Urban water demand assessment for sustainable water resources management, under climate change and socioeconomic changes

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ABSTRACT

The relationship between water abstraction and water availability has turned into a major stress factor in the urban exploitation of water resources. The situation is expected to be sharpened in the future due to the intensity of extreme meteorological phenomena, and socio-economic changes affecting water demand. In the city of Volos, Greece, the number of water counters has been tripled during the last four decades. This study attempts to simulate the city's network, supply system and water demand through a forecasting model. The forecast was examined under several situations, based on climate change and socio-economic observations of the city, using meteorological, water pricing, users' income, level of education, family members, floor and residence size variables. The most interesting outputs are: (a) the impact of each variable in the water consumption and (b) water balance under four management scenarios, indicating the future water management conditions of the broader area, including demand and supply management. The results proved that rational water management can lead to remarkable water conservation. The simulation of real scenarios and future situations in the city's water demand and balance, is the innovative element of the study, making it capable of supporting the local water utility.

Key words | climate change, demand forecasting, socio-economic analysis, urban water management, Volos Greece, WEAP

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INTRODUCTION

Domestic water management has become more challenging in the last decades due to several factors, environmental, social and economic. South-Mediterranean cities face more problems, as the environmental conditions are more challenging, the demand increases periodically, and the infrastructure does not always remain abreast of the latest requirements (Morley *et al.* 2015; Liemberger & Wyatt 2018).

Climate change reduces the renewable water and restraints the resources availability and quality, while the demand is increasing. Water pricing is expected to increase as a counter-measure for the resources' degradation, through the implementation of Article 9 of the Water Framework Directive (European Commission 2000). The touristic water use is also a stress in many regions regarding the coverage of the demand in summer months, when the water balance is probably deficit. South-Mediterranean cities also faced more intensively the economic crisis, which created constraints for the maintenance and the proper operation of their infrastructure. Furthermore, many external factors such as social, educational, population, etc. may affect the water consumption and its management.

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On the other hand, many studies have addressed these problems and provided modern solutions: Velasco *et al.* (2018) analyzed urban area's resilience to climate change, Rinaudo *et al.* (2012) examined different pricing policies. Also, several studies have traditionally focused on water demand forecasting techniques (Al-Zahrani & Abo-Monasar 2015; Chen *et al.* 2017). Despite the interest, a few studies have considered socio-economic parameters in urban water planning and management (Hoekstra *et al.* 2018). To the best of our knowledge, no previous study has simulated together, in a single model, parameters such as domestic demand forecasting, water balance, pricing, climate change, education and socio-economics. The present study integrates the above factors in the city of Volos, a typical Mediterranean urban area. The overall aim is to examine: (a) the future potential of serving the population with the optimum way of exploiting the existing resources, (b) the impact of each one of these factors and their combinations on the water consumption, (c) management scenarios for providing the necessary info supporting the local decision-makers. The approach presented herein attempts to improve the demand management of Volos and provide additional support and evidence to the local water utility, for the sustainable supply management.

STUDY AREA

The study area is the wider region of the city of Volos, Greece. With a population of approximately 144,000 inhabitants, Volos is the capital city of the prefecture of Magnesia. It is situated at the center of the Greek mainland, approximately equidistant from the country's two main urban centers, Athens and Thessaloniki. The Municipal Water Utility of Volos is responsible for the water supply of the urban complex of Volos (Fafoutis 2008). The city is served by the Utility's network, which covers the broader area, including the industrial area of Volos (Figure 1).

Economic crisis resulted in less operational and maintenance control. Subsequently, the network losses are estimated to be above the 40% of the total supplied water, according to the water utility. The water adequacy problems are sharpened in the summer period (May–September). The demand is covered exclusively from groundwater, coming from overexploited aquifers, quantitative and qualitative (due to the neighboring agricultural and industrial water use). Additionally, despite the WFD's recommendations on water costing according to its full value, the price remains at the same or lower levels every year. The general mismanagement regarding the implementation of economic tools

