

Article

Assessing the Performance of a Citizen Science Based Water Quality Monitoring Program for Nitrates Using Test Strips Implemented in the Medjerda Hydrosystem in Northern Tunisia

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Abstract: Recent technological progress in water management of hydrosystems has been made to deploy efficient and effective water quality monitoring systems (WQMS). Among these, a citizen science (CS)-based water quality monitoring (WQM) program using test strips is considered as a smart tool that may aid in the production of reliable, continuous, and comprehensive data on the water quality resources of hydrosystems over a broad range of spatial and temporal scales. In this case study, the objective is to evaluate the performance of a CS-based WQM for nitrates assessment using test water quality strips for the Medjerda watershed in Northern Tunisia. Overall, 137 samples were collected from 24 sampling sites and were analyzed by 33 participants. Citizens involved in the program were regrouped in five citizen types according to their socio-economic characteristics. Statistical tests, analysis of variance (ANOVA) and multiple correspondence analyses (MCA) were achieved to survey the goodness of fit of CS as a contribution to data collection in terms of the socio-economic profile of the participant. The results show that this tool could be reliable for obtaining the levels of nitrate in water samples. Water quality test trips can conveniently be used by citizens for WQM of nitrates when they are rigorously following the manufacturer's instructions. Additional efforts in communication and training could help to improve the performance of this CS-WQM program for nitrate in the Medjerda watershed.

Keywords: water CS; water quality assessment; nitrate; test strips; citizen's typology; Medjerda hydrosystem



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1. Introduction

Problems of environmental degradation, diseases, and economic stagnation caused by water pollution are increasing rapidly with population growth, urbanization, industrialization, and anthropogenic activities [1]. Pressures on water resources jeopardize the Africa Water Vision 2025 [2] and the United Nations (UN) Sustainable Development Goals (SDGs). Most African countries have very limited experience of pollution control measures, and efficient pollution control strategies require efficient and effective water quality monitoring. Many additional monitoring efforts are needed to make pollution control measures effective and reach development goals related to water [3]. Hence, this WQM issue concerns all African countries, as the water quality of hydrosystems is central to human wellbeing and socio-economic development [2,4]. Water quality assessment is a prerequisite for evaluating SDG indicator 6.3 to ensure access for all to water, sanitation, and hygiene services. SDGs target 6.6 points to bolster and reinforce the interest of local communities in moving forward water and sanitation management and to inform on the

most common pressures on water quality at the global level [5–7]. In order to reach this target, participatory WQM methods are suggested to be deployed [8,9].

Recent technological progress has been made to deploy efficient and effective water quality monitoring systems (WQMSs). Technological innovation in this area includes online automated data that capture pollutant sources monitoring [10], novel transmission networks [11], advanced data analysis software [12], remote sensing [13,14], the internet of things [15], smart sensors [16], paper strips, and kit tests [17–20]. Such technological innovation may aid in the production of reliable, continuous, and comprehensive data on water quality resources over a broad range of spatial and temporal scales. Furthermore, by developing community science techniques, any citizen may participate in WQM. With respect to CS-based WQM, data implications, success factors, and stories of CS-based WQM projects are reported in the literature [21–26]. In contributory projects, citizens are essentially included in data collection. In a collaborative structure, more types of partners are included. Citizens have control that is more decisional in this administrative structure. Such projects may be successful if there is adequate community and stakeholder support.

We assess in this case study the performance of a CS-based WQM program for nitrate based on test water quality strips for the Medjerda hydrosystem. Different citizen types (students, researchers, water operators, agricultural hand labor, farmers, and volunteers belonging to different social layers) were involved in CS-WQM data collection. We therefore analyze the performance in terms of citizen types and propose a correction mechanism of WQ observations in terms of citizen type.

2. Materials and Methods

2.1. Study Area Description

Tunisia and Algeria share the waters of several transboundary rivers, notably the Medjerda River, which accounts for 37% of Tunisia's surface water and 22% of its renewable water resources [27]. The present study focuses on the Medjerda catchment on Tunisian soil. The Medjerda River Basin (MRB) begins in North-Eastern Algeria and flows eastwards to Tunisia, at that point entering the Inlet of Utic in the Mediterranean Sea [28]. The population within the Medjerda hydrosystem was estimated to be 2.453 million in 2021 (20.8% of Tunisia's population) [29], while the basin occupies 9.8% of the land area of Tunisia. Water resources produced were estimated at around one km³ of water per year, which is effective for domestic water production, irrigated agriculture and transfer to the eastern regions of the country. The precipitation average in the basin is about 350–600 mm/year, reaching more than 1000 mm/year in a small area and for 40 to 70 days of rain. The most common irrigation technique in the area is drip and surface irrigation. Irrigated perimeters are exploited at a rate of 73%, while existing perimeters are intensified at a rate of 80% [27]. The MRB faces many agro-hydrological challenges, in particular the deterioration of water quality due to inappropriate fertilizer use.

The sampling stations considered in this study are mainly from surface water resources. Yet, some groundwater resources are also considered (Figure 1). The first sub-watershed of Wadi Khaled has its outlet located just downstream of the Sidi Salem dam. The second sub-watershed is that of the Wadi Siliana, the outlet of which is located in the western city of Testour. The third sub-watershed corresponds to the medium valley of the Medjerda watershed located between Testour and Medjez El Bab. The last sub-watershed is the Lahmar wadi. Several samples were collected from other tributaries such as Wadi Mellegue, Wadi Tessa, Wadi BouHertma, Wadi Beja, and Wadi Zarga, located in the High Valley of Medjerda.

