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Short communication

Testing a citizen science water monitoring approach in Tunisia

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ABSTRACT

Citizen Science (CS) has been emerging in the last decade as a new field of environmental monitoring involving a direct collaboration between everyday citizens and scientists. In Tunisia, several recent governmental efforts aimed at reinforcing and renovating the existing official water monitoring systems. However, the lack of reliable hydrological data is still an issue, which could be better addressed through integrating a CS approach. The latter approach is tested for rainfall monitoring in the Medjerda catchment in Tunisia using cost-effective and publicly available manual rain gauges. We used a step-by-step approach to target, engage and train citizens on using the monitoring tools and transmitting the data to a user-friendly online platform. The ongoing approach involved 7 citizens from different generations and different educational backgrounds. The collected daily CS data are compared with data from reference stations. Results yield a significant correlation between CS data collected at 3 different sites and the reference stations with r (Pearson Correlation Coefficient (PCC)) ranges between 0.91 and 0.98 for all citizens. Student's *t*-test was applied to evaluate the significance of the agreement between the CS and reference data. In addition, the variability of the CS data is compared with the variability associated with the official governmental data. The CS approach delivered consistent outcomes to complement existing Tunisian monitoring systems, and also to enhance innovation, adaptation, and local capacity building in the Tunisian water sector.

1. Introduction

Under the current global water crisis and the future climate change scenarios, several water-related issues are expected to exacerbate many regions around the world and especially in southern Mediterranean, identified as a water-scarce region in recent years (FAO, 2018). Within this region, Tunisia is considered as one of the most water-stressed countries. The Medjerda catchment, the most important river basin in the country, reached severe water scarcity with the SDG-6 water stress indicator exceeding 100 % in recent years (Fehri et al., 2019). Yet, the robust evaluation of water stress remains complicated due to the lack of sufficient, meaningful, and consistent data. Despite the recent governmental efforts to reinforce the existing hydrometrological monitoring systems, and availability and accuracy of the data, several issues persist for assessing water scarcity. Current official hydrometric and meteorological water monitoring networks (especially rainfall and discharge) are not spatially dense and suffer from data gaps, incomplete time-series, and often leading to poor quality databases. Novel water-related data acquisition and handling strategies are therefore required to improve the characterization of catchments' behavior and to support national and local decision-making. This major issue can be partially addressed through CS. Buytaert et al. (2014) defined CS as the participation of the general public (i.e. non-scientists) in the generation of new scientific knowledge. In our perspective, CS is a complex process built on civic engagement into science, environmental monitoring, and capacity building. Regardless of the definitions of CS, fostering public engagement, participation, and empowerment at any level suggests that everyday citizens have the potential to offer timely and low-cost solutions to the data collection in any given region (Starkey et al., 2017). The concept of CS is also based on the potential social benefits of engaging, collaborating and actively involving local communities within catchments and regions such as raising hydrological knowledge and empowering citizens to take actions themselves (Jollymore et al., 2017; Walker et al., 2016). Although CS and the activity of community-based monitoring, known in the literature as crowdsourcing, citizen observatory, and participatory monitoring, is rapidly expanding around the world (Buytaert et al., 2014; See et al., 2016), considerable attention needs to be paid to the validation of CS approaches. Indeed, the quality of the CS-collected data may strongly depend on the CS data monitoring strategy, the variables that are observed and the socio-economic profile of the region in which the CS program is implemented. Hence, scope exists to evaluate the validation status of CS-based

