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Application of a Stochastic Model for Water Demand Assessment under Water Scarcity and Intermittent Networks †

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Abstract: Climate change is affecting water resources and other aspects of life in many countries, generating more frequent extreme events. Users react to intermittent supply by implementing local private tanks to collect as much water resources as possible to cope with water distribution suspension periods. Such tanks are commonly overdesigned due to the common perception that water resources are essential for human activities and the general need of users to safeguard their water supplies. This study evaluated the impact of water scarcity and users' self-adaptation strategies on water demand under intermittent flow conditions by implementing an experimental campaign in a real network. The analysis was conducted using a short-term water demand forecast model that reproduces periodic patterns observed at an annual, weekly and daily level to evaluate the adaptation response of users concerning the scarcity of water resources through a comparison between the real pattern of the network and the pattern of local tanks.

Keywords: intermittent networks; local tanks; stochastic model; user adaptability; water scarcity

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1. Introduction

Climate change is affecting water resources and other aspects of life in many countries, generating more frequent extreme events [1]. In particular, droughts and the consequent urban water scarcity events make water supply management critical [2]. Cities are particularly sensitive to this issue as they face increased demand to meet human needs due to the increase in urban populations worldwide and, at the same time, due to aging infrastructures losing their efficiency in delivering water resources to users [3]. Frequently, non-forecasted water scarcity conditions are managed by implementing intermittent water supply to reduce pipe leakages and compress water consumption by rationing water resources among users [4]. The impact of such practices on asset aging and increased maintenance needs are well documented in the literature [5].

Users react to intermittent supply by implementing local private tanks to collect as many water resources as possible to cope with water distribution suspension periods. Such tanks are commonly overdesigned due to the common perception that water resources are essential for human activities and the general need of users to safeguard their water supplies.

This study evaluated the impact of water scarcity and users' self-adaptation strategies on water demand under intermittent flow conditions by implementing an experimental campaign in a real network. This was analyzed using consumption data, monitored at the inlet and outlet of private tanks for a residential area in the metropolitan area of Palermo. Different pressure conditions and levels of overdesign were considered to better characterize demand patterns in intermittent supply. The analysis was conducted using a short-term water demand forecast model that reproduces periodic patterns observed at

an annual, weekly and daily level, in order to evaluate the adaptation response of users concerning the scarcity of water resources, through a comparison between the real pattern of the network and the pattern of local tanks.

2. Materials and Methods

This study was developed in a small district, called network 11 (Noce-Uditore), part of 1 of the 17 subnetworks of the distribution system of the city of Palermo (Figure 1), made up of 434 m of main pipes, with polyethylene measuring a diameter of 110 mm and 14 service connections that supply a total of 52 users. All users are provided with private tanks downstream of the incoming water meters, as in the past the water supply was intermittent.

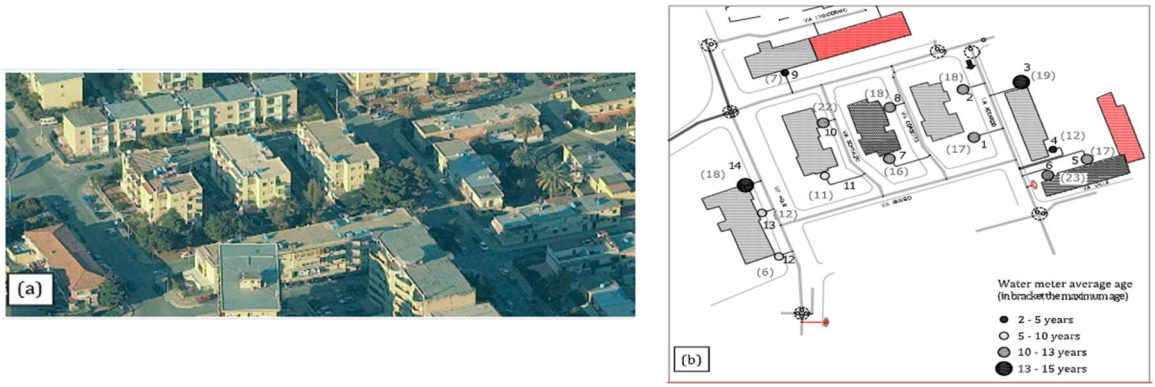


Figure 1. Top view of the Palermo district area (**a**) and schematic representation of the network with an indication of the water meters (**b**).

To date, the service is provided continuously, but users do not bypass the tank due to a lack of confidence in the reliability of the service. The data were collected following a monitoring campaign, in which users were monitored according to the scheme proposed in Criminisi et al. (2009) [6], installing flow meters upstream and downstream of private reservoirs with a time resolution of 1 min; the pressure was monitored on the network node with a time resolution of 15 min. The multivariate stochastic model developed in Fontanazza et al. (2016) [7], which is based on copula functions, was integrated with reservoir continuity equations (Equation (1)) and the float valve outflow law (Equation (2)) to take into account the filling and emptying phases of the tank, considering both a supply with intermittent and continuous operation over a 24 h period, in order to evaluate the users' adaptation response to the scarcity of water resources. For the values of the outflow coefficient, C_v, and the effective outflow area, a, we referred to the parameters calibrated in Criminisi et al. (2009) [6].