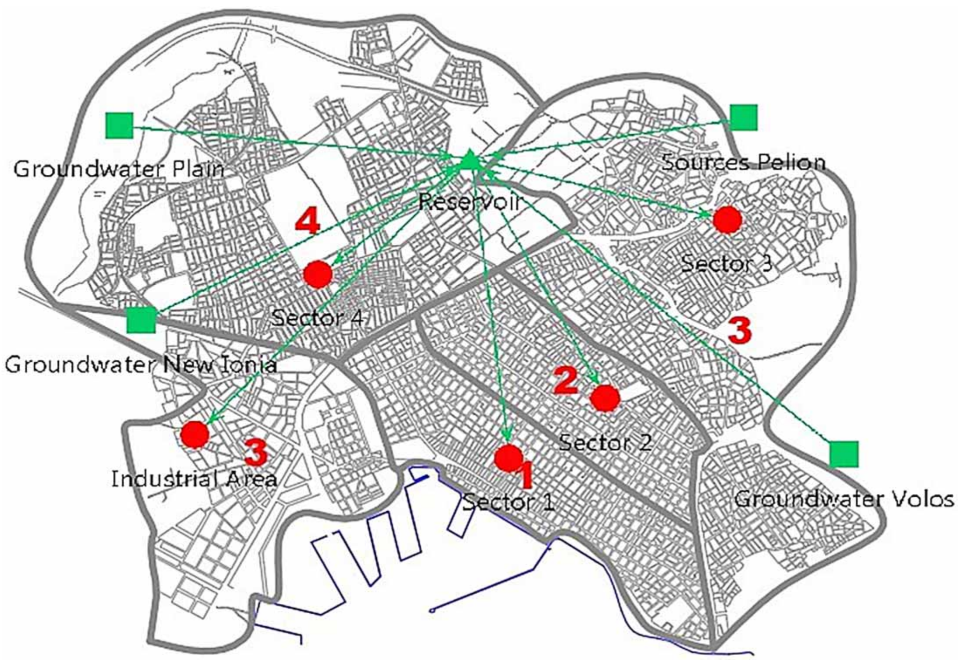

Figure 1 | The study area with its sectors and the supply sources as simulated in WEAP.

was and still is a challenge (Fafoutis 2008; Moss et al. 2009). The stakeholders' incomes have been also tested through the crisis, and thus an increment in the price is a tough political decision (Biewald et al. 2015). Another phenomenon that many attach to the crisis is the slight decrement of the population, as indicated from census databases.

METHODS

Initially, the city's network and water supply system were studied. The city is serviced by three pumping systems (Groundwater of Volos, Nea Ionia and Plain – 40 wells in total) and the sources of Mountain Pelion (five springs). The water is collected to a central block of eight reservoirs which feed the city's network (Figure 1). Data concerning the pumping capacity of each supply source (monthly water production), reservoir's characteristics, network structure and condition, and the number of water meters were retrieved from the databases of Volos' water utility for the period 1988–2017. The study area is divided into five main sectors, according to the segregation of the Municipal Water Utility of the city of Volos. Sectors 1, 2, 3 and 4 cover the urban area, while the fifth sector refers to the industrial area (Figure 1). Furthermore, the water consumption for each sector from 2007 to 2017 was known. Rainfall and temperature data were also collected from the city's meteorological station.

A WEAP (Water Evaluation And Planning system) model was developed (Stockholm Environment Institute, weap21.org), setting the above data, the models used and the scenario simulations. The 'schematic view' of the model is shown in Figure 1.

The water demand forecasting model was then developed, employing the consumption per unit of a citizens' category (hereby expressed in water meters), to the annual water demand (Brekke et al. 2002). The model is based on the equation first used in IWR-MAIN's software 'Build Forecasting Model' (AIWR 1987) (Equation (1)). This has since been used in various similar studies, for the same purpose (Mentes 2001; Mylopoulos et al. 2017).

$$Q_y = N \cdot q^* \cdot (X_{1,y}/X_{1,b})^{\beta 1} \cdot (X_{2,y}/X_{2,b})^{\beta 2} \ldots (X_{i,y}/X_{i,b})^{\beta} \quad (1)$$

where:

Q_y: the residential water consumption for the month m,
N: the number of water meters
q^*: the specific consumption per capita per day in the base year,
$X_{i,y}$: the value of parameter i in the year of prediction y,
$X_{i,b}$: the value of parameter i in the base year b (2014)
β_i: the elasticity of parameter i

The specific consumption was estimated by dividing the monthly consumption to the residents and was considered constant through the future years, as it is not changing significantly. The forecasting period was until 2028. In the studied case, the examined variables X_i were the following: rainfall, temperature, water pricing, users' income, level of education, family members, floor and size of their residence. The eight variables for the base year were retrieved from a door-to-door survey including 236 questionnaires (Mylopoulos 2015). From the same survey's data, the elasticity of each parameter was estimated as the proportionate difference in the purchased quantity divided by the proportionate difference in price paid, as described from logarithmic 3rd degree equations. Table 1 shows the results.