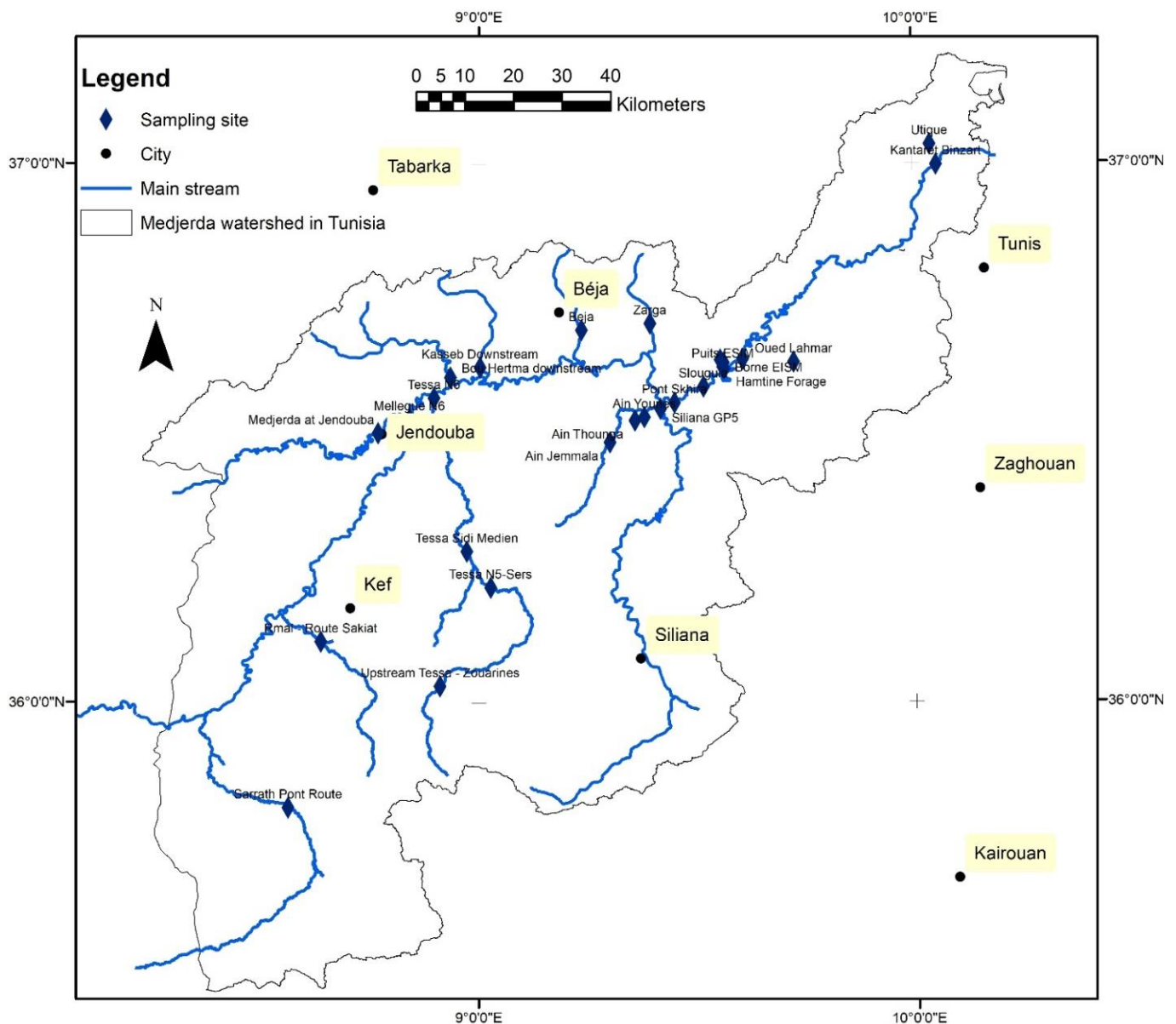


Figure 1. Location of the sampling sites along the mainstream of the Medjerda watershed and its tributaries in Tunisian territories.

2.2. Sampling Sites and Nitrates Analysis

Overall, 137 samples were collected from 24 sampling sites and were analyzed by 33 citizens. Samples should be analyzed as soon as possible after sampling, preferably within a few hours. Sample bottles were cooled during the 24 h period between field sampling and laboratory analysis according to EN ISO 5667-3 standards [30]. Sampling sites were selected based on the distribution of the volunteers and the availability of reference WQM stations. For groundwater sampling, samples were collected directly from well discharge pipes and boreholes for at least a quarter of an hour during the pump operation. Low cost nitrate measurements were conducted using commercially available Velda Aqua Test Strips (6:1). Nitrate sample measurements were achieved by immersion of the test strips in the bottles for 5 s, waiting for approximately 1 min, and by referring to the color chart of the pads provided with the test strip. A short guideline to test strip use was consulted by the citizen trainers. In parallel, nitrate concentrations were also analyzed following the standard sodium salicylate method in the laboratory. Filters free of contaminants with an appropriate pore size, e.g., 0.40 μm Whatman filters, were used before

laboratory standard nitrate analysis. In this method, nitrate reacts with available salicylate to yield the yellow-colored sodium paranitrosalicylate susceptible to spectrophotometric determination at 415 nm [31].