$$Q_{up} - D = \frac{dV}{dt} = A\frac{dh}{dt} \tag{1}$$

$$Q_{up} = C_v \cdot a \cdot \sqrt{2gP} \tag{2}$$

$$C_v = \begin{cases} seh < h_{min} \Rightarrow C_v = C_v^* \\ seh > h_{min} \Rightarrow C_v = C_v^* \cdot \left(\frac{h_{max} - h}{h_{max} - h_{min}}\right)^n \end{cases} \tag{3}$$

$$a = \begin{cases} seh < h_{min} \Rightarrow a = a^* \\ seh > h_{min} \Rightarrow a = a^* \cdot \left(\frac{h_{max} - h}{h_{max} - h_{min}}\right)^m \end{cases} \tag{4}$$

3. Results and Discussion

Figure 2 shows the results obtained from the aforementioned application on a single user, with their average daily consumption shown in Figure 2a. The analysis was conducted considering a supply with continuous operation over 24 h and intermittent operation, with

a filling time of 8/24 h, in order to evaluate the adaptation response of users to the scarcity of water resources.

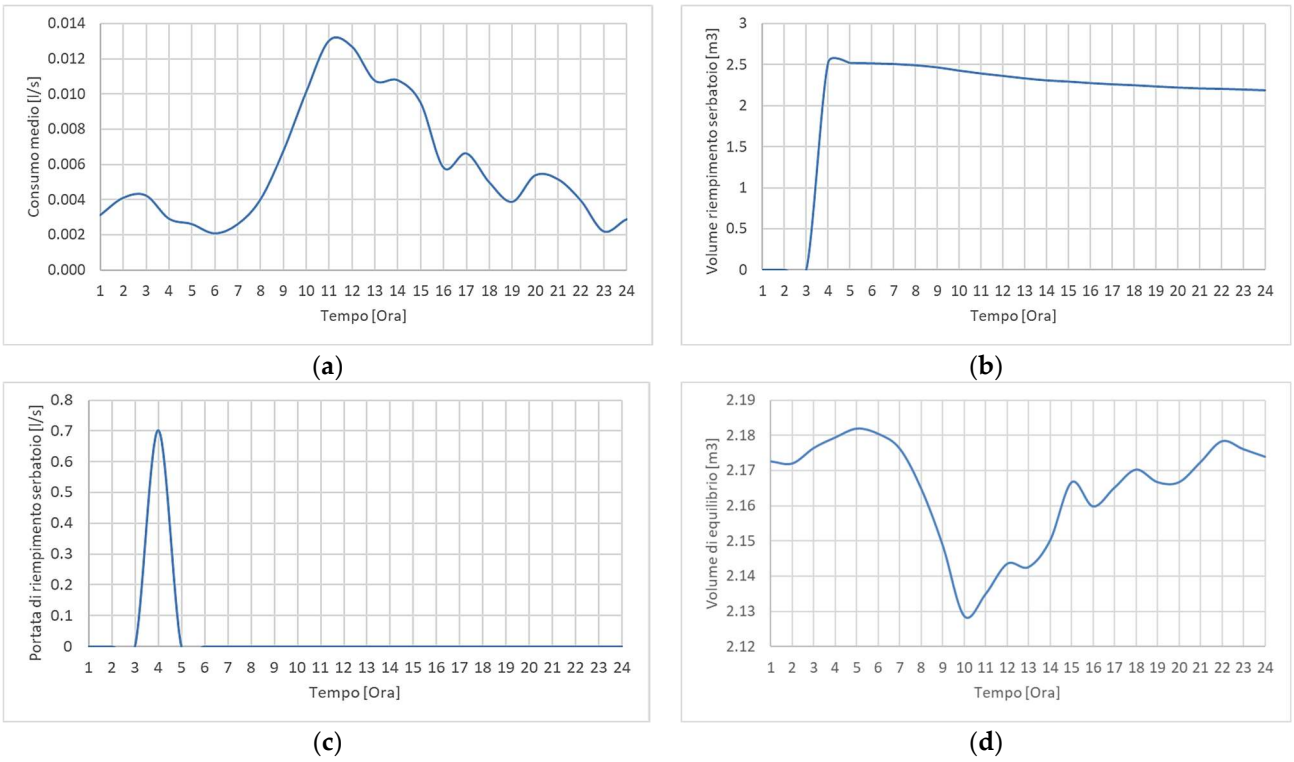


Figure 2. Trend of average consumption over the course of the day (**a**), of the volume of the tank being filled (**b**) and of the flow rate entering the tank (**c**), considering intermittent supply and the presence of a float valve, as well as the trend of the equilibrium volume of the tank (**d**).

By analyzing the tank filling/emptying phases in both operating conditions, it was possible to determine the maximum volume to be assigned to the private tank.

4. Conclusions

Using the data of the average daily consumption of a user in the area under study, the model made it possible to evaluate users' adaptation response to water scarcity, considering two types of flow supply: continuous and intermittent operation over 24 h. The model used made it possible to simulate the filling and emptying of the tank, verifying the correct delivery of the service as the service delivery time varied.

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Data Availability Statement: Dataset available on request from the authors.

Conflicts of Interest: The authors declare no conflicts of interest.

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