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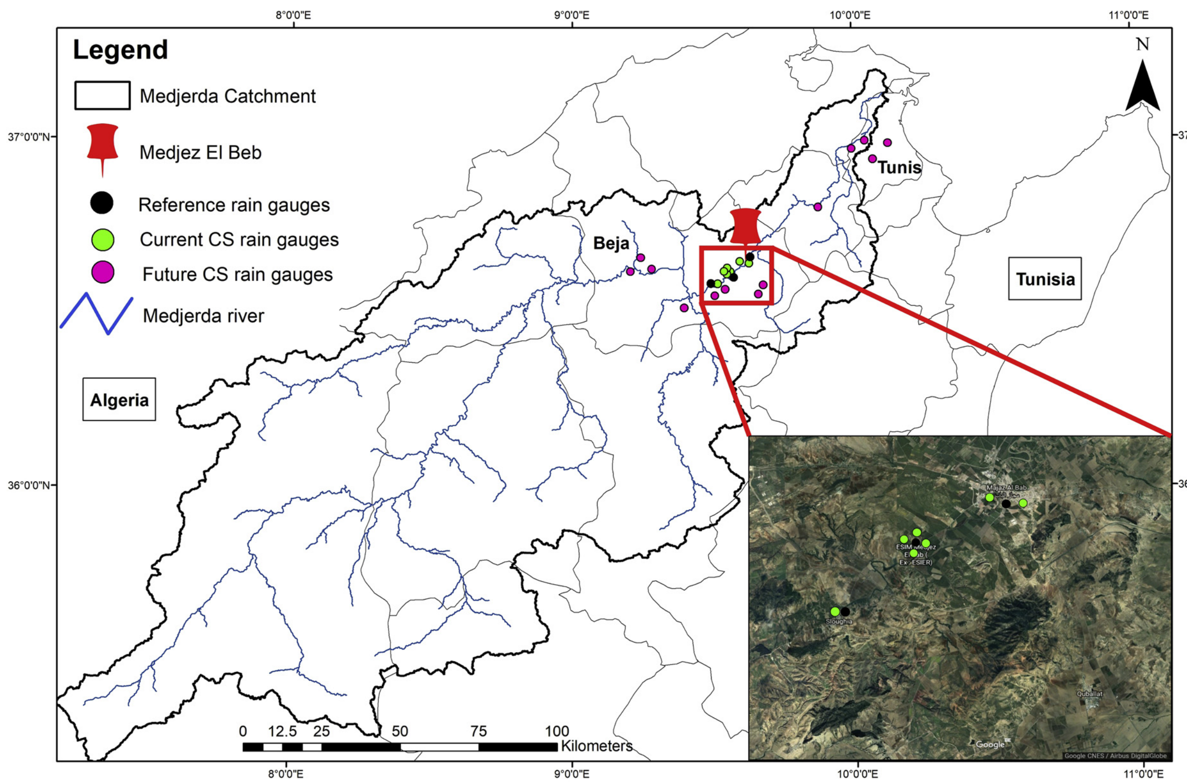

Fig. 1. The study area. The right down inset is Medjez-El-Beb city, the CS test region.

hydrometrological monitoring programs. Since there are currently no reported CS initiatives in Tunisia to monitor water-related data, we launched in 2018 the Together4Water project in collaboration with local Tunisian institutes and schools in a test region of the Medjerda catchment "Medjez-El-Beb city" (Fig. 1). The study area is mainly based on agricultural activities and lacks operational water resources management (Fehri et al., 2019). One aspect of the program aims at engaging citizens from different generations in monitoring precipitation using cost-effective tools. The precipitation is highly variable in space and time in the study area, however, existing official observing networks are too far apart to see much of this variability and suffer from inconsistent and low-quality data.

In this paper, we present results from the ongoing validation of the Together4Water CS field campaign in the test region. We used a step-by-step approach to engage and train volunteered citizens in the region. We assess the quality of daily precipitation monitored in 3 different sites in the test region (Medjez-El-Beb city center, ESIM, and Slouguia) based on data of 3 reference stations. We evaluate the agreement and variability of measurements between citizens for each site and we compare this with the mean and variability of the reference stations.

2. Approach

2.1. Step-by-step citizens science approach

In this research, we adopted a step-by-step citizens' engagement method (Fig. 2) in the test region at the start of the Together4Water field campaigns in October 2018. First, the Together4Water online platform (available here) was created to facilitate reaching a larger number of citizens via social media regardless of their educational backgrounds. The online platform provides all the needed information about the main objectives of the project, the different field activities, and the tools to be used. In addition, an instant message tool was setup (Section 3.1.5), which is designed for real-time data transmission. Then, 3 potential sites (Medjez-El-Beb city center, ESIM, and Slouguia) were selected in the region based on the spatial distribution of the volunteers and the availability of reference monitoring stations. Cost-effective traditional rain gauges (Fig. S1) were tested in the field and distributed to citizens to be fixed at their households around the chosen sites. Citizens were trained in advance on how to use the rain gauges so that they were confident to participate and collect good quality observations in all sites. This field preparation phase is crucial to any CS field campaign to avoid technical issues and to guarantee continuous monitoring. After successfully finalizing the previous steps, we launched the start of monitoring and data transmission.

