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Drinking water demand forecasting using artificial neural network in Tunisia

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1. Introduction

Managers of drinking water systems hardly work to supply consumers with appropriate quality, quantity and pressure with the least treatment and management costs. This task can be strongly enhanced if water demands are accurately known in advance as long as possible.

The stochastic nature of drinking water demand (DWD) at daily and hourly time step is an evidence and was largely studied for characterization. DWD patterns of large cities depend on socio-economic rhythms, sizes (population), supply network proprieties and climate. DWD long-term (annual) trend can be identified using statistical analyses seen the dominance of the population annual growth and/or socio-economic sectors. Short-term (daily and hourly) patterns of DWD are more influenced by climatic conditions and socio-economic rhythms, difficult to fit with statistical approaches.

A literature review confirmed the efficiency and the robustness of artificial neural network (ANN) to forecast DWD in a large specter of socio-economic contexts as California (Ghiassi et al., 2008), Bangkok (Babel et Shinde, 2010), Mecca en Arabie Saoudite (Ajbar et Ali, 2015) et Laminga Jos (Gwaivangmin, 2017).

Seen the huge increase of DWD in Tunisian cities, starting from 2010, without a parallel reinforcement of water resources and hydraulic infrastructures, drinking water shortage becomes a real risk that can affect citizen's welfare and the economic activities of many sectors (hotels, industries, restaurants, schools, universities, administration, etc.).

In order to contribute to reduce risk of water shortage associated to inadequacy between hydraulic systems and DWD, this research aim is to develop robust models to forecast short-term DWD using ANN. The challenge is to forecast daily DWD for the longest period, for different supply networks to optimize tanks and water treatment plant (WTP) management.

2. Methodology

The calibrated methodology to forecast daily DWD is composed of three steps: (i) building of a daily database of drinking water supply and the lowest and heighted temperatures (January 2008 to December 2017); (ii) pre-processing and statistical analysis to identify the explanatory variables of the DWD; (iii) building, training and validation of the designed ANN using MATLAB script. In this step, the elaborated database is divided in two sets: the first one (90%) for ANN training and the remaining (10%) for validation.

Statistical indicators used to evaluate the performances of the trained ANN as well as to evaluate the validation phase are: (i) correlation coefficient; (ii) average absolute error and (iii) maximal absolute error.

3. Case study

Tunis City is supplied by drinking water by the main WTP "Ghedir El Golla" (GEG) through 21 main tanks, by gravity (Fig. 1).

Tunis City consumes almost 150 million m^3 per year, supplied by GEG WTP, with an average of 5.0 m^3/s.

The proposed methodology is applied for two supply networks in Tunis city feed by two tanks: "Belvedere Haut" and "Manouba 72", each of them have a capacity of 10,000 m^3 and characterized by maximal water level equal to 72 m. Next figure shows the daily supply trend as well as daily maximal air temperatures observed at Carthage meteorological station (2008–2017).

Their respective maximal daily supplies are estimated to 50,000 and 25,000 m^3.

4. Results

4.1. Statistical analysis and selection of ANN inputs

Statistical analysis was used to evaluate the correlation between water supply (VDJ1) and minimal and maximal temperatures (exogenous variables) as well as the previous 7 d water supply (endogen variables): VDJ-1 to VDJ-7. Tables 1 and 2 shows the detailed correlation results:

For both tanks, it is proved the strong relationship between temperature (min and max) and the supply volume. Maximal temperature was more correlated to supply volume for both studied tanks. It is also shown that previous