2.3. Participant Recruitment, Training and Socio-Economic Characteristics

The participants were recruited with the aid of local officers of the water sector (regional agricultural services, water treatment authority, national company for the exploitation and distribution of drinking water, etc.); through personal contacts with motivated and available volunteers mainly in the vicinity of Medjez El Bab city and through social media. The main socio-economic characteristics of the involved citizens are summarized in Table 1. Before their commitment, we first explained to the citizens the aim and purpose of the project. In addition, students from the School of Engineers of Medjez El Bab participated and were allowed to practice the use of the analytical test strips within the classroom under the assistance of the trainer, who was able to supply input and reply questions.

Table 1. Main socio-economic characteristics of the involved citizens (%).

Age (Year)	<25	25–45	45–60	60<
	18.2	48.5	27.3	6.1
Main Occupation	Agricultural Labor	Engineer or Staff	Student	Researcher
	18.2	48.5	21.2	12.1
Number of Observed Samples	<15	15–25	25–30	30<
	24.2	27.3	42.4	6.1
Educational Level	Primary	Secondary	Higher	
	27.3	15.2	57.6	

The methodological approach of this study consists of the following steps (Figure 2):

1. Organization of workshops and mini meetings to explain detailed procedures, precautions and operating techniques that will be used to perform the nitrates test strip measurements. This allowed complying with the participatory principle of a CS-WQM program.
2. Organization of a mixture of both theoretical and practical training activities (literature overview and demonstration of the test strips analysis using water samples). Training quizzes, periodic testing, and review of data for all participants were investigated to ensure reliability of test strip readings and to check that the use of test strips' water quality met the training requirements. These activities enhance the level of training of the CS-WQM program and can affect the quality of the gathered data. It also ensures that the CS collected data consistently meet the standard requirements.
3. Organization of a Likert scale survey as a rating scale with a series of answer statements following interest and questions during training, volunteers' commitment, and volunteers' participation.



Figure 2. Participants training and reading test strips nitrates measurements. (A) Guidelines for water quality test strips; (B) Demonstration of test strips reading for water operators; (C,D) Volunteers reading strips; (E) Training in site for agricultural hand labor; (F) Test strips for nitrates analysis (G) Theoretical training for scientists.

2.4. Statistical Data Analysis

Statistical correlation coefficients and ANOVA and MCA analysis were used to evaluate the goodness of fit of citizens' data. Cronbach's alpha is one of the most widely used indices to assess the reliability or internal consistency of questions asked during a survey. The MCA on the qualitative variables made it possible to construct a typology of citizens. To proceed with the typology of citizens, the Ward's aggregation criterion according to Chebyshev's metric was adopted. In order to represent the variations in the observations collected by the participants, we adopted the analysis of variance, which is a statistical tool measuring the dispersion of a set of data in relation to its mean. We also carried out a descriptive analysis of the data making it possible to summarize a set of data as a box plot. Descriptive statistics were additionally applied to the data collected by the citizens and those from the laboratory. Regression analyses were established in order to predict the observations obtained according to the standard protocols and those collected by the citizens. The regressions envisaged, of the linear type, were carried out for nitrates and those for each type of citizen and for two ranges of turbidity. Other variables, participation in the collection of samples, involved in the water sector, gender, eyeglasses and valuing the project' objectives, were binary, and yes or no were used.

3. Results and Discussion

3.1. Variation Patterns of Nitrates Measurements

Across the reach of the sampling sites in the Medjerda watershed, nitrates levels measurements recorded using test strips and standard laboratory analysis indicated that the water quality is good in 98.5% ($n = 135$) of samples ($[\text{NO}_3^-] < 50.0 \text{ mg/L}$) and of low quality in 1.5% ($n = 2$) of samples ($[\text{NO}_3^-] > 50.0 \text{ mg/L}$) according to the national environmental hydrosystems' water quality standards for nitrates in Tunisia. For the purposes of US-EPA standards, nitrates values of $< 1.0 \text{ mg/L}$ indicate high-quality water. Excess nitrates values at higher concentrations of more than 10.0 mg/L , indicative of lower quality, can cause low levels of dissolved oxygen (hypoxia) and can become eco-toxic for hydrosystems under certain conditions. Variations in nitrates level measurements recorded seem to be related to fluctuations in turbidity (values exceeded 50 NTU and more than 1000 NTU). This is because turbidity values depend on rainfall and therefore on sampling dates and sites. Nitrates may be flushed across the reach of lower water quality sampling sites in Medjerda than other sites of the river by runoff from urban and agricultural surfaces during precipitation events. There are also spatial differences in nitrate concentrations across the sample sites on the Medjerda River (Table 2). The analysis of variance indicates that the citizen type and the water sampling sites significantly affect the nitrate measurements, with a probability lower than 5%. The hydrologic season does not significantly affect nitrate concentration. The only significant interaction is the citizen type \times water source with a probability lower than 5%. Thus, the nitrate level is mainly related to the water source.

Table 2. ANOVA analysis of nitrates collected by citizens under various variables.

Citizen Nitrates' Measurements	F	p Value
Citizen type	3.272	0.011
Water source sampling sites	31.154	0.000
Hydrologic season (wet and dry season)	2.559	0.110
Citizen type \times Water source	2.732	0.004
Citizen type \times Hydrologic season	0.721	0.539
Citizen type \times Water source \times Hydrologic season	2.009	0.092

3.2. Reliability and Agreement between Nitrates Test Strips and Field Standard

Results show a high correlation between data collected from CS-water quality test strips and those obtained by standard methods (Figure 3). Nitrate-sensitive water quality test strips seem to be reliable in the $0\text{--}125 \text{ mg/L}$ concentration range. Agreement between the citizen's readings and the standard methods is observed by the comparison of the means and standard deviations of nitrate contents. The results show moderate to very good agreement between the results of citizen-based monitoring and the standard methods. Results also show a high correlation between data collected from CS-groundwater compared to CS-surface water quality test strips and those obtained by standard methods. Nitrate surface water quality test strips seem to be sensitive to variations in turbidity value.