The elasticity of the parameters is a measure of how much each variable affects the water consumption. The size and floor of the user's residences (Ar) and (Fl) were found to be of low-elasticities, thus they were not involved in the developed predictions. The forecasting was examined under several prediction scenarios, based on climate change and socio-economic observations of the studied city, depicted on each variable's variances. Table 2 shows the variance (percentage of change) of each studied variable, as considered in Mild, Middle and Extreme (worst) situations.

Table 1 | The elasticities of the variables used, as found in Mylopoulos (2015)

Variables	Elasticities
Rainfall (P)	−0.026
Temperature (T)	0.109
Water pricing (W.P)	−0.524
Users' income (Inc)	0.025
Level of education (Edu)	−0.162
Family members (Fam)	0.083
Floor (Fl)	0.007
Size of residence (Ar)	0.047

Table 2 | The examined situations of water demand forecast

Situation	P	T	P/T	W.P	Inc	Edu	Fam
Mild	−1.07%	+1.21%	−1.07%/+1.21%	+0.05%	–	+0.05%	−0.10%
Middle	−2.95%	+2.47%	−2.95%/+2.47%	–	−0.05%	–	−0.05%
Worst	−4.36%	+4.11%	−4.36%/+4.11%	−0.05%	−0.10%	−0.05%	–

A water demand forecast was applied for each one of these 21 situations, and combinations of them. Thus, the forecasts include a range of possible future projections, providing realistic and integrated results. The percentages of change are the outcomes of our previous analyses on climate change and socio-economic factors:

- The changes in P and T occurred from the results of the simulations of 10 Regional Climate Models (RCMs) for the study area, considering a stringent mitigation scenario, one intermediate scenario and one scenario with very high greenhouse gas (GHG) emissions until the year 2100. The Representative Concentration Pathways (RCPs) were used for the estimations (IPCC 2014). The numbers indicate the short-term period's statistically downscaled results, using the Delta-Test method, as presented in Alamanos *et al.* (2018).
- The changes in W.P. illustrate the recommendations of WFD's Article 9. From January 2018, the price of urban water was expected to include its full cost, but it has remained stable, with slight reductions in the overall examined period. The numbers refer to the minimum and maximum observed price levels.
- The changes in incomes, education level and family members are also referring to population census data and statistical records of the Hellenic Authority.

After the forecast, the water balance was examined, assuming that the pumping capacity will remain stable in the future (according to the designing studies of the pumping stations and the reservoirs). According to the Water Utility's databases, the typical annual water supply is 14.3 hm^3. Considering the water demand, the monthly water supply and adjusting the aforementioned network losses, the monthly (and thus the annual) water balance was estimated.

The water balance was further examined under four management scenarios, indicating the future water management conditions of the broader area:

- Scenario BAU. The baseline scenario of the current situation.
- Scenario A. Reduction of network losses by 10%. Maintenance and strict operational control are required for the implementation of this demand-management scenario.
- Scenario B. Reduction of network losses by 20%.
- Scenario C. Reduction of network losses by 10% and increased water supply by 10 hm^3. In the future, when the new reservoir of the neighboring technical Lake Karla will operate, 50 new drilling wells will also be used for the coverage of the urban water demand of Volos city (Alamanos *et al.* 2018). Their total pumping capacity is designed to be 10 hm^3. Herein, this situation is considered as an extra combinational demand and supply management scenario. The operation of the reservoir is considered to start in 2020 for the purpose of this scenario.
- Scenario D. Reduction of network losses by 20% and increased water supply by 10 hm^3.

Summarizing, climate (RCPs) and socioeconomic trends (statistics) led to the development of three situations (Mild, Middle and Worst), i.e. extreme variations on factors affecting water demand (Table 1). These factors (variables Xi) were inserted in Equation (1) as inputs (assuming each time a situation of their change), finding thus the future water consumption (Q). Each one of the forecasted consumptions was examined also in terms of pressure on water availability (water balances) under the future management plans of the broader area (scenarios).