2.2. Data quality assessment and validation

The quality assurance of data is crucial within a CS program. Hence, we focus in this paper on the evaluation and validation process of CS rainfall data. The validation methods reported in the literature typically compare CS with reference data using statistical techniques based on the correlation coefficient, the bias, and comparative tests such as Student's *t*-test (Wolff et al., 2005). For this study, the CS and reference data were compared using the Pearson Correlation Coefficient (PCC) r, the percent error, and the Student's *t*-test (Table S1). The latter assesses the significance of the difference between the means of two datasets. The variability associated with the means of the two data sources is further compared. The theoretical basis and limitations of Student's *t*-test are detailed and described by Zabell (2008).

3. Achievements and challenges

3.1. Achievements

3.1.1. Data variability

The collected data so far cover the period from October 2018 till July 2019. We removed the dry months (June and July) from the analysis since there was no precipitation measured during these months. The monthly variability of cumulative CS and reference rainfall

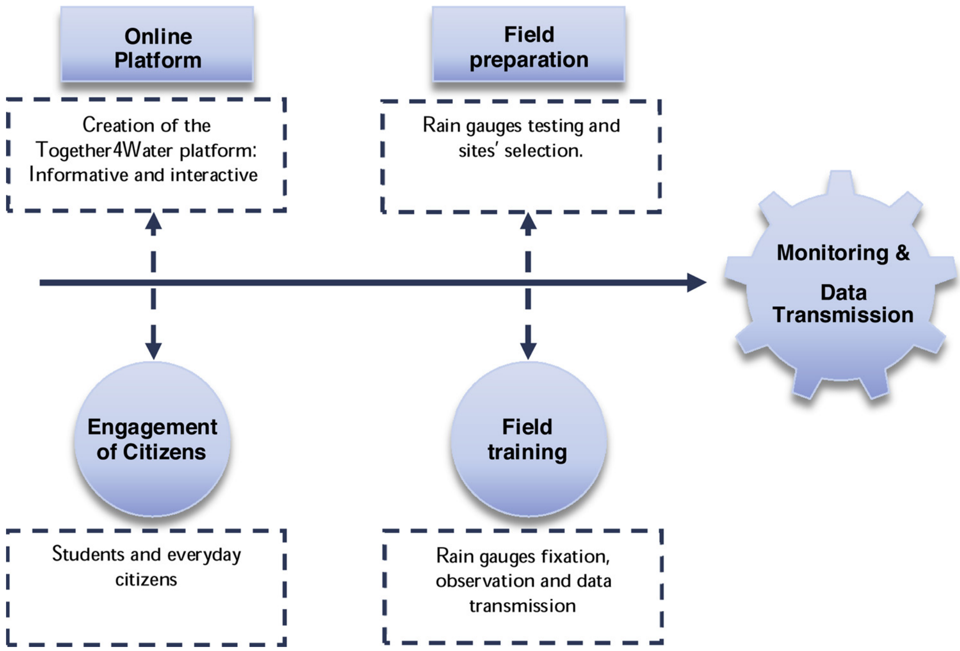

Fig. 2. CS step-by-step approach.

for the 3 sites is shown in Fig. 4. Daily rainfall data were converted at a monthly scale for better visualization of the timeseries. The variability increases slightly with higher precipitation events. This variability could be due to the spatial distribution of citizens' rain gauges in the study sites and experimental bias.

3.1.2. Correlation analysis

The PCC of each citizen's daily measurements and reference data yielded good agreements at all sites with r ranges between 0.91 and 0.98 (Fig. 5). Many reasons for this high correlation are proposed. First, the spatial variability of rainfall is not affecting the CS measurements as all rain gauges are mostly 900 m apart from the reference stations. In addition, citizens were trained to take measurements at the same hour