Nitrate test strips provide slight reliability in the $0\text{--}10 \text{ mg/L}$ nitrate concentration range where zero nitrates are indicated while the standard revealed measurable concentrations. However, the agreements are best for intermediate to high nitrates concentrations (i.e., 10 to 25 mg/L nitrates). Previous results revealed the critical importance of the interpretation of the test strip readings, especially in the range of 10 mg/L nitrates, i.e., the upper health advisory limit for nitrates in ground water [32]. Common interfering colloids agents may affect the reliability of nitrate test strips compared to standard methods. Good agreement was also obtained between nitrate data collected by citizens using test strips' measurements and those from measurements by high performance liquid chromatography and colorimetric analysis [32], ion-selective electrodes, the Szechrome reagent method [33], and molecular absorption spectrometry [19,20].

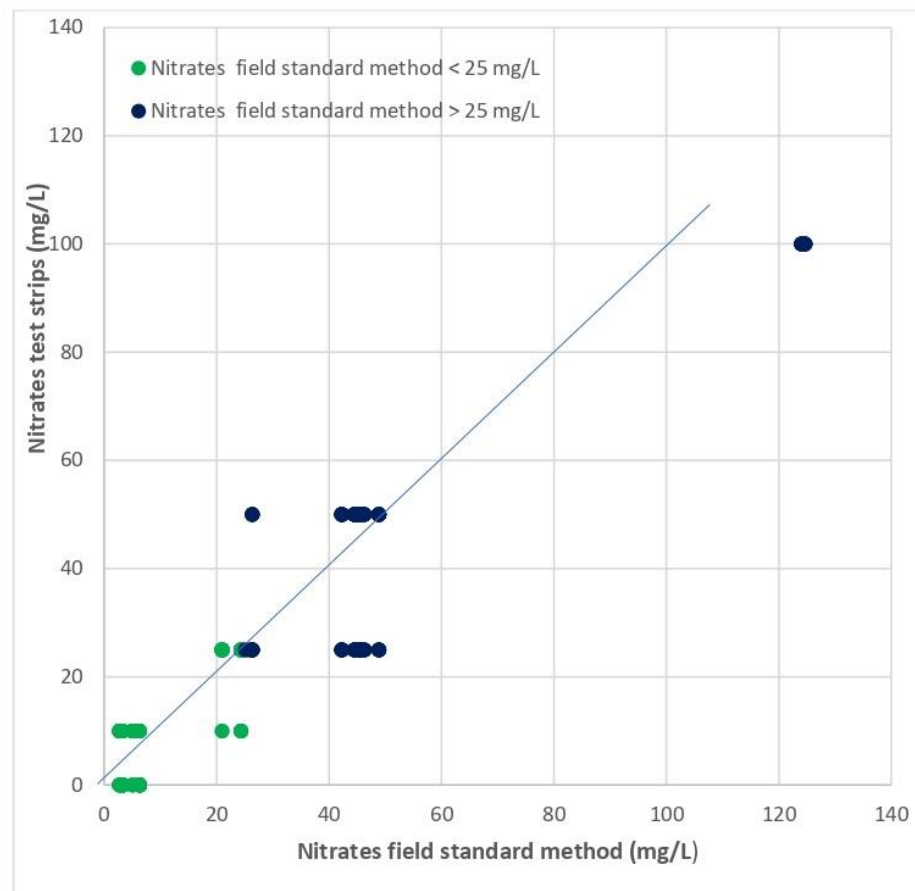


Figure 3. Plot for nitrates CS test strips versus field standard methods.

3.3. Compensation of Turbidity Interference in Nitrate Measurements

In view of turbidity interference that leads to inaccuracy in nitrate measurements using test strips and standard laboratory analysis, a bias correction is made to compensate for the turbidity interference. The bias correction was specific for each citizen type and for two ranges of turbidity (Table 3). Despite potential interferences, standard method and test strips measurements were reliable as shown in a strong consistency across a wide range of turbidity values (R and $R^2 > 0.9$). Nitrate measurements from the laboratory standard correlated well with nitrate test strips for each citizen types for turbidity values under 50 NTU. For each citizen types and for all citizens, equations slopes are significantly close to one, and intercepts are significantly close to zero at $p < 0.05$. Nitrate measurements from laboratory standard and test strips are affected by turbidity interference for values exceeding 50 NTU. For each citizen types and for all citizens, equation slopes are significantly different from zero (0.8 to 0.9), and intercepts are not significantly close to zero (from 0.6 to 6) at $p < 0.05$. It seems that suspended particles and other dissolved substances lead to an overestimation of nitrate measurements, which alters the appearance of the linear regression. Turbidity interference caused by many particles and dissolved solids, which soak up light as ultraviolet, highlights the need for checking test strips data to correct values under turbidity variation of samples and to enhance the performance of nitrate test strips measurements for the final data product. The presence of particles and other suspended solids that cause light scattering leads to a general overestimation of nitrate measurements and thus influences the color change in strip bands and absorption over the entire spectrum [19,34]. A sedimentation time of more than 15 min is operationally recommended to allow particulates and other suspended substances to become settled before reading the samples.

