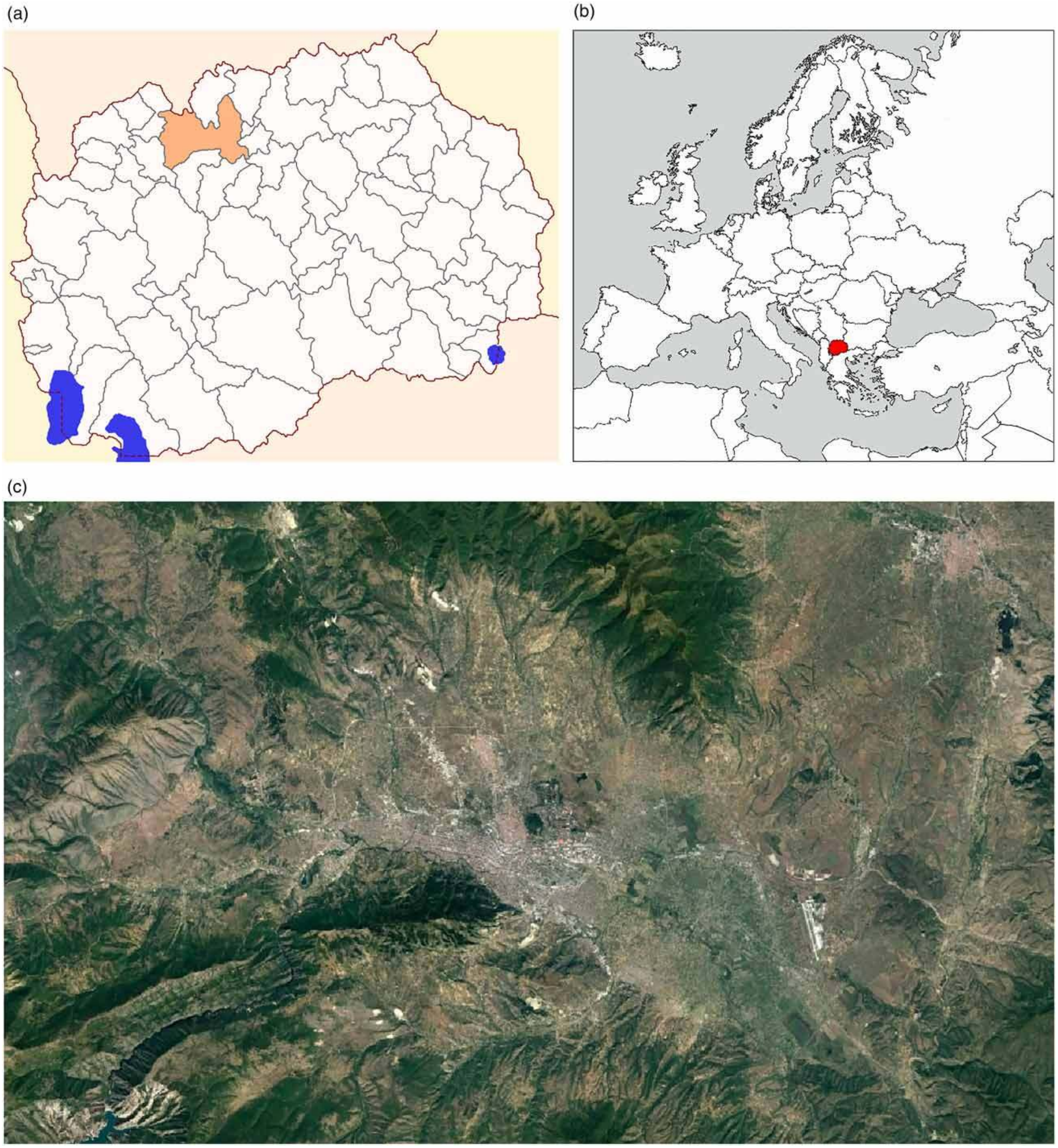

Figure 1 | (a) Location of the study area in the country; (b) position of the country in Europe; (c) study area relief (Google Earth).

on the local conditions. Total groundwater yield in the valley is assumed to be 54.49 million m^3, out of which 16.4 million m^3 per year are used for the water supply of industry (Local Environmental Action Plan for the City of Skopje 2011). In the upstream part of the river Vardar, two wells for municipal water supply were drilled with a total yield of wells at the location of Nerezi of 730 l/s and a total yield of 690 l/s at the location of Lepenec.