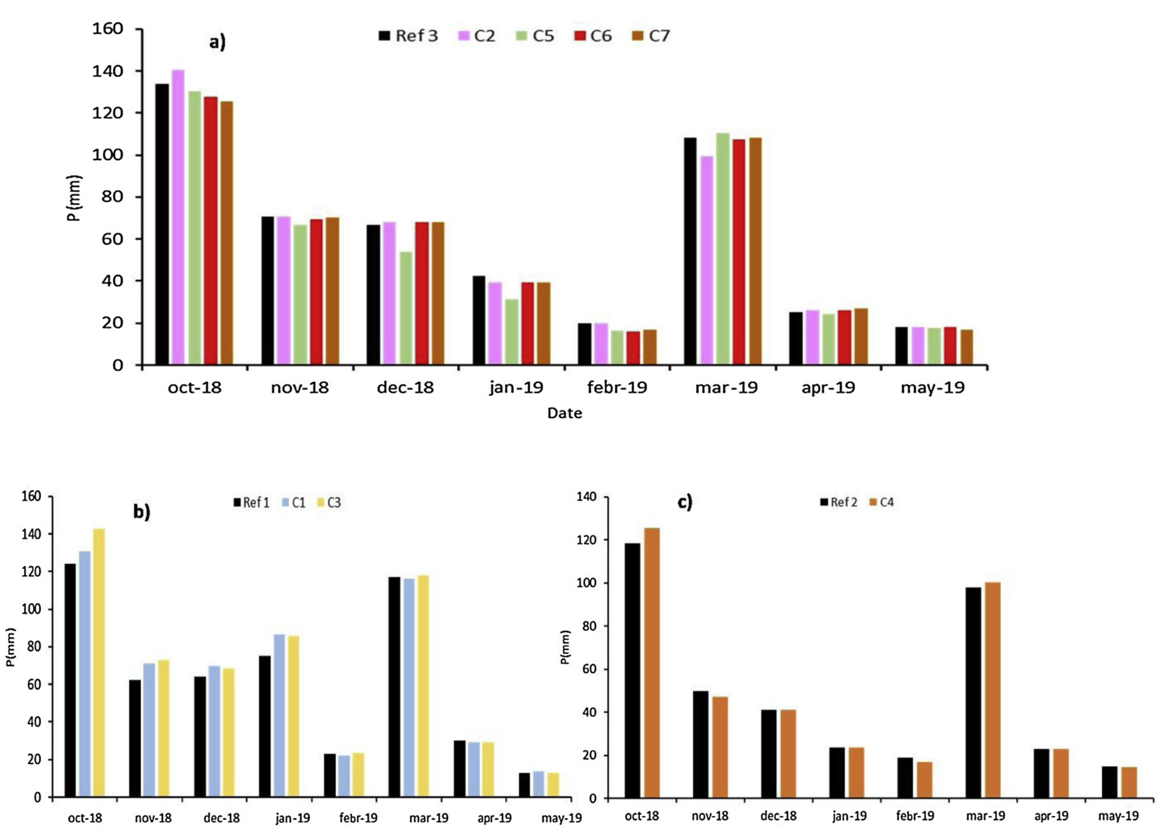

Fig. 3. Variability of monthly cumulative CS and reference data (Ref) at ESIM site (a), Medjez-El-Beb city center (b) and Slouguia (c).

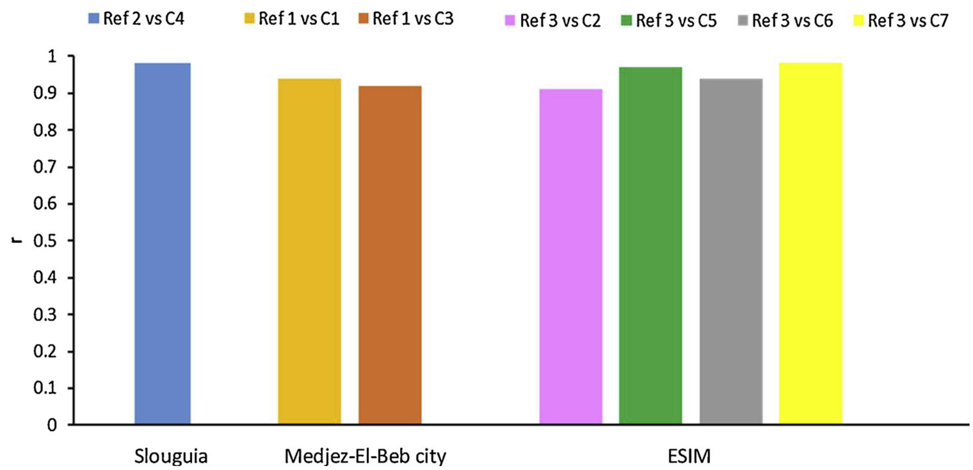

Fig. 4. Correlation between CS measurements and reference data at all sites.