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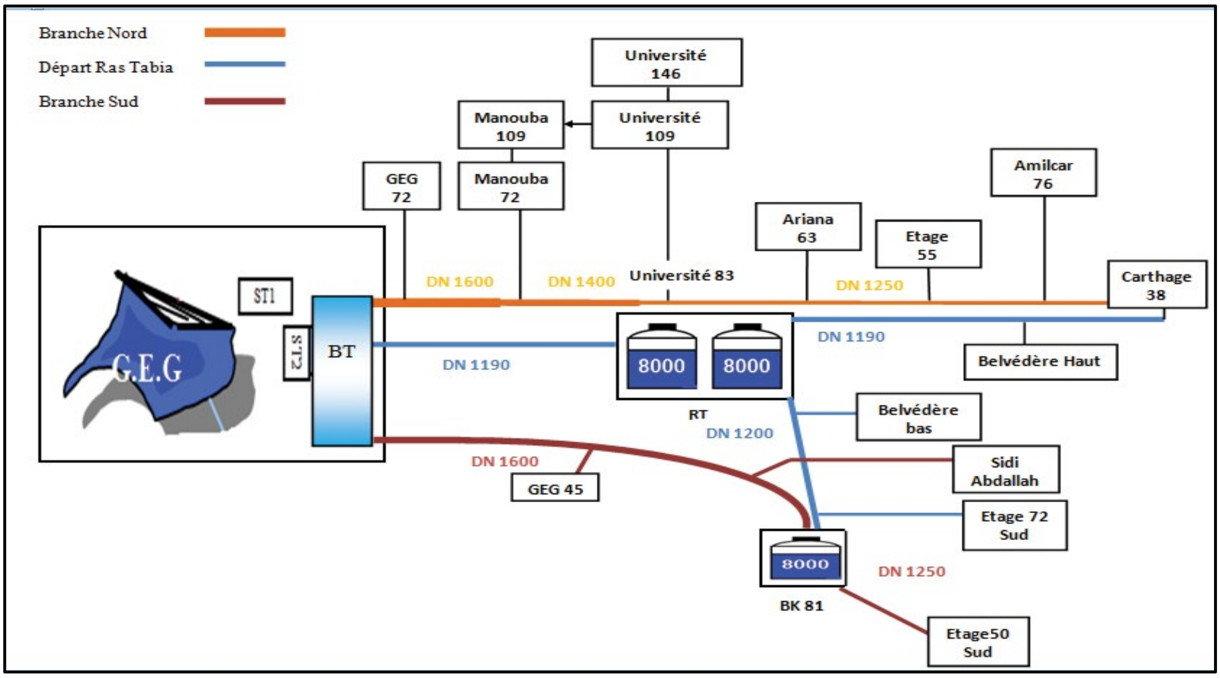

Fig. 1. Simplified schematic of the drinking water supply network for Tunis City.

Table 1
Matrix of correlation coefficients for Manouba 72 tank

Variables	Tmin	Tmax	VDJ1	VDJ-1	VDJ-2	VDJ-3	VDJ-4	VDJ-5	VDJ-6	VDJ-7
Tmin	1									
Tmax	0.882	1								
VDJ1	0.574	0.580	1							
VDJ-1	0.572	0.576	0.958	1						
VDJ-2	0.571	0.572	0.928	0.958	1					
VDJ-3	0.572	0.573	0.904	0.928	0.958	1				
VDJ-4	0.574	0.573	0.888	0.904	0.927	0.958	1			
VDJ-5	0.572	0.575	0.873	0.888	0.904	0.927	0.958	1		
VDJ-6	0.572	0.574	0.861	0.874	0.888	0.904	0.928	0.958	1	
VDJ-7	0.573	0.574	0.85	0.862	0.874	0.888	0.905	0.928	0.958	1

Table 2
Matrix of correlation coefficients for Belvedere haut tank

Variables	Tmin	Tmax	VDJ	VDJ-1	VDJ-2	VDJ-3	VDJ-4	VDJ-5	VDJ-6	VDJ-7
Tmin	1									
Tmax	0.879	1								
VDJ	0.370	0.374	1							
VDJ-1	0.369	0.376	0.890	1						
VDJ-2	0.373	0.374	0.801	0.89	1					
VDJ-3	0.372	0.375	0.744	0.801	0.89	1				
VDJ-4	0.373	0.373	0.710	0.744	0.801	0.89	1			
VDJ-5	0.376	0.377	0.693	0.71	0.744	0.801	0.89	1		
VDJ-6	0.376	0.378	0.680	0.693	0.71	0.744	0.801	0.89	1	
VDJ-7	0.375	0.377	0.673	0.68	0.693	0.71	0.744	0.801	0.89	1