The water balance was calculated for each one of the 21 situations of Table 2 under each management scenario, resulting in total 105 simulations in monthly (and annual) time step.

RESULTS

Initially the forecast model's reliability was checked through comparing the observed water demand with the simulated results (Figure 2).

Having ensured that the model (equation and elasticities values) are reliable, we proceeded to the water demand forecast for every situation described in Table 2. The results of the procedure are presented indicatively in Table 3, for every two years of forecast.

Another interesting factor we examined during the forecasting procedure was the impact of each variable in the final water demand (Q). The impacts were found from the demand's results under the extreme variations considered in the forecast, according to Tables 1 and 3.

Figure 3 shows the importance of water pricing as an economic demand-management tool. Its effects on the demand decrement could be equivalent with a potential increment in the water supply. Educational level follows, proving the correlation between the final consumption and the environmental consciousness, which proved also to be much more important than income and climate change. The situations assuming changes in T and P separately are not considered realistic, but had an investigation role for the formation of Figure 3: to better understand the relations of our system and have an idea about the uncertainties that may occur.

Table 3 | Consumption under each forecast situation, compared to BAU scenario

Years of forecast	2020	2022	2024	2026	2028
Situation	**Water demand (hm^3)**				
Mild P	8.236	8.413	8.595	8.772	8.954
Middle P	8.238	8.416	8.598	8.776	8.958
Worst P	8.240	8.418	8.600	8.779	8.962
Mild T	8.240	8.419	8.602	8.780	8.963
Middle T	8.246	8.426	8.611	8.791	8.975
Worst T	8.253	8.435	8.622	8.804	8.991
Mild T/P	8.242	8.420	8.603	8.782	8.965
Middle T/P	8.249	8.430	8.615	8.795	8.981
Worst T/P	8.260	8.441	8.629	8.811	9.000
Mild W.P	8.164	8.303	8.445	8.581	8.720
Middle W.P	8.235	8.412	8.593	8.770	8.951
Worst W.P	8.307	8.523	8.745	8.964	9.189
Mild Inc	8.225	8.399	8.577	8.751	8.929
Middle Inc	8.230	8.405	8.585	8.760	8.940
Worst Inc	8.235	8.412	8.593	8.770	8.951
Mild Edu	8.202	8.369	8.541	8.708	8.879
Middle Edu	8.235	8.412	8.593	8.770	8.951
Worst Edu	8.268	8.455	8.646	8.832	9.024
Mild Fam	8.201	8.368	8.540	8.706	8.877
Middle Fam	8.218	8.390	8.566	8.738	8.914
Worst Fam	8.235	8.412	8.593	8.770	8.951

The water balance was calculated for every situation, under every scenario, as mentioned above. The city has insignificant touristic water use, so the monthly variation of the water balance is low. The overall results are presented

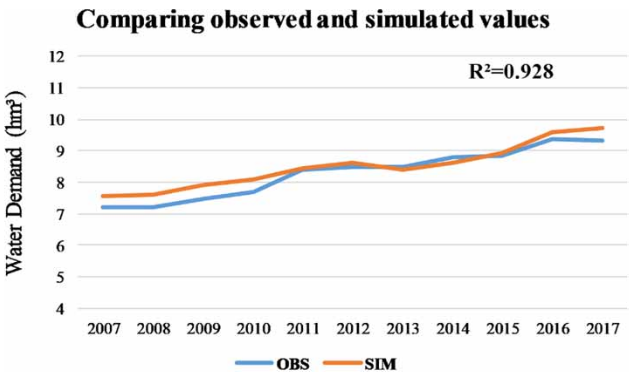

Figure 2 | The performance of the developed model.

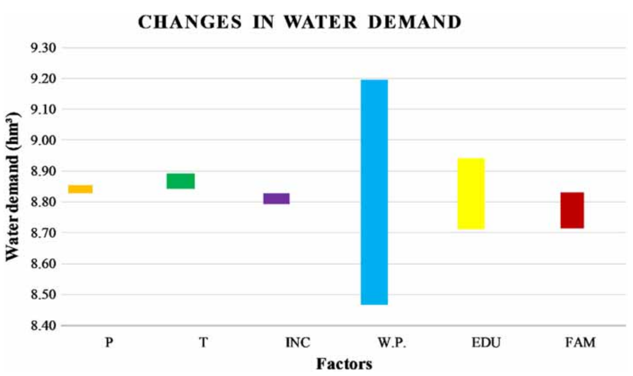

Figure 3 | Impacts of each variable in the total water demand.

in Figures 4–7. Indicatively, the balances are presented for the extreme situations, every four years of forecast.