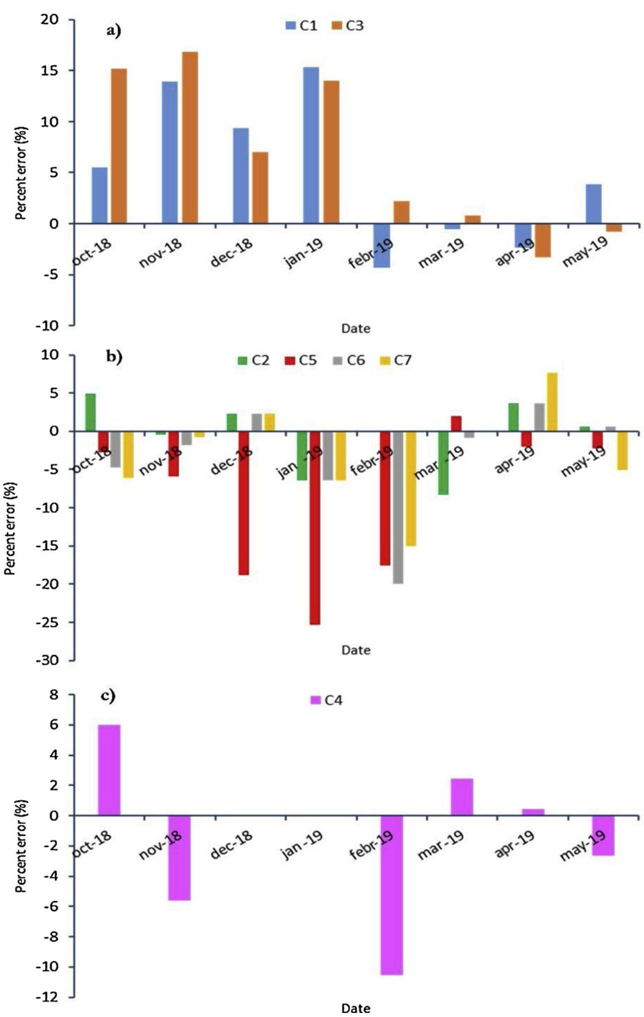

Fig. 5. Variation of monthly rainfall PE at (a) Medjez-El-Beb city center, (b) ESIM, and (c) Slouguia.

daily as the reference measurements (at 07:00 am) to guarantee the consistency in sampling time between CS data and the reference ones.

3.1.3. Percent error (PE) assessment

We performed a PE assessment at the study sites for all citizens' daily measurements. The average daily PE at Medjez-El-Beb city center site was 9 % for citizen-1 and 13 % for citizen-3. At ESIM site, the daily PE averaged 8 %, 20.5 %, 9 %, and 11 % for citizen-2, citizen-5, citizen-6, and citizen-7 respectively. At Slouguia, the average daily PE of citizen-4 measurement was 13.5 %. In order to have more understanding of the error in citizens' measurements, the monthly PE was computed. Fig. 6 shows the variation of monthly PE at all sites. Citizens at Medjez-El-Beb city center site tend to slightly overestimate rainfall with relatively more consistent measurements delivered by citizen-1. At ESIM site, volunteers slightly underestimated rainfall. Citizen-2 measurements showed more consistency than the other volunteers. For Slouguia, citizen-4 delivered consistent measurement with a slight overestimation in February 2019. Hence, CS data showed acceptable error and, importantly, good consistency with the official data at all sites, suggesting that the measurement errors are not strongly contaminated by systematic bias. The variable measurement error between citizens at all sites could be due to short-range spatial variability, under catch as the citizens' rain gauge could be close to a small tree, wall or exposed to wind; and other observational measurements.

3.1.4. Student's t-test and mean variability comparison

Student's t-tests were performed to assess the significance (at the 5 % level, alpha = 0.05) of the difference between the means of citizens' measurements and the reference data at all sites. The null hypothesis (H0) considers the difference between the means equals zero while the alternative hypothesis (Ha) considers the difference is different from zero. Results of Student's *t*-test are shown in Table S2. At all sites, we can't reject the null hypothesis since p-values are greater than the level of significance which suggests that the mean of CS measurements for all citizens is significantly close to the mean of the reference data. This confirms the consistency and good quality of the CS data.