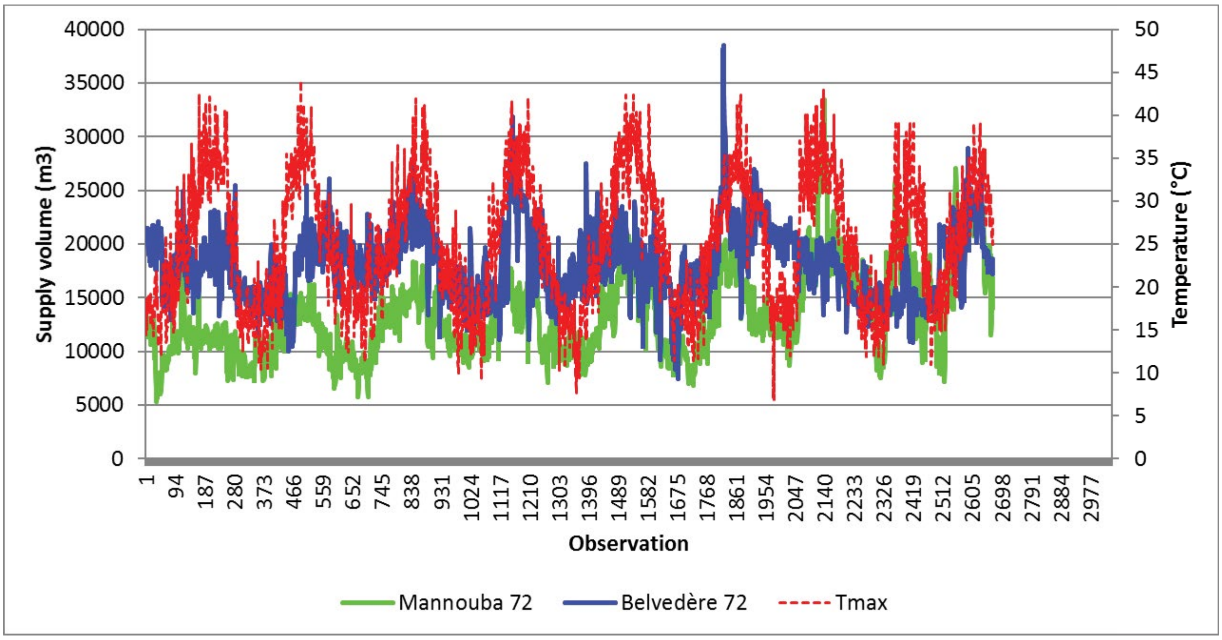

Fig. 2. Daily supply of "Manouba" and "Belvédère Haut" tanks.

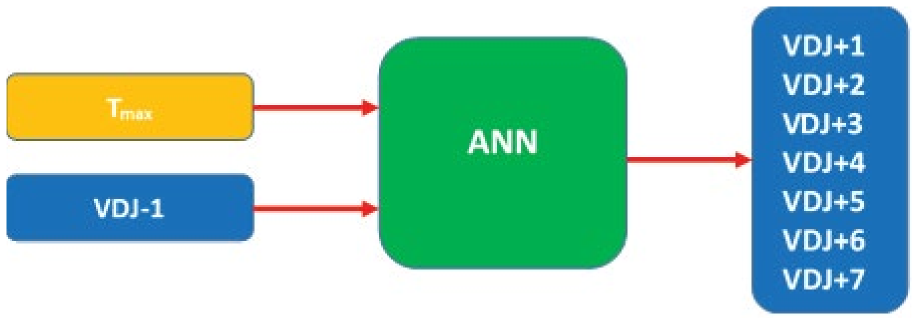

Fig. 3. ANN structure to forecast daily DWD for Manouba 72 and Belvedère Haut tanks.

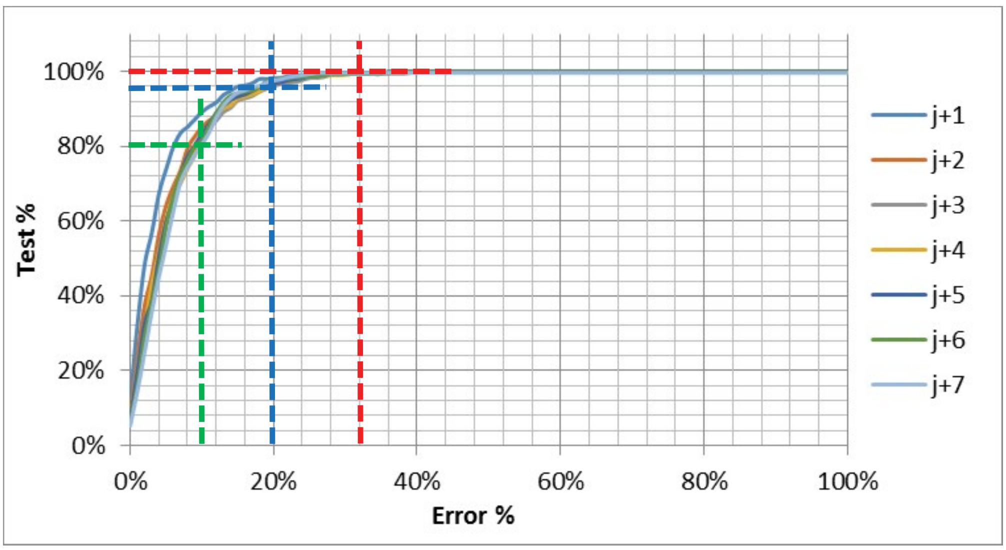

Fig. 4. Frequency curve of forecasting errors for "Belvédère Haut" tank.