DISCUSSION

Urban water demand forecasting techniques have been scrutinized by many studies, but the practical implementation of such techniques is rare. A lot of techniques have been proposed, but their complexity, the nature, the quality of the available data and the number of variables make them stay in the academic circles. In previous stages of the research we examined other forecasting models (random forest, neural networks, multiple regression models) but the lack of some basic outputs in specific time units lead us to the choice of the presented equation. For the same reasons this simple model is used by most water utilities in practice (Jentgen *et al.* 2007; Billings & Jones 2008). Furthermore, the proposed model has been judged to provide the right balance between data needs and accuracy (Donkor *et al.* 2012), however, a detailed description and models' comparison is in our future concerns.

The performance of the model is satisfactory and the conditions that developed the forecasts are considered as realistic as possible. Water price had the biggest impact on water consumption, followed by education level and family members, while climate changes do not seem to affect significantly Volos's water demand in the decade.

Scenario A (Figure 4) assumes a network losses reduction of 10%. Increased future water demand (Table 3) is the competitive force, that seems to affect significantly water balance after 2020. Scenario B (losses reduced by 20%), appears to give a solution to every situation for the long-term. By reducing the network losses by 20% in Scenario B (Figure 5) the water balance is significantly improved compared to Scenario A, still decreasing but remaining positive for all situations until year 2028. Scenario C (Figure 6) consists of Scenario A plus an increased water supply by 10 hm^3 from the reservoir of the neighboring Lake Karla starting from the year 2020. The increase of water balance is spectacular for the years 2020–2028, due to the total pumping capacity (10 hm^3) of the 50 new drilling wells, pumping from the reservoir of the lake. In Figure 7 Scenario D (reduction of network losses by 20% and increased water supply by 10 hm^3) is an improved scenario C, where the increase of water balance is positive for all situations examined until the year 2028.

Scenarios A and B are feasible (since the total leakages are estimated above 40%), more environmental-friendly solutions compared to the increment of water supply (Scenarios C and D), and in a lower cost. Despite the performance of the losses-reduction scenarios, they are not considered at the time, in contrast with the (unnecessarily high) increment of water supply. The above findings indicated that if proper network improvements are applied, then it is not necessary to use water from every supply

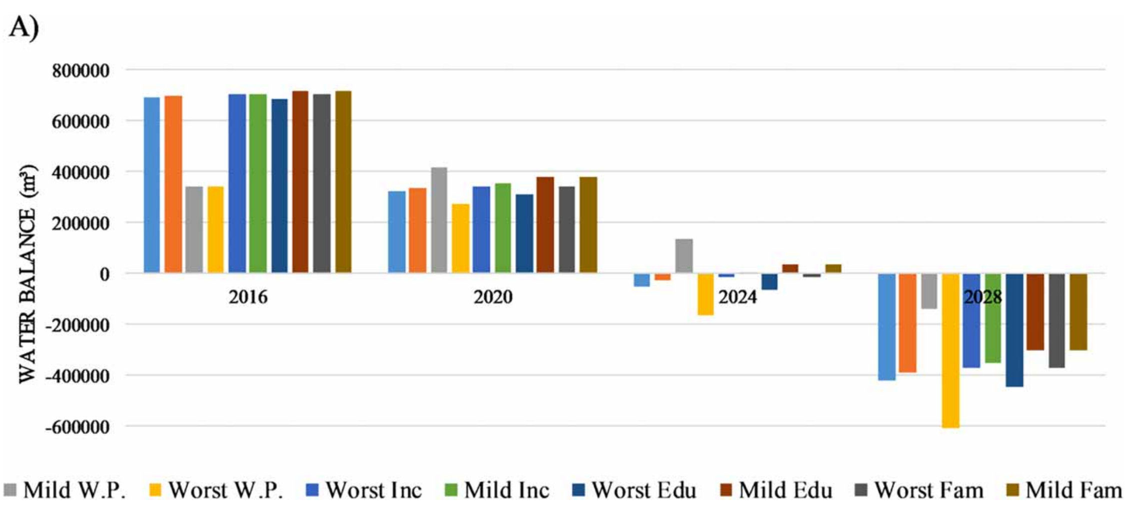

Figure 4 | Future water balances for Scenario A.