Table 3. Nitrates' assessment in water samples according to citizen type for two turbidity ranges.

Citizen Type	N _{citizens}	N _{samples}	Equation	F Test	p Value	R	R ²
Motivated volunteers	9	* 171	$N_{lab} = 1.052 \times N_{strip} + 0.114 \times \text{Turbidity}$	1108.3	0.000	0.964	0.929
		** 152	$N_{lab} = 0.868 \times N_{strip} - 0.028 \times \text{Turbidity} + 6.094$	437.4	0.000	0.948	0.898
Agricultural hand labor	7	* 109	$N_{lab} = 1.073 \times N_{strip} - 0.067 \times \text{Turbidity}$	927.5	0.000	0.972	0.945
		** 46	$N_{lab} = 0.940 \times N_{strip} + 0.008 \times \text{Turbidity} - 1.342$	233.3	0.000	0.971	0.942
Students	6	* 106	$N_{lab} = 1.000 \times N_{strip} + 0.597 \times \text{Turbidity}$	262.2	0.000	0.940	0.884
		** 50	$N_{lab} = 1.000 \times N_{strip} + 0.296 \times \text{Turbidity} - 0.683$	155.0	0.000	0.953	0.908
Researchers	4	* 82	$N_{lab} = 1.000 \times N_{strip} - 0.645 \times \text{Turbidity}$	408.8	0.000	0.969	0.953
		** 8	$N_{lab} = 1.000 \times N_{strip} + 0.285 \times \text{Turbidity} - 0.629$	38.4	0.000	0.979	0.958
Water operators	7	* 17	$N_{lab} = 0.917 \times N_{strip} - 0.059 \times \text{Turbidity}$	34.5	0.000	0.938	0.881
		** 52	$N_{lab} = 0.907 \times N_{strip} + 0.004 \times \text{Turbidity}$	72.2	0.000	0.901	0.811
All citizens	33	* 485	$N_{lab} = 1.036 \times N_{strip} - 0.040 \times \text{Turbidity}$	1890.7	0.000	0.960	0.922
		** 308	$N_{lab} = 0.882 \times N_{strip} - 0.001 \times \text{Turbidity}$	436.6	0.000	0.955	0.911

* Turbidity less than 50 NTU. ** Turbidity more than 50 NTU.

3.4. Citizen's Typology for Nitrates Water Quality Monitoring

Projections of the citizens in the factorial plan are composed of the two main correspondence axes. The citizen types are defined according to the Ward criterion using the Chebyshev measure. The representation of citizens in the factorial plan shows the dispersion of five types of volunteers around the two axes (Figure 4). Regarding the personal interest of citizens in data collection on WQM in Medjerda, the factor that most motivates them is learning about the water quality analysis (57.6% of interest during training). The correlation matrix for transformed variables related to citizens involved in nitrates' assessment using a strip test indicates that motivation and commitment levels are correlated with all the variables except for employment, wearing glasses, mode of observation and the relationship with the project team (Table 4). The factorial correspondence axis, explained variance, and eigenvalues of the citizens involved in nitrates' assessment are summarized in Table 5. Two factorial correspondence axes with correlated variables of the citizens involved in nitrates' assessment are identified:

- Axis 1: Relevance of the project to the citizen's attitude. Participants involved in the water sector showed commitment to the CS-WQM project, an interest during training sessions by addressing questions, and by following the water strip test learning instructions.
- Axis 2: Citizen identification. Motivation levels of the participants are linked to their education level, main occupation, and relation with the project team and age.

We studied and categorized five types of citizens based on their education, commitment, motivation, socio-economic background, and how they were recruited into the group. Type 1, being motivated volunteers, have the lowest inertia while Type 3, being students with high and low inertia, considering the second and first axis. Regarding the personal interest of these types in data collection (57.6% of interest during training), previously achieved using the Likert scale survey, learning about water quality test strips analysis as a new easy tool for the WQM of Medjerda is considered the most important motivation factor in the project involvement. Citizens belonging to Type 2, mainly representing agricultural hand labor, have moderate inertia considering both axes. Types 4 and 5, being to researchers and water operators, have the highest values of inertia these axis.

