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Multi-scale Modelling of Urban Water Demand under Urban Development and Societal Uncertainties: The Case Study of Milan, Italy.

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Urban water demands vary across multiple spatio-temporal scales, driven by population growth, climate change, and urbanization. Demand-side management emerged as an important complementary measure to supply-side interventions to address urban water scarcity, foster water conservation, and inform water governance. Moreover, rapid development and deployment of Advanced Metering Infrastructure (AMI) and so-called digitalization in the water sector unfold new opportunities to uncover water demand patterns and model water demands at increasingly high spatial and temporal scales. However, challenges to modelling water demands arise from the uncertainties of water demands under abrupt environmental and societal change. The current Covid-19 Pandemic with the Stay-at-Home order is an example of such sources of uncertainty because it rapidly and unexpectedly changed people's working patterns and lifestyles. Understanding and modelling water demands across spatial and temporal scales considering an uncertain world is, thus, key to designing robust demand management strategies.

In this work, we investigate urban water demand changes at multiple spatio-temporal scales in Milan (Italy). We combine different state-of-art data-driven models (i.e., Ruptures breakpoint detection framework, LightGBM, Hierarchical clustering, and Recurrent Neural Networks) to extract water demand characteristics from heterogeneous data sources, including historical time series of water consumption recorded with AMI, drinking water volumes pumped in the water distribution network, and socio-demographic characteristics of different urban districts. At the city scale, we found that a significant declining trend in water consumption occurred in 2017-2020, especially during the Pandemic and the first lockdown measures. At the sub-city scale, we explored the relationships between water demand and different socio-demographic, economic, and urban form features with data from 2004 to 2020. Finally, we analyzed AMI data collected at the water account level in 2019-2021 to assess the effect of Pandemic on demand pattern change and cross-correlate it with spatial heterogeneity of neighborhood features. While the investigation of historical demand pattern change gives insights to design long-term demand management strategies, accurate prediction of future demand can help improve short-term operational efficiency for water utilities. In this regard, in the last phase of this work, we compare state-of-art predictive models to explore how accurately machine learning/deep learning models can predict

water demand at city and sub-city scales. Preliminary prediction results show that advanced models like Long Short Term Memory networks (LSTM) with wavelet transform technique can attain model accuracies (R^2) of 0.80 to 0.95 for 1-day ahead prediction.