The study area, mostly in the valley, is under the influence of a Continental and Mediterranean type of climate, as well as under the influence of a mountain climate at higher elevations. Lower parts of the valley experience very hot and dry summer periods and average cold and wet winters. The average annual air temperature for the valley is 12.9 °C, showing an increasing trend from 1978 to 2015. Usually, there are short heat waves that last for up to 6 days, being most frequent in the last 10 years. The average annual sum of precipitation is 484.8 mm. The uneven spatial and temporal distribution of precipitation results in long dry periods in summer, while there is abundant precipitation in autumn.

Drinking water requirements of the city of Skopje and its suburbs are mainly met by the city water supply system managed by the Public Enterprise (PE) 'Water Supply and Sewage' – Skopje. The water supply system has constant water supply sources: the principal one is the spring Rasce, while groundwater from the well-system Nerezi–Lepenec is used when the water demands exceed the capacity of the spring. Due to the aging of the water infrastructure, the PE recognized a large amount of leakage, which resulted in a high ratio of non-revenue water. This was acknowledged as a severe issue for the water supply system mainly due to: maintenance activities like washing the water supply network and reservoirs, irrigation of urban green spaces, washing streets, water losses within the network (leaks) and illegally used water.

The industry is a great consumer of water, part of it is supplied by the city water supply system, while the other part uses groundwater through local wells with capacity from 60 l/s to 225 l/s.

Methodology and data

The research was based on data series for: average monthly and average annual temperatures for the period 1978–2015; monthly and annual sum of precipitation for the period 1978–2015; data for predicted changes of air temperature and precipitation according to the climate change scenarios (Climate Change Scenarios 2012); data for delivered water quantities for drinking water supply of the population and industry for the period 1990–2015; and data about the available water resources of the spring Rasce and well-system Nerezi–Lepenec.

Within the Climate Change Scenarios (2012), projections of the climate change were performed by the use of MAGIC/SCHENGEN software package 5.3, using the six scenarios A1B-AIM, A1FI-MI, A1T-MES, A2-AS, B1-IMA and B2-MES. Precipitation and air temperature changes were forecast for the period of 2015–2100 (reference period 1961–1990), for four characteristic years (2025, 2050, 2075, 2100) for each of the six scenarios and three values of climate sensitivity.

Prediction of water consumption was based on several statistical multi-regression models. The purpose of the multi regression analysis is to create a plane in *n*-dimensional space, where *n* is the number of independent variable sizes. The disadvantage of regression models, as well as most other models, is their inability to fully simulate the local peaks.

The applied methodology consists of two phases.

I. The first phase is about generating synthetic sequences of climate series.

Monthly and annual precipitation and temperature data series were generated up to 2050. This is enabled by the use of projected seasonal changes of average air temperature (°C) and precipitation (%) under the average scenario (Climate Change Scenarios 2012) for 2025 and 2050. To expand the seasonal data of precipitation and temperature for years 2025 and 2050 into monthly values, fourth-degree polynomial equations were developed. Finally, the monthly values of both climate parameters were interpolated for each year within the period of 2025–2050.

Generated series of climate elements present the differences in terms of change of air temperature in °C and precipitation in %. These time-distributed changes of climate elements were added to the historical records of climate data to obtain forecast data.

II. The second phase incorporated prediction of future water demands:

- Data about delivered water quantities for drinking water supply of the population and industry for the period 1990–2015 were statistically analysed. A multi-regression model was defined with a set of independent variables including precipitation and temperature data, so the model might be applied to forecast water consumption under climate change conditions. The regression model used to forecast the future water consumption of the population and industry was formed using data for independent variables such as the number of the population for time sets (t, t-1, t-2, t-3) and precipitation and average air temperature for the same time sets (t, t-1, t-2, t-3).
- Time series used in the regression models were normalized and statistical tests and analyses were performed on the transformed (normalized) model. The series

consisted of 300 data and was divided into two parts. The first part was used for forming/calibration of the model, and the second part for testing/validation of the adaptability of the adopted regression model. The applied models were evaluated in terms of regression coefficient and standard error of the models. The models showed good adaptability, with extremely high correlation and a relatively small error of the model. Graphical presentation of the measured and generated data indicated that the generated series do not fit the extremes of the measured series. However, the simulation was performed for average monthly data, therefore the error of the model in terms of the peak may be considered as tolerant as the absolute error of the volume of the analysed series is minimal.

- Based on the adopted predictive multi-regression model $WP = f$ (Population, T, P, n, n-1, n-2, n-3), a forecast of future demands of water for the population and industry was performed, as a function of the previous number of the population and climate data for the current year and the previous time sets.