We assessed as well the variability (95 % confidence interval (CI)) associated with the mean of each data source. Fig. 7 compares the mean and variability of citizens' measurements to the mean and variability of the reference data. At all sites and for all citizens, similar uncertainty of the mean to the reference ones can be observed, which confirms the goodness of CS-collected data.

3.1.5. Importance of the step-by-step citizens' engagement

The step-by-step citizens' engagement approach delivered promising outcomes in terms of effectiveness and rapidity with respect to message spreading and communication with motivated and interested citizens. At the start of the field campaigns in October 2018, 7 citizens from different generations and educational backgrounds (students and everyday citizens) were selected to measure rainfall in the 3 sites: two citizens (C_1 and C_3) at Medjez-El-Beb city center, four (C_2, C_5, C_6, and C_7) at ESIM site, and one citizen (C_4) at Slouguia. At the time of writing, 17 more citizens were engaged and equipped with rain gauges in newly

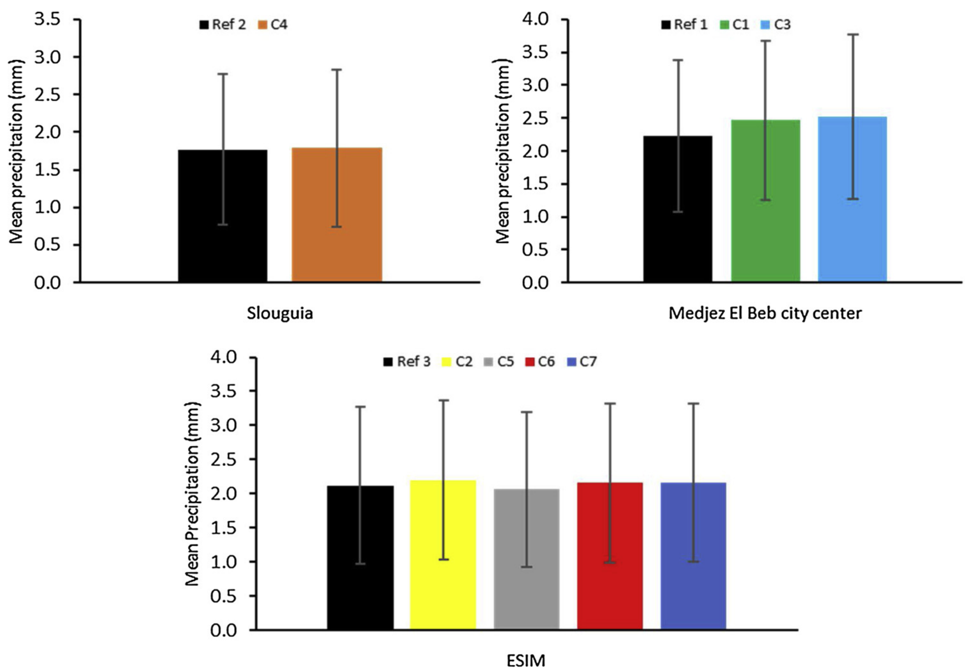

Fig. 6. Comparison of the mean and the variability (95 % CI) of the CS measurement to the reference data.

selected sites (Fig. 1). The progressive approach of CS engagement helped volunteers better understand the importance of environmental monitoring in the region, which created a motivation to take actions and participate in the Together4Water field campaigns. Younger citizens (students) were more acquainted to utilize the online platform for data transmission via the instant messaging tool. Older citizens did need more training, which helped them better learn how to deal with data in terms of management and description. Citizens send daily rainfall measurements via the platform with a description of the circumstances of the measurements. Such an approach allowed to collect actual data as well as metadata of the target variable (Fig. 3). This is highly important since metadata such as observation time, environment and weather at the time of measurement, or a photo of the rain gauge at time of measurement (Fig. S2), allows improving the quality of the data and understanding precipitation variability.

3.2. Challenges

With the Together4Water initiative, new challenges emerge at regional and national scales. The main ones are described as follows.

The Together4Water program involved everyday citizens from different generations in a small region. Moving to a larger scale is a challenge at different levels such as training process and data management. It is important then to improve our training and communications programs.