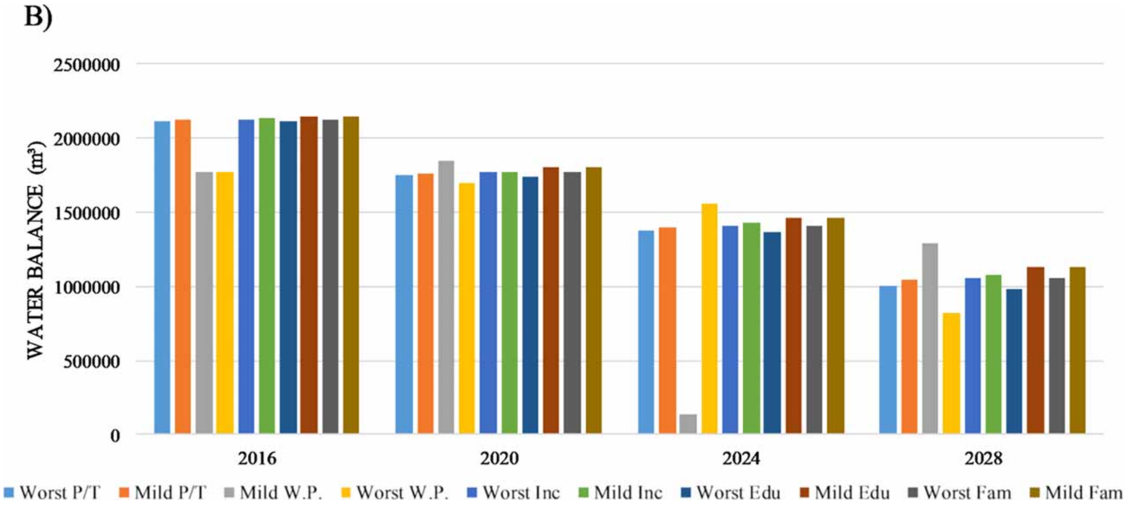

Figure 5 | Future water balances for Scenario B.

source. Furthermore, the extra water supply from the 'Groundwater Plain' can cover a big part of the water needs. Thus, a supply management control should be planned in order to find the optimum amount of pumping from each source throughout every year.

CONCLUSIONS

The study attempted to simulate the water demand of the city of Volos, in a detailed and integrated way. For the first time, these parameters are considered in the same framework, in order to give useful feedback to the Water Utility of Volos regarding the coverage of the future water demand. Climate change, water pricing, users' income, education and family members were examined within the study, combining climate and socio-economic changes. The development of realistic scenarios and future situations and their simulation for the city's future demand and water balance is the innovative element of the study.

The examined variables affecting the water demand were: rainfall, temperature, water pricing, users' income, level of education, family members, floor and size of their residence. The forecasting was examined under several

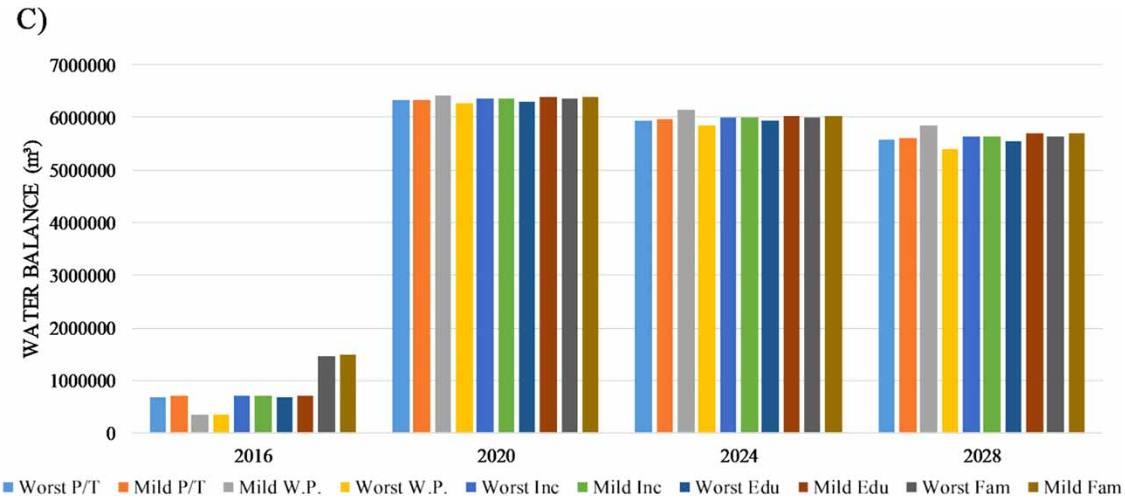

Figure 6 | Future water balances for Scenario C.