The multi-regression equation that expresses the linear relationships between a single dependent variable and more independent variables is:

$$\begin{aligned} WP = {} & a_0 Pop + a_1 T_{\mathrm{t}} + a_2 T_{\mathrm{t}-1} + a_3 T_{\mathrm{t}-2} + a_4 T_{\mathrm{t}-3} \\ & + a_5 P_{\mathrm{t}} + a_6 P_{\mathrm{t}-1} + a_7 P_{\mathrm{t}-2} + a_8 P_{\mathrm{t}-3} \end{aligned}$$

- *WP* (water consumption) is the predicted value of the dependent variable.
- Values of the independent variables are denoted by: *Pop* (number of the population), precipitation *P* and average air temperature *T* for the main meteorological station Skopje for the same time sets (t, t-1, t-2, t-3).
- a_0, a_1, …, a_n are regression coefficients. Values are assigned to the independent variables based on the principle of least squares.
- The aim of linking the quantity of produced water and main climate data was to analyse the impact of future climate change on water demands. Two scenarios were analysed: first – the number of the population until 2050 remains the same, second – the increase of the number of the population is on average an annual rate of increase of 0.58%. The first scenario of no population increase is a hypothetical, aimed to analyse the impact of precipitation and temperature changes on water demands. For the second scenario, the average annual rate of increase of 0.58% was assumed, taking into consideration an average annual population increase of 0.7% (Spatial Plan of Skopje Region 2005–2020 – draft 2009) and anticipated emigration.

RESULTS AND DISCUSSION

The analysis of climate change impact on the water supply demands for the city of Skopje is a statistical one. Results of the generation of synthetic sequences of climate series are presented subsequently: quinquennial estimates of the monthly distribution of precipitation until 2050 in Figure 2, quinquennial estimates of air temperature in Figure 3.

Results of the phase of prediction of future water demands indicate the following:

- For the first scenario, if the number of the population until 2050 remains the same, water demands during the period 2016–2050 show nearly 12% increase compared with the analysed period 1990–2015. The increase is due to the climate change conditions, i.e. decrease of precipitation and increase of temperature (Figure 4).
- For the second scenario, i.e increase of the number of the population on an average annual rate of increase of 0.58%, the results present an increase of nearly 26% of future water demands during the period 2015–2050 compared with the analyzed period 1990–2015. The increase is mainly due to the increase of the population (Figure 5).

CONCLUSIONS

Taking into consideration the average capacity of the spring that supplies the city of Skopje with drinking water (spring Rasce), as well as the yield of groundwater wells, the forecasted water demands for both scenarios using the historical pattern of water supply of consumers were linked with available water resources.

Results indicate that for the first scenario, i.e. in climate change conditions and no increase of the number of the

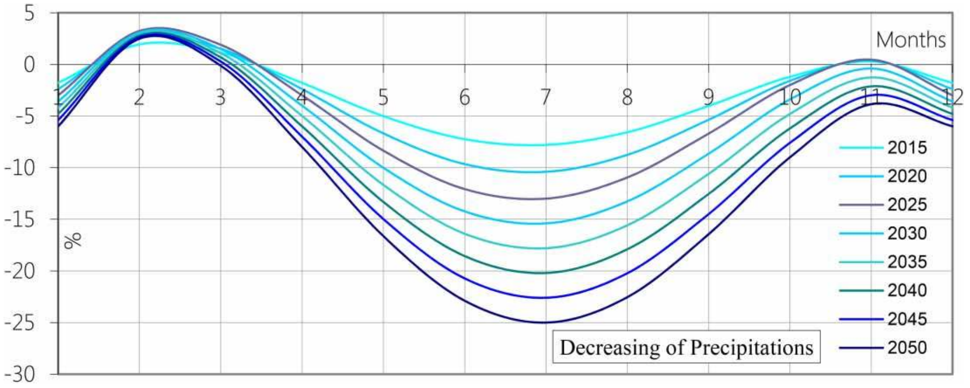

Figure 2 | Forecast of quinquennial estimates of monthly precipitation until 2050.

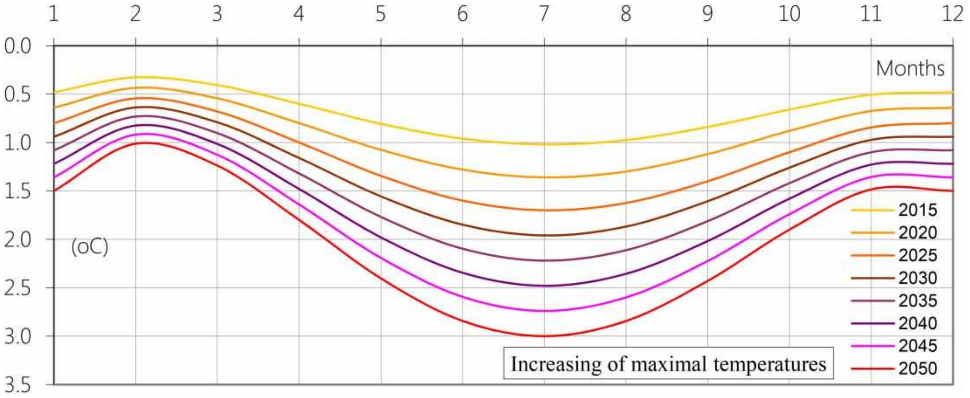

Figure 3 | Forecast of quinquennial estimates of monthly temperatures until 2050.