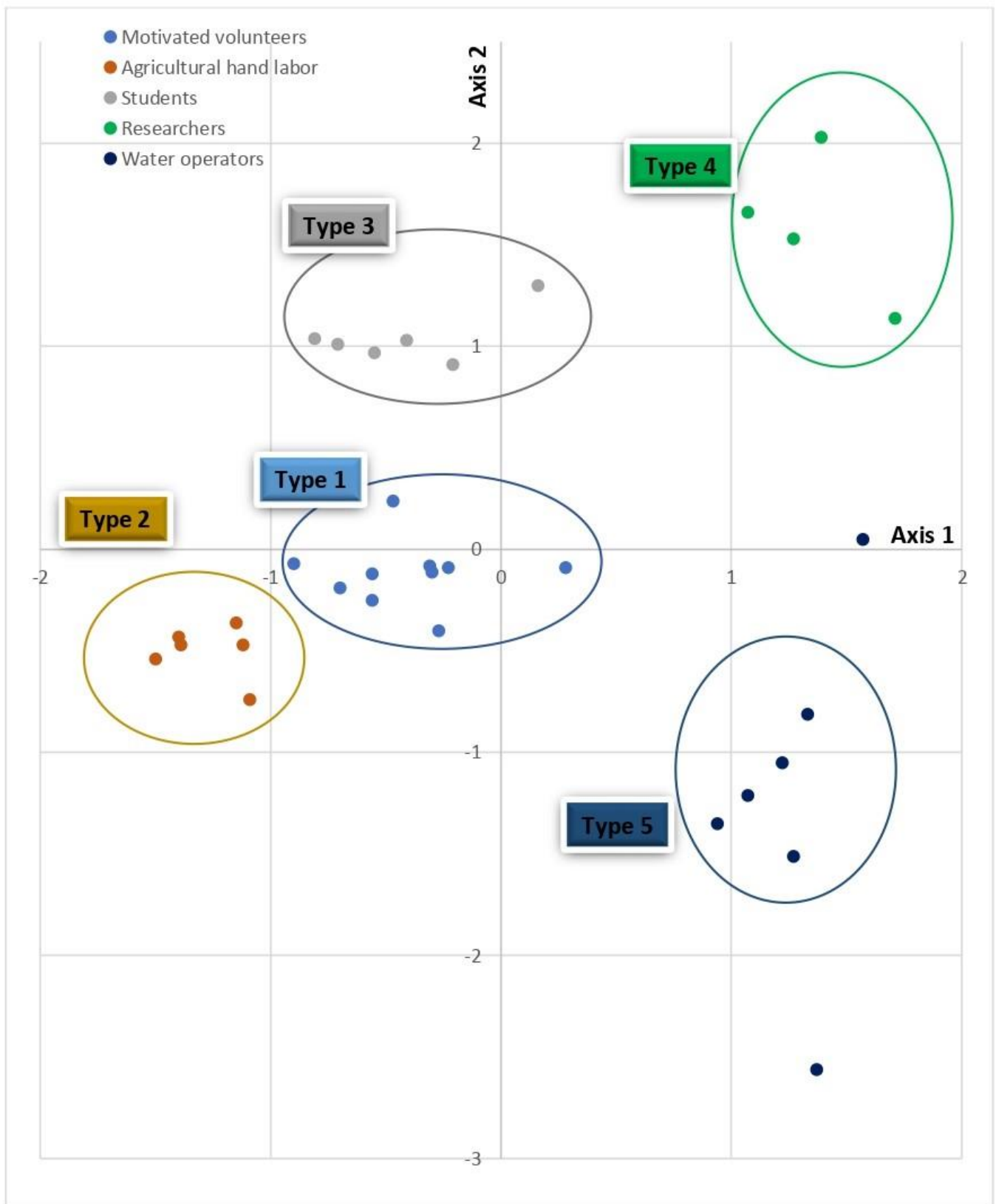


Figure 4. Projection of the citizens in the factorial plan composed of the two main correspondence axes. The citizen types are defined according to the Ward criterion using the Chebyshev measure.

Table 4. Correlation matrix for transformed variables related to citizens involved in nitrates’ assessment using strip test.

Variable	Motivation Level	Education Level	Involved in Water Sector	Main Occupation	Relation with the Project Staff	Interest during Training	Questions during Training	Commitment	Strip Learning Mode	Number of Observed Samples	Participation in Collection of Samples	Age	* Gender	* Eyeglasses	* Valuing the Project’s Objectives	
Motivation level	0.123															
Education level	0.176	0.186														
Involved in water sector	0.176	0.186	0.629													
Main occupation	0.398	0.485	0.629	0.374												
Relation with the project staff	0.427	−0.040	0.416	0.374	0.017											
Interest during training	0.218	0.405	0.623	0.603	0.017											
Questions during training	0.411	−0.019	0.693	0.585	0.402	0.597										
Commitment	0.393	0.478	0.717	0.636	0.425	0.476	0.529									
Strip learning mode	0.496	0.051	0.645	0.543	0.477	0.655	0.858	0.541								
Number of observed samples	0.419	−0.079	0.626	0.442	0.625	0.399	0.771	0.524	0.807							
Participation in collection of samples	0.110	0.289	0.486	0.382	−0.140	0.663	0.568	0.339	0.472	0.254						
Age	0.241	− 0.410	0.156	−0.077	0.225	−0.041	0.296	0.201	0.252	0.498	−0.066					
* Gender	0.081	−0.113	0.097	0.234	0.299	0.002	0.178	0.050	0.158	0.234	− 0.231	0.048				
* Eyeglasses	0.230	0.029	0.583	0.404	0.396	0.160	0.556	0.447	0.445	0.603	0.283	0.354	0.056			
* Valuing the project’s objectives	0.224	0.181	0.349	0.339	−0.148	0.715	0.591	0.205	0.541	0.243	0.750	−0.055	−0.012	−0.015		

* Supplementary variable; bold coefficients are significant at 5% level.

Table 5. Factorial correspondence axis, explained variance, and eigenvalues of the citizens involved in nitrates’ assessment.

Variable	Axis 1: Relevance to the Citizen	Axis 2: Citizen Identification
Motivation level	0.276	0.387
Education level	0.074	0.284
Involved in water sector	0.692	0.004
Main occupation	0.585	0.745
Relation with the project staff	0.279	0.317
Interest during training	0.530	0.516
Questions during training	0.772	0.718
Commitment	0.604	0.538
Strip learning mode	0.787	0.180
Number of observed samples	0.654	0.363
Participation in collection of samples	0.317	0.367
Age	0.065	0.490
* Gender	0.022	0.129
* Eyeglasses	0.326	0.033
* Valuing the project’s objectives	0.269	0.752
Cronbach’s Alpha	0.906	0.828
Active eigenvalue	5.635	4.909
% of Variance	46.957	40.908

* Supplementary variable.