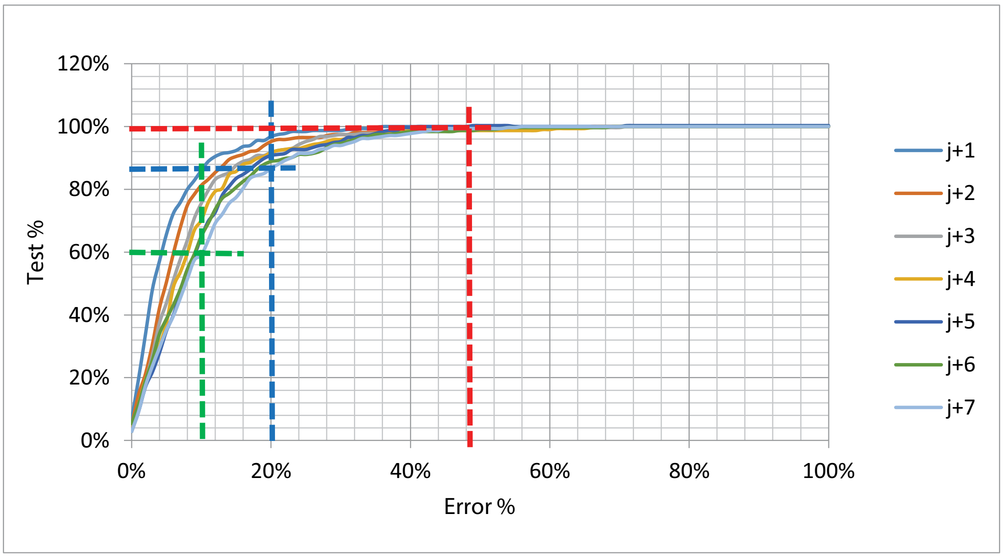

Fig. 5. Frequency curve of forecasting errors for "Manouba 72" tank.

supply volumes are strongly correlated to supplies of the following days. Indeed, historical supply represents indirectly importance of the supply network and the population as well as the socio-economic activity category. Supply of the previous day was the most correlated to supply volume.

Seen the previous results, it is decided to use the maximal temperature and the supply volume of the previous day as inputs for the ANN to forecast daily supply volumes for the following 7 d. Therefore, the ANN structure adopted in this research is given by Fig. 3.

4.2. Forecasting drinking water supply

After training phases using 90% of the database, the ANN of the two tanks were used to forecast supply volumes of the seven following days for the remaining 10% of the study period. The Fig. 4 summarize the relative estimation errors.

It is clear that for "Belvédère Haut" tank, the ANN was efficient to forecast drinking water supply up to 7 d with acceptable error. The error was the lowest for 1 d and the highest for 7 d. 100% of the forecasting tests are characterized by errors less than 36%. Among them, 96% are characterized by errors less than 20%. For 80% and 88% of the tests, respectively, for the forecast of 7 d and 1 d, the errors are less than 10%.

For "Manouba 72" tank, the ANN was efficient for the first day forecast. The error increases in parallel to the forecasting horizon. 100% of the forecasting tests are characterized by errors less than 48%. Among them, 84% to 96% are characterized by errors less than 20%, respectively, for the forecast of 7 d and 1 d. For 60% to 88% of the tests, respectively, for the forecast of 7 d and 1 d, the errors are less than 10%. More explorations, in terms of inputs and data processing, are required to improve the obtained forecasting performances for "Manouba 72" tank.

Forecasts of DWD showed acceptable results proving that ANNs are successful in predicting daily DWD supplied by the studied tanks. Only the maximum temperatures and the supply of the previous day are used as input to accurately forecast DWD for seven following days.

5. Conclusions

The main conclusion of the present research is the robustness of ANN to forecast daily DWD for one following week using one endogen (historical demand) and one exogenous (temperature) variables. Long time series and good quality of the input data are necessary to succeed the training and the validation of the ANN. As a perspective, this research can explore the forecasting efficiency for longer period (15 to 30 d).