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Validating Citizen Science Monitoring of Ambient Water Quality for the United Nations Sustainable Development Goals

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Abstract

Citizen science (CS) may be described as research carried out by members of the public with the aim of gathering scientific information for the purpose of aiding in scientific projects. It has many potential advantages, including data collection at a scale not possible by professional scientists alone. The United Nations (UN) has recently recognized citizen science as a potential source of data that may contribute to the UN Sustainable Development Goals (SDGs). The availability of relatively inexpensive water quality monitoring field equipment suitable for CS suggests great potential for increased spatial coverage far beyond that of traditional, laboratory-based monitoring networks for water quality. In support of work towards the achievement of Sustainable Development Goal 6: “Clean Water and Sanitation”, this study tested the use of such field equipment by citizen scientists for SDG Indicator 6.3.2: “Proportion of bodies of water with good ambient water quality”. Data generated by 26 citizen scientists were compared with the results produced by an accredited laboratory. The results compared well for most parameters, suggesting that citizen science may be able to contribute towards monitoring ambient water quality for the Sustainable Development Goals.

Keywords: SDG 6; capacity development; volunteer monitoring; United Nations; community science

1. Introduction

SDG Indicator 6.3.2 is defined as the “proportion of bodies of water with good ambient water quality” (UNEP, 2018). Together with SDG Indicator 6.3.1 on the “proportion of wastewater safely treated”, these indicators provide a means of monitoring progress towards achieving SDG Target 6.3 with the aim of improving global water quality. Due to the issues facing many Member States regarding the collection of sufficient data on ambient water quality, the United Nations has expressed significant interest in the potential for citizen science to contribute to supporting progress towards achieving the ambient water quality SDG Indicator 6.3.2 (UNEP, 2018). The indicator methodology currently makes use of a water quality index that summarizes data gathered through the analysis of basic core water quality parameter groups, namely oxygen, salinity, nitrogen, phosphorus and acidification (UN Water, 2018). All Member States are asked to monitor to this level and are required to report a national indicator score designed to reflect overall water quality in that region (UNEP, 2018). As part of the United Nation’s 2017 baseline data drive, submissions were received from 52 of the 193 Member States, comprising data of varying levels of coverage and completeness (UNEP, 2018). The data drive highlighted that some Member States were prevented from reporting on the ambient water quality indicator for SDG 6 due to insufficient monitoring activities, and that other States with limited resources focused on monitoring a few key water bodies (UNEP, 2018).

Citizen science refers to the participation of citizens in scientific projects with the objective of gathering scientific information (Bonney *et al.*, 2014; Silvertown, 2009). The practice employs the joint efforts of both professional scientists and members of the public, who need not hold any preliminary knowledge or training on the subject matter, but who volunteer to collaborate with professionals to conduct scientific research (Cappa *et al.*, 2018; Dickinson & Bonney, 2012). Although citizen science traces its roots back to the beginnings of modern science (Cohn, 2008), scientific research involving volunteers has seen a surge in popularity in recent years (McKinley *et al.*, 2017). The United Nations has recognized citizen science as potentially being a necessary source of support for the monitoring of ambient water quality for SDG 6 (UNEP, 2018). Greater effort is therefore needed in order to encourage the use of this cost-effective and abundant resource. The five core water quality parameter groups of the ambient water quality SDG Indicator 6.3.2 (oxygen, salinity, nitrogen, phosphorus and acidification) may be measured using a range of simple and inexpensive field techniques that are accessible to citizen science networks (UNEP, 2018). Thus, where the proper resources are put in place to ensure responsible data collection and submission, citizen science networks could prove a vital source of additional data on ambient water quality by providing greater spatial and temporal coverage of data than is currently possible through the sole use of traditional, laboratory-based monitoring networks (UNEP, 2018).