One of the main goals of the initiative is involving stakeholders in the monitoring program. It is a challenge to establish an operational link between citizen scientists and stakeholders to move forward towards an integrated water monitoring system in the Medjerda catchment. A more advanced step-by-step engagement approach is therefore needed.

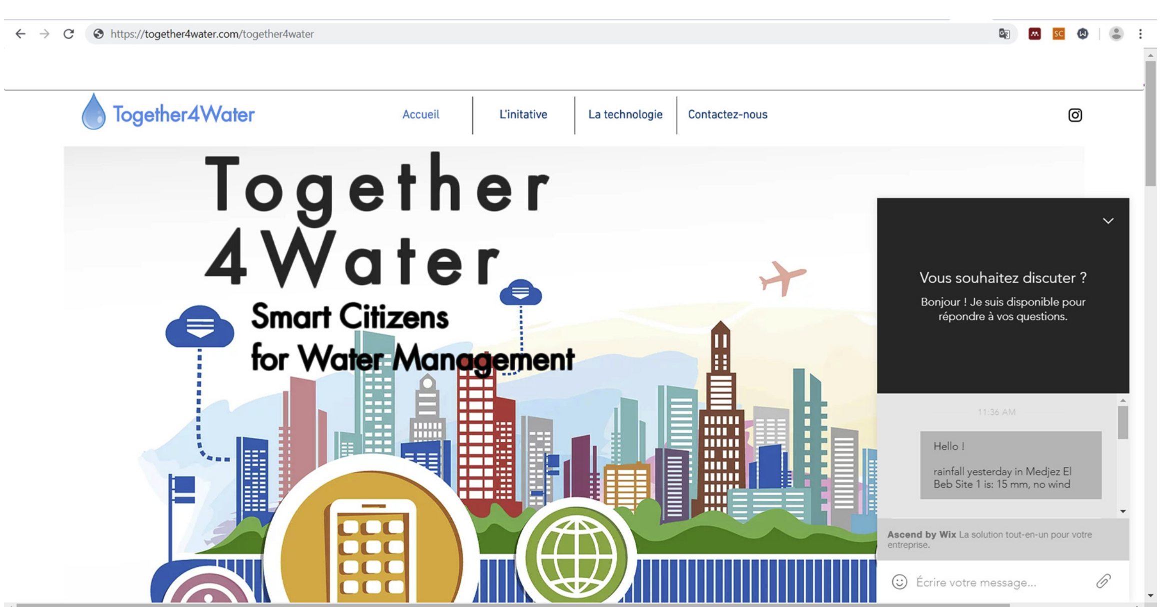

Fig. 7. Rainfall CS data transmission example with a short description of the event.

4. Ambitions for the future

- The Together4Water CS approach is moving to the next phase, which will include more volunteers and a larger number of monitoring sites in other regions of the Medjerda catchment.
- The program has the ambition to monitor discharge and water quality using smart, cost-effective tools.
- Future work should apply Data Fusion techniques to combine CS data with the reference ones to generate more robust outcomes.

5. Conclusion

We presented in this study a test of the Together4Water CS initiative in Tunisia. The step-by-step citizens engagement approach showed promising results in motivating citizens in the test region. The Together4Water platform helped to reach a range of locals through social media and regional websites. In addition, the variability of CS data between citizens, at all sites, was slightly higher for high rainfall events. This could be due to short-range spatial variability of rainfall, the presence of other disturbing factors like the wind, which affects the quality of measurement, and measurement error. In contrast, lower events measurements showed more consistency for all citizens. Statistical comparisons (correlation analysis, PE, Student's *t*-test, and means' variability) of CS measurements against the reference data at all sites validate their quality for use in further studies.

In addition to the validated quality of data, we consider the following lessons learned from the field. The field training is a crucial part of the field campaign. We provided consistent guidelines to citizens to better understand the technical aspects of rainfall measurement, data transmission and the added value of metadata. Younger citizen scientists (students) are more familiar with using the rain gauge and the Together4Water platform for data transmission than older citizens. Therefore, the latter category of citizens requires further assistance throughout the start of monitoring. Furthermore, we learned that the local community had a greater understanding of their local hydrology, a sense of responsibility of their water resources, and a sense of being a research partner in a community project.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2019.11.009.

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