Typologies of citizen science based on involvement in research steps and goals are crucial. Success factors for CS in environmental monitoring may be considered during project steps (design, start, and during implementation) [34]. In previous studies, the level of involvement and influence in CS-WQM programs were categorized into three levels based on the Cornell Lab of Ornithology (CLO) (contribution, collaboration, and co-creation) [35]. A vast majority of the CS-WQM projects in previous case studies are of the contributory type, including most that collect water quality data, where citizens are responsible for gathering data information, while the scientists or experts are the ones who come up with the question and plan for the research. Goal-setting and data analysis should be reached at the citizen participation level [36,37]. The participation of citizens in other steps should lead to other typologies of CS than the CLO model. Education, resource management, and data collection are the goals distinguished for knowledge increase and outreach creation [38]. Participants who took part in the project felt like they belonged to the community and they were more likely to do things such as talking to people they know about the project or going to public meetings [39]. In this participative CS approach, levels of harmony, trust, and cooperation in society should be enhanced [40].

Box plots of nitrates collected by citizens using strips and those obtained by conventional methods for each citizen type and for two turbidity ranges across all sites in the Medjerda watershed are presented in Figure 5. Variations in nitrate level measurements recorded seem to be related to turbidity variations and citizen types. Besides turbidity interference in readings samples, educational, socio-economic background, and recruitment modality of citizens as well as the amount of nitrate had an influence on variations in nitrates' measurements.

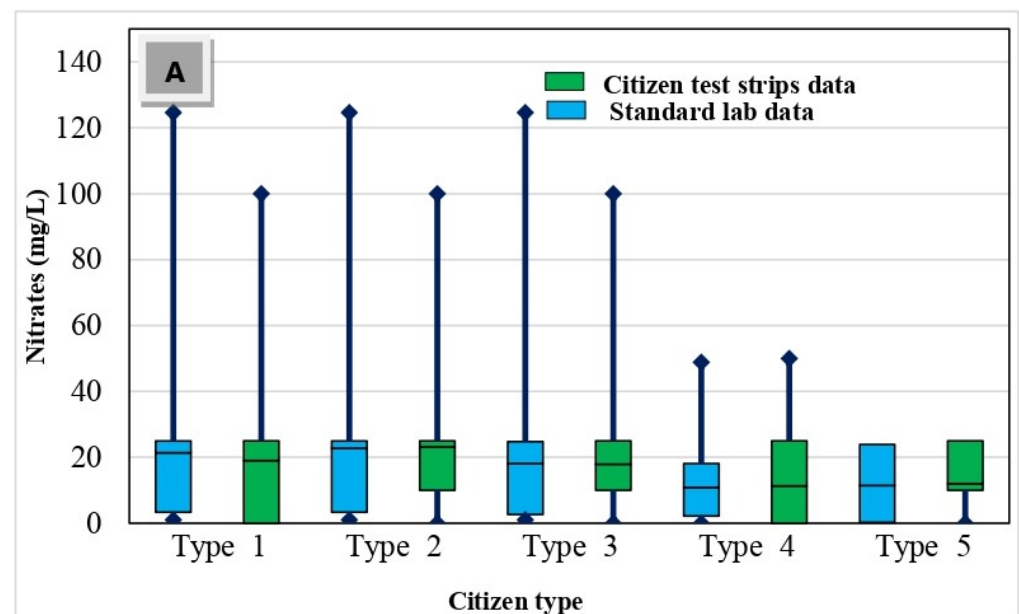


Figure 5. Cont.

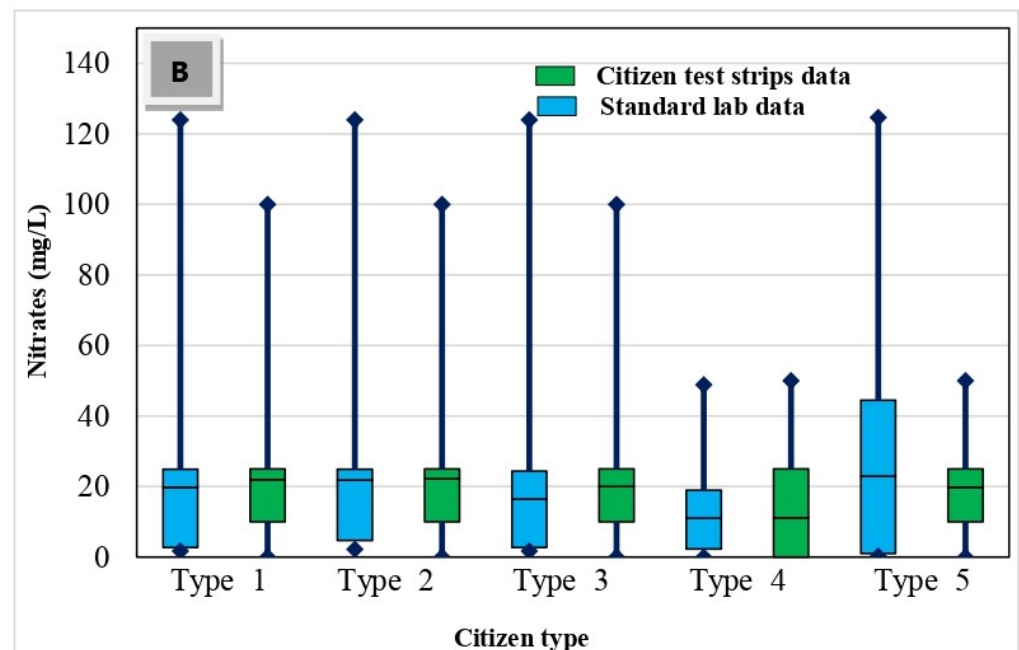


Figure 5. Box plots of nitrates collected by citizen using strips and those obtained from conventional methods for each citizen type (A) Turbidity < 50 NTU; (B) Turbidity > 50 NTU. Type 1: Motivated volunteers; Type 2: Agricultural hand labor; Type 3: Students; Type 4: Researchers; Type 5: Water operators.

3.5. Futures Implications of CS-WQM

Because most African countries have very limited experience of CS-hydrological monitoring and pollution control, much effort is needed to build data collection capacity in WQM. An overview of CS related to hydrological monitoring and WQM in some African countries is presented in Table 6.

The African capacity is still often very poor compared to other continents as a component of WQM. Hence, Tunisia, like all African countries, should be concerned with the promotion of efficient use of such tools and a CS-based WQM approach for their socio-economic sustainable development and for tackling CC-related challenges. The CS-based WQM program in the Medjerda hydrosystem provides opportunities and benefits in terms of powerful smart tools for tackling CC challenges and their impact on water management. The CS-WQM approach in Medjerda has the potential to enhance conservation efforts by providing knowledge, motivating the public to take action, supporting scientific research, and involving citizens actively. The CS-WQM approach also provides a cheap way to gain knowledge and feedback on water monitoring and related policies by using non-traditional data sources and analytical skills, and by involving citizens. CS-WQM as a flexible and robust participative approach can induce socio-economic and institutional transformation, reduce water resource uses, increase ecosystem health, and induce functionality, resilience and integration of the ecosystem.

More community initiatives have to be undertaken progressively to monitor water quality across the Medjerda watershed. Besides contribution involvement of volunteers in data collection, participation should lead to collaboration and co-creation levels. We should be more engaged if we want to use CS to improve water governance and get citizens involved in local problems. We need to put more effort into improving communication, training, feedback, motivation, and connection to make this participatory approach in WQM even better. The attitudes of the citizens, their type and complete acceptance of test strips' tools are the main factors that determine the success of a CS-based nitrates WQM program. This kind of CS-WQM approach has great potential for identifying local sources of nitrate contamination, which could ultimately be used to reduce the community's impact on the Medjerda watershed.

Table 6. Overview of CS-related to hydrological monitoring and WQM in African countries.

Country	Number of Sites/Participants	Time Scale	Monitoring Focus	Training	Type of Project	Program	References
Tunisia	2 sites/8 participants	1 year	Discharge measurements				Fehri et al. [24]
	3 sites/7 participants	10 months	Rainfall monitoring	Yes	Collaborative	Together4Water project	Fehri et al. [25]
Kenya	13 sites/ 125 participants	1 year	Water level	yes	Contributory	n.a.	Weeser et al. [41]
	13 sites	1 year	Water level	yes	Contributory	n.a.	Rufino et al. [42]
Tanzania	24 sites	6 years	Water flow	yes	Co-created	IMoMo/GI	Njue et al. [43]
	39 sites	n.a.	Water level & flow precipitation	n.s.	Collaborative	RACC	Gomani et al. [44]
Ethiopia	8 sites	>1 year	Precipitation, stream water & groundwater levels	yes	Collaborative	AMGRAF	Walker et al. [45]
	28 sites	n.a.	Precipitation, water level	yes	Collaborative	n.a.	Zemadim et al. [46]
South Africa	n.a.	2 years	Stream flows & precipitation	yes	Collaborative	n.a.	Kongo et al. [47]
	3 sites	1 year	Precipitation	yes	Collaborative	n.a.	Kosgei et al. [48]
			Water quality monitoring				
Kenya	6 sites	<1 year	Water quality	yes	Contributory	n.a.	Gräf [49]
	12 sites/3 participants	1 year	Water quality (Nitrates, Total alkalinity, and Sodium chloride)	yes	Collaborative	Smart Medjerda	Chaabane et al. [19]
Tunisia	12 sites/3 participants	6 months	Water Salinity	yes	Collaborative	Project	Chaabane et al. [20]
	24 sites/33 participants	1 year	Water quality (Nitrates)	Yes	Collaborative		This study

n.a.: not available.

4. Conclusions

This study presents the assessment of a ready-to-use, low-cost, and reliable test strips method used for monitoring nitrate water quality according to the CS approach for sustainable water resource management and assistance in decision-making in the Medjerda watershed. The results show that this tool could be reliable for obtaining the levels of nitrate in water samples. It can be concluded that, while standard methods are more reliable, rapid and simple measurements using the test strips can conveniently be used by citizens for the WQM of nitrates if citizens follow rigorously the manufacturer's instructions. With adequate training of users, the test strips should allow for reliable, sensitive, and accurate nitrate water quality measurements. Motivation of citizens, recruitment, contribution, collaboration, and co-creation involvement levels will be a key factor in enhancing the CS-WQM program in Medjerda. Participant data collection of nitrate measurements can be used with governmental conventional data in supporting the monitoring of surface and groundwater water resources in the Medjerda watershed. The results of this case study will help in better design of CS activities in the Medjerda WQM and facilitate the achievement of the UN SDG.

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Data Availability Statement: Data used for the WQM-CS of the Medjerda watershed presented in this study are available upon request from the author Safa Chaabane. Data are not publicly available and should be provided upon specific request.

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