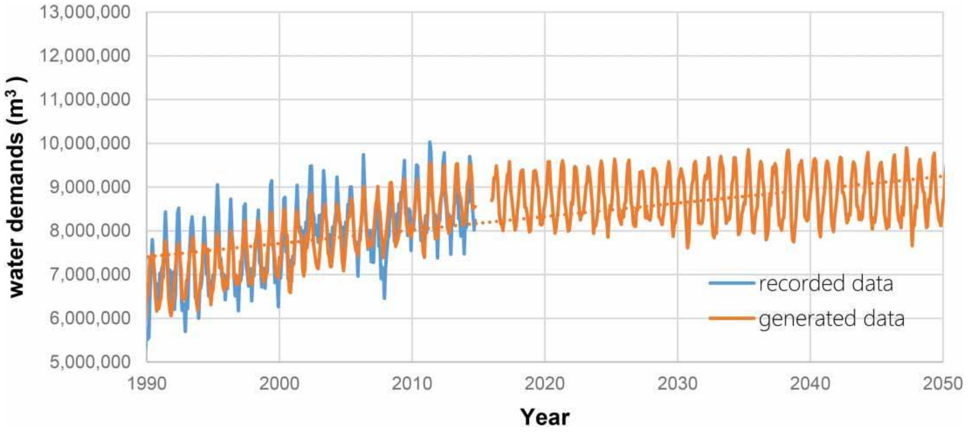

Figure 4 | Dependency of water demands for the period 2016–2050, scenario I: constant number of population, increase of temperature and decrease of precipitation.

population, the current pattern of water supply of consumers by the city water supply can be met. Even an increase of the number of the population by a 0.58% annual rate of increase contributes towards use of maximal capacities of the spring and groundwater wells to meet the forecast demands. The predicted water demands cannot be met by existing sources of the water supply system if we assume the minimal capacity of the spring Rasce, and/or

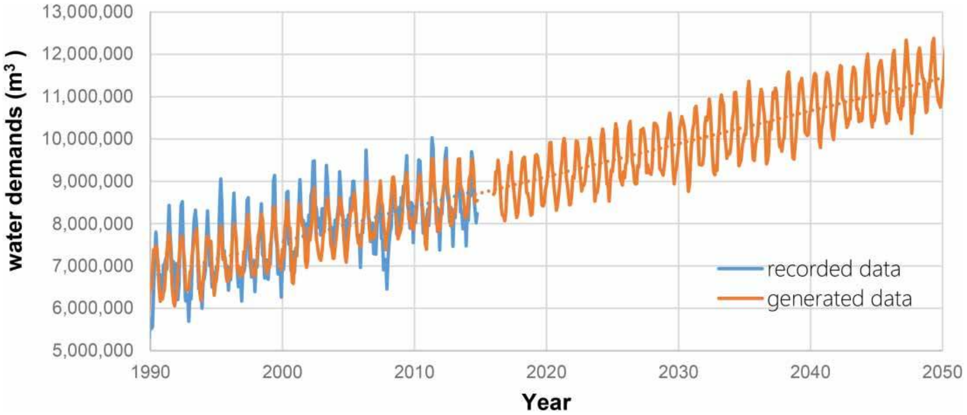

Figure 5 | Dependency of water demands for the period 2016–2050, scenario II: increase of population, increase of temperature and decrease of precipitation.

decreased discharges/yield of the Nerezi and Lepenec wells in drought conditions induced by climate change.

Adaptation to the anticipated climate change is mainly focused on reconstruction and modernization of the city water supply system of Skopje in terms of improving efficiency and reducing leakage; and targeted raising awareness activities for increasing the level of education of citizens in water saving techniques aimed to reduce per capita consumption and use alternative water sources for garden irrigation in suburban areas.

Climate changes have been already observed, unlike adaptation to climate change. Climate change adaptation is a problem of the future both requiring prediction and committment. As any prediction contains errors, we must highlight the need for including uncertainties in future projections.

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