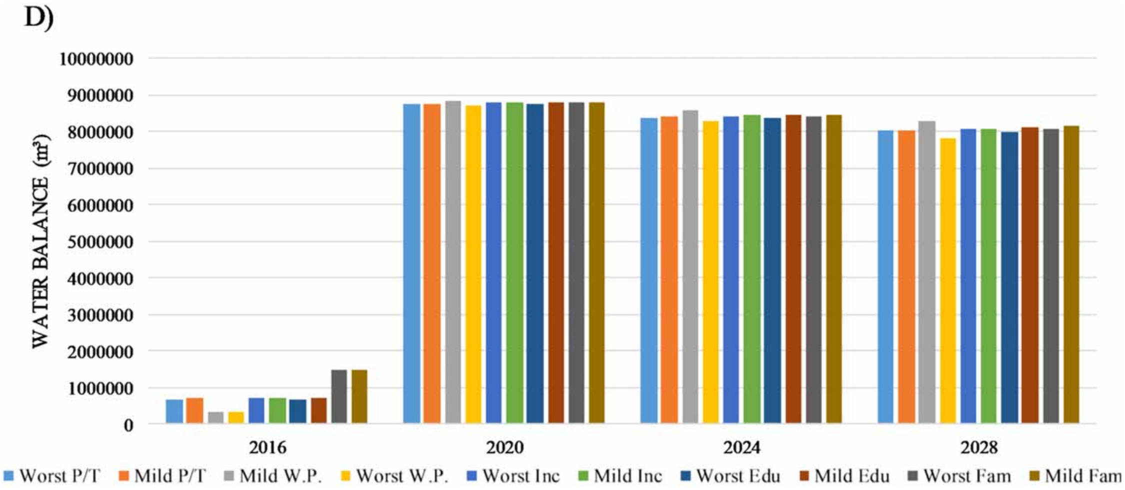

Figure 7 | Future water balances for Scenario D.

prediction scenarios, based on climate change and socioeconomic observations of the studied city, depicted on each variable's variances in mild, middle and extreme (worst) situations. The water balance was calculated for each situation under possible management scenarios.

This work did not intend to propose a new management or forecasting framework, but to simulate the conditions of water supply and demand in the city of Volos for different plausible futures. Unavoidably it has limitations, such as the constant elasticities in future years, but the main purpose was to sensitize the local water utility.

Water underpricing prevails, causing water demand to increase significantly. On the other hand, the exploitation of the water resources is proved insufficient, since the use of a large number of wells for water supply drains the aquifer. Water pricing is proved to be a very important financial tool for the water demand management, since it is the only factor perceived directly by the consumers and is compatible with the principles of the Sustainable Water Resources Management and the Water Framework Directive 2000/60/EC (European Commission 2000; Fafoutis 2008). The results of scenario 5, indicate that water pricing strongly contributes to water saving. In any case, the Water Utility of Volos should adopt a demand-oriented water use policy, in order to achieve water conservation and sustainable use.

An integrated pipe-network management could lead to the reduction of water losses and save a percentage of 20–35% of the total volume of water needed. This solution, based on modern systems and techniques, ensures that water needs (present and future) will be covered, with minimum environmental impact. In order to overcome all administrative and political difficulties, the collaboration of the stakeholders is necessary.

CONFLICT OF INTEREST

None.

DATA AVAILABILITY STATEMENT

Data available after request from the authors.

REFERENCES

Alamanos, A., Mylopoulos, N., Vasiliades, L. & Loukas, A. 2018 Climate change effects on the availability of water resources of Lake Karla watershed for irrigation and Volos city urban water use. In *Proceedings of the 14th Protection and Restoration of the Environment (PRE) Conference*, July 3–6, 2018, Thessaloniki, Greece, pp. 3–12.

