Enhancing rainfall monitoring in urban areas by integrating crowdsourced personal weather stations into official networks

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Introduction

Measuring rainfall accurately represents a significant challenge due to its high variability in space and time (Kidd et al. 2017). Recent technological innovations, such as Personal Weather Stations (PWS), leverage crowdsourced Internet-of-Thing (IoT) technologies to share local precipitation data on online platforms (McCabe et al. 2017). These low-cost tipping bucket rain gauges are installed by citizens for home automation and could be exploited as a promising tool for rainfall data collection. However, their non-standardized installation and user-maintained nature pose challenges regarding data quality and accuracy (de Vos et al. 2017; Bardossy et al. 2021; Chen et al. 2021). One of the leading PWS platforms is Netatmo (https://www.netatmo.com/it-it/smart-weather-station), whose rain gauge communicates with an internal module and transmits data to it through wireless technologies. Rainfall records measured by PWSs are sent every five minutes to a cloud service that collects and stores such data, allowing users to retrieve them through an API.

Given the potential of these widely distributed stations, the research question that guides this study is: are those stations reliable enough to obtain rainfall estimates suitable for hydrological modelling in urban areas? In this work, we try to answer this question by processing raw PWS rainfall data and integrating them with official networks to increase the spatial resolution of rainfall patterns.

Materials and methods

In this work, we selected 11 Italian cities as case studies, retrieving both official meteorological data and Netatmo PWS observations at hourly resolution in the October 2020 – September 2024 period. These cities provide a diverse range of climatic and topographical conditions that can affect rainfall patterns and are characterized by differences in the data densities.

In a first step, measurements from the two networks are compared to capture the correlation and deviations in recorded precipitation. Each PWS station is here compared to the closest official station. The comparison is performed using raw observations at hourly resolution, followed by an analysis of key precipitation metrics, including annual average rainfall, annual 1-hour maxima, and the probability of dry.

In a second step, by synthesizing and refining existing quality-control methods from scientific literature and adapting them to the diverse geographical and climatic conditions of Italy, we aim to provide, assess and improve the reliability of PWS rainfall observations.

Then, we evaluated the added value of this crowdsourced information in the spatial representation of rainfall extremes by considering two different intense rainfall events occurred during the analysed period that produced major pluvial flooding. In these case studies, we performed spatial interpolations using both datasets to assess the capacity of PWS data to improve spatial rainfall estimates. By comparing interpolated rainfall fields, we aimed to identify the extent to which quality-controlled PWS data can enhance spatial resolution and provide insights into rainfall variability within urban areas, especially when intense and localized rainfall events are considered.

Results and concluding remarks

The comparison between the raw observations and the precipitation metrics of the two datasets and the subsequent application of the quality-control procedure highlighted a modest agreement among them but also allowed us to identify unreliable stations that should be discarded, whose low accuracy is probably induced by incorrect installation or poor maintenance performed by non-expert owners. It is interesting to note that PWSs exhibit both overestimations and underestimations of precipitation depth, and this behavior appears to vary not only between different stations but also across different years.

The inclusion of quality-controlled PWS data allowed us to refine the spatial representation of rainfall extremes in the two selected case studies, providing high rainfall amounts in ungauged areas that are consistent with information reported in the news.

Our final aim is to develop a guideline for hydrologists, engineers and regional hydrological agencies on how to treat such a huge and promising collection of rainfall data for hydrological applications, providing a step-based procedure that does not require the needs of other sources of data. This would help practitioners in retrieving rainfall observations at high spatial and temporal resolution without facing data fragmentation problems induced by the decentralization of the Italian rain gauge network. The development of a QC methodology can make the rapidly growing network of PWSs a more useful resource for hydrologic applications, greatly improving the knowledge of rainfall patterns in areas with dense PWSs, and providing also additional information in poorly gauged regions.

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