A number of challenges remain before citizen science can be seen as a viable method of scientific research producing reliable data that can be used to support scientific and decision-making processes across a diversity of fields, including those relating to the monitoring of ambient water quality for the Sustainable Development Goals. The most significant barrier to the widespread use of citizen science is the perception of scientists who question the quality and reliability of data produced by non-professionals (Burgess *et al*., 2017; Fore *et al*., 2001; Penrose & Call, 1995; Riesch & Potter, 2013). Data quality issues are not isolated to citizen science monitoring programmes – experienced researchers also make errors. However, the perception that volunteer-generated data would not be well received by the scientific community contributes to a prejudice against its use (Crall *et al*, 2011; Dickinson *et al*., 2010; Foster-Smith & Evans, 2003; Riesch & Potter, 2013). In contrast, numerous studies have shown that volunteers are capable of collecting data of equal quality to that of professional scientists, provided they are given the proper training and resources, and provided the study design matches the collectors' abilities, and many validation studies to date have reported the high standard of water quality data collected by citizen scientists (Dyer *et al*. 2014; Herman-Mercer *et al*., 2018; Levesque *et al*., 2017; Loiselle *et al*., 2016; Loperfido *et al*., 2010; McGoff *et al*., 2017; Muenich *et al*., 2016; Safford & Peters, 2017; Scott & Frost, 2017; Shelton, 2013; Thornhill *et al*., 2017; Thornhill *et al*., 2018; Wilderman & Monismith, 2016). Water quality and water resource management within EU Member States is governed by the Water Framework Directive (WFD), a piece of European Commission legislation, that requires the incorporation of public participation in its implementation, mainly through public consultation and information supply (Hadj-Hammou *et al*., 2017; Van der Heijden & Ten Heuvelhof, 2013). As with the methodology for the ambient water quality indicator for SDG 6, Member States within the EU have the freedom to develop their own strategies for the monitoring and assessment of waterbodies (Van der Heijden & Ten Heuvelhof, 2013). While public input has been encouraged with regard to both the WFD and ambient water quality SDG Indicator 6.3.2 (UNEP, 2018; Van der Heijden & Ten Heuvelhof, 2013), the specific role of citizen science in monitoring and assessing water quality is limited, and no study to date has explored the potential for citizen science to support ambient water quality monitoring as part of the SDGs specifically.

This study explored whether a group of citizen scientists based in Killarney, Co. Kerry, Ireland, were capable of collecting high-quality data on a number of the core and alternative ambient water quality parameters associated with SDG Indicator 6.3.2. The citizen scientists conducted analyses on water samples using simple citizen science field kits provided by FreshWater Watch (https://freshwaterwatch.thewaterhub.org/), the freshwater initiative of the global NGO, Earthwatch (https://earthwatch.org/). The overall accuracy of the citizen science field kits was evaluated by comparison with an ISO/IEC 17025:2017 accredited laboratory in Co. Kerry, Ireland. The feasibility of citizen science to support monitoring of ambient water quality parameters for the SDGs was assessed. The challenges and opportunities encountered with applying this scientific approach to monitoring for the ambient water quality SDG Indicator 6.3.2 are discussed here.

2. Methods

2.1 Participant Recruitment

Participants were recruited from St. Brendan's College, Killarney, Co. Kerry, Ireland, from a class of 74 male students, between the ages of 16 and 17. Each student was given a screening survey to assess their interest in science, environmental issues and working outdoors. A total of 34 students were identified as potential participants for the project, based on the level of interest shown by their responses to the screening survey. They then took part in a briefing session and underwent training. The level of training among citizen scientists can influence the accuracy of monitoring data (Fore *et al*., 2001), therefore training was provided to all potential participants. During the training session, students were taught about water quality issues within freshwater ecosystems and the background to the research project, namely the UN Sustainable Development Goals and the potential for citizen science to contribute to supporting SDG 6. FreshWater Watch training materials provided the baseline for training of all participants, and this was supplemented with a demonstration of the analysis techniques using water samples provided for the purpose of training. Having been split into small groups, the students were allowed time to practice using the analytical kits within the classroom under the supervision of the trainer, who was able to provide feedback and answer questions. Following this practical training session, all students were required to complete a training quiz, to confirm that the participants were sufficiently trained and that their results could be trusted for uploading to the FreshWater Watch global database (https://freshwaterwatch.thewaterhub.org/content/datamap). Based on the results of the training quiz, 28 students were selected to participate in the research study.

2.2 Site Description

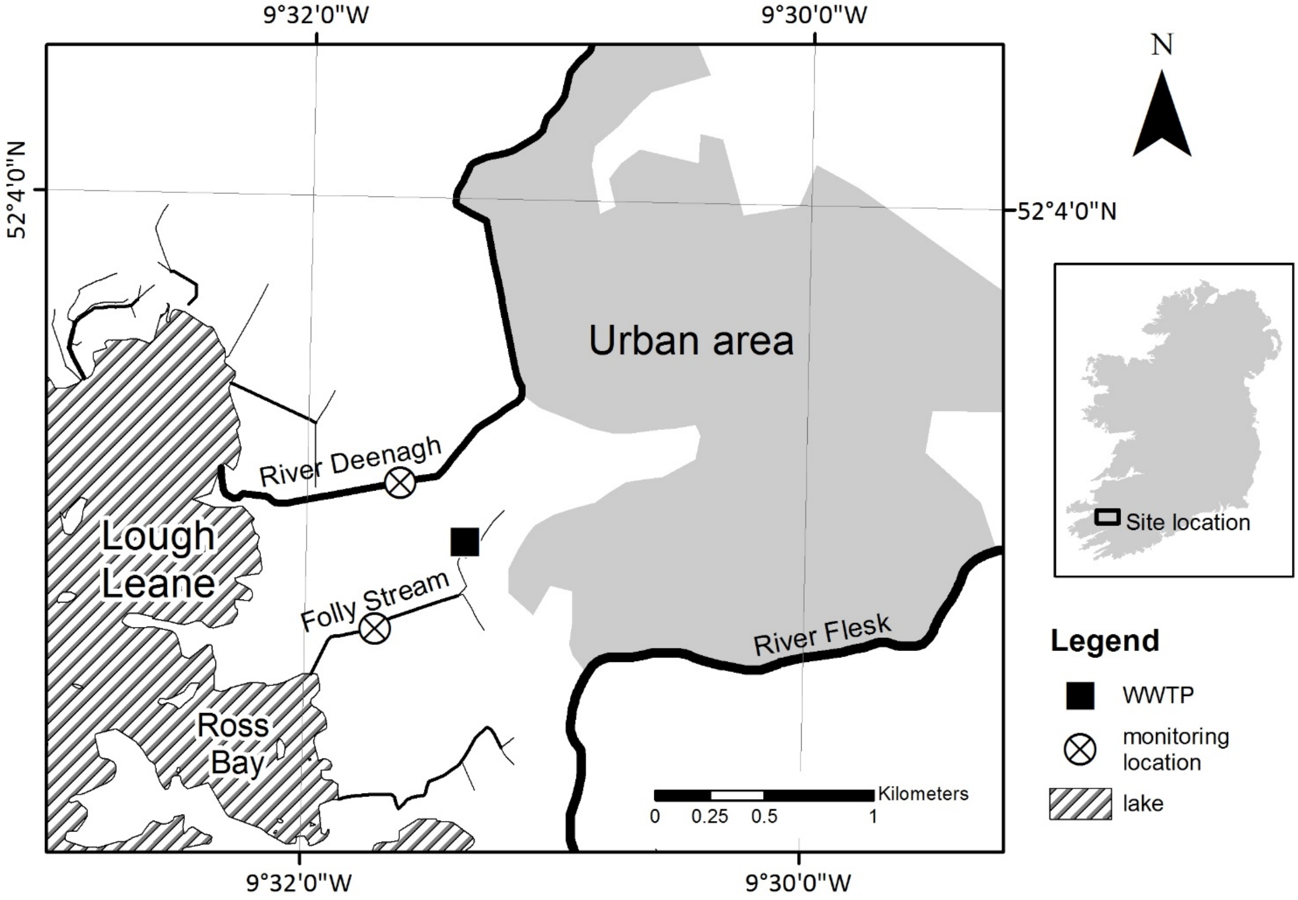

Figure 1. Locations of the monitoring sites within the River Deenagh and Folly Stream catchments in southwest Ireland.

Lough Leane is a freshwater lake located within Killarney National Park, draining a catchment of 553 km^2 near the town of Killarney, County Kerry in southwest Ireland. The rivers Flesk, Deenagh and Long Range are the main sources of input to Lough Leane, which flows to the Atlantic Ocean via the River Laune (Jennings *et al.*, 2013). The Folly stream is a minor stream of approximately 1.5 km in length that drains a small area of roughly 0.9 km^2 and enters Lough Leane near Ross Bay. The main wastewater treatment plant for the town of Killarney is located 1km upstream of Ross Bay. Two Storm Water Overflows (SWOs) carrying untreated wastewater enter the Folly stream during times when the WWTP is under stress from high-inputs (Irish Water, 2018).

The River Deenagh and Folly stream were identified as suitable for inclusion in this study due to the evident differences in water quality between the two waterbodies. Monitoring at the Folly stream has indicated that good status surface water standards for ammonia and biochemical oxygen demand (BOD) are exceeded both upstream and downstream of the wastewater treatment plant. Good status standard for orthophosphate is also exceeded downstream of the plant (Environmental Protection Agency, 2012). It was acknowledged in the last waste water discharge license application that the Folly stream was unable to accommodate the discharge from the WWTP, despite the fact that it operated well within its design parameters and capacity (Environmental Protection Agency, 2012). The Folly stream has appeared as a cause of local concern in recent years due to the deteriorating water quality, though it is currently not monitored by the EPA and is not assigned a status under the Water Framework Directive (Environmental Protection Agency, 2012). Conversely, a number of EPA monitoring stations are located along the length of the River Deenagh, with the most recent assessment determining that the two lower stations located near Killarney town achieved "Good" ecological status (Environmental Protection Agency, 2019). The differences in water quality between the two waterbodies allowed for an examination of the effectiveness of the FreshWater Watch equipment in more and less polluted environments.

A preliminary survey was carried out on 24th February 2019 and two sampling sites were carefully selected based on accessibility and safety, one located on the River Deenagh (52˚ 3' 17" N, -9˚ 31' 38" W) and another along the Folly stream (52˚ 2' 56" N, -9˚ 31' 44" W) (Figure 1). On the day of sampling conditions at both sites were calm with a steady water flow and average water levels. The sampling site at the River Deenagh was located upstream of a bridge and featured clear water and a rocky bottom with bank vegetation on one side of the river and a small pedestrian path on the other. The surrounding and overhead vegetation consisted of deciduous forest. The sampling site along the Folly stream featured murky water and a muddy bottom, with thick bank vegetation and a surrounding deciduous woodland.

2.3 SDG Indicator 6.3.2 Parameters

The five core water quality parameter groups for the ambient water quality SDG Indicator 6.3.2 are outlined in Table 1. Some parameters are included in the methodology in order to characterize the water quality in a particular waterbody, while others provide a direct measure of water quality for ecosystem or human health (UN Water, 2018). Deviation from normal ranges (such as with salinity and acidification) and comparison of measured values with target values (in the case of phosphorus, nitrogen and oxygen) allow for the detection of instances where the waterbody may be experiencing harmful impacts. This enables the classification of water quality as either “good” or “not good” in relation to these target values for each monitoring location. The classifications are aggregated by catchment, and then nationally, to generate the indicator percentage (UN Water, 2018).

The water quality data which feed into the indicator are derived from in-situ measurements and analysis of water samples. The citizen science field kits provided by FreshWater Watch (FWW) were capable of measuring four of the recommended ambient water quality parameters: Orthophosphate, Nitrate, Electrical Conductivity and pH. The field kits did not include tests for the other recommended parameter, dissolved oxygen (DO), so Chemical oxygen demand (COD) was included here.

Table 1. Recommended monitoring parameters (in bold) required for the water quality index used for SDG Indicator 6.3.2 for three water body types. Alternative parameters (in italics) may be substituted for the recommended parameters, depending on data availability and applicability for specific water body types (UN Water, 2018).

Parameter group	**Parameter**	**River**	**Lake**	**Groundwater**
Oxygen	**Dissolved oxygen** *Biological oxygen demand, Chemical oxygen demand*	x	x	
Salinity	**Electrical conductivity**	x	x	x
	Salinity, Total dissolved solids			
Nitrogen*	**Total oxidised nitrogen**	x	x	
	Total nitrogen, Nitrite, Ammoniacal nitrogen			
	Nitrate**			x
Phosphorus	**Orthophosphate**	x	x	
	Total phosphorus			
Acidification	**pH**	x	x	x
***** Countries should include the fractions of N and P which are most relevant in the national context				
****** Nitrate is suggested for groundwater due to associated human health risks				

2.4 Citizen Analyses

Sampling took place on 22nd March 2019 as part of an activity for World Water Day. At each sampling site a large plastic bucket was first rinsed three times in the water from the sampling site. Taking care not to disturb the sediment, the bucket was then filled from the centre of the waterbody and placed in a secure location on the bank, where the sample water was mixed well with a clean plastic spatula. All sampling by citizen scientists was conducted using the sample water contained in the bucket, therefore minimizing any spatial and temporal differences between results. The samples taken for analysis at an accredited laboratory were also taken from the same sample of water in the same bucket. The citizen scientists wore gloves while sampling and a large sheet of plastic tarp was placed on the ground where volunteers could place equipment in order to avoid contamination of the water sample and materials used.

Nitrate (NO_3-N), phosphate (PO_4-P) and chemical oxygen demand (COD) Kyoritsu PackTest (Kyoritsu Chemical-Check Lab, Corp., Tokyo, Japan) water chemistry kits were obtained from FreshWater Watch (Earthwatch Institute, Oxford, United Kingdom). All parameters were measured in transparent plastic tubes which are designed to mix a small water sample with reagents that produce increasing colour values with increasing concentration (Scott & Frost, 2017). The PO_4-P method using 4-aminoantipyrine with phosphatase enzyme (Berti *et al*., 1988), and nitrate NO_3-N method using zinc and subsequently following the Greiss method (Nelson *et al*., 1954), provided nutrient concentrations that fell into one of seven categories ranging from <0.02 - >1.0 mg/L P and <0.2 - >10 mg/L N (Table 2) (Scott & Frost, 2017). Chemical oxygen demand was determined by an oxidation reaction with potassium permanganate in an alkaline medium, which provided concentrations