Al-Zahrani, M. A. & Abo-Monasar, A. 2015 Urban residential water demand prediction based on artificial neural networks and time series models. *Water Resour. Manage.* **29**, 3651. https://doi.org/10.1007/s11269-015-1021-z.

Army Institute of Water Resources (AIWR) 1987 *IWR-MAIN Water Use Forecasting System, Version 5.1, User's manual* *and System Description*. Water Resources Support Center, Institute of Water Resources, Ford Belvoir, VA, USA.

Biewald, A., Kowarsch, M., Lotze-Campen, H. & Gerten, D. 2015 Ethical aspects in the economic modeling of water policy options. *Global Environ. Change* **30**, 80–91.

Billings, B. & Jones, C. 2008 *Forecasting Urban Water Demand*, 2nd edn. American Waterworks Association, Washington, DC, USA.

Brekke, L., Larsen, M., Ausburn, M. & Takaichi, L. 2002 Suburban water demand modeling using stepwise regression. *J. Am. Water Works Assn* **94** (10), 65–75.

Chen, G., Long, T., Xiong, J. & Bai, Y. 2017 Multiple random forests modelling for urban water consumption forecasting. *Water Resour. Manage.* **31**, 4715. https://doi.org/10.1007/s11269-017-1774-7.

Donkor, E. A., Mazzuchi, T. A., Soyer, R. & Roberson, J. A. 2012 Urban water demand forecasting: review of methods and models. *J. Water Resour. Plann. Manage.* **140** (2), 146–159.

European Commission 2000 Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of European Communities, 22 October 2000.

Fafoutis, C. 2008 *Integrated Approach to Water Demand Management in the Residential Sector-Costing According to the Full Value*. PhD Thesis, Department of Civil Engineering, University of Thessaly, Thessaly, Greece.

Hoekstra, A. Y., Buurman, J. & van Ginkel, K. C. H. 2018 Urban water security: a review. *Environ. Res. Lett.* **13**, 053002. https://doi.org/10.1088/1748-9326/aaba52.

Intergovernmental Panel on Climate Change, Synthesis Report 2014 *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Core Writing Team, R. K. Pachauri & L. A. Meyer, eds). IPCC, Geneva, Switzerland.

Jentgen, L., Kidder, H., Hill, R. & Conrad, S. 2007 Energy management strategies use short-term water consumption forecasting to minimize cost of pumping operations. *J. Am. Water Works Assn* **99** (6), 86–94.

Liemberger, R. & Wyatt, A. 2018 Quantifying the global non-revenue water problem. *Water Supply* **19** (3), 831–837. https://doi.org/10.2166/ws.2018.129.

Mentes, A. 2001 *Demand Management in Water Supply Sector. Development of an Integrated System of Alternative Policies in Water Demand Management*. PhD Thesis, Department of Civil Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece.

Morley, M. S., Vitorino, D., Behzadian, K., Ugarelli, R., Kapelan, Z., Coelho, S. T. & Do Céu Almeida, M. 2015 Decision support system for the long-term city metabolism planning problem. *Water Supply* **16** (2), 542–550. doi: https://doi.org/10.2166/ws.2015.167.

Moss, T., Medd, W., Guy, S. & Marvin, S. 2009 Organising water: the hidden role of intermediary work. *Water Altern.* **2** (1), 16–33.

Mylopoulos, N. 2015 Assessment of urban water full cost under the conditions of an economic crisis. *Eur. Water* **49**, 89–105.

Mylopoulos, N., Fafoutis, C., Sfyris, S. & Alamanos, A. 2017 Impact of water pricing policy and climate change on future water demand in Volos, Greece. In: *10th World Congress of EWRA*, 5–9/7/2017, Athens, Greece.

Rinaudo, J. D., Neverre, N. & Montginoul, M. 2012 Simulating the impact of pricing policies on residential water demand: a southern France case study. *Water Resour. Manage.* **26**, 2057. https://doi.org/10.1007/s11269-012-9998-z.

Stockholm Environment Institute (SEI) Water Evaluation and Planning System. weap21.org.

Velasco, M., Russo, B., Martínez, M., Malgrat, P., Monjo, R., Djordjevic, S., Fontanals, I., Vela, S., Cardoso, M. A. & Buskute, A. 2018 Resilience to cope with climate change in urban areas – a multisectorial approach focusing on water – The RESCCUE project. *Water* **2018** (10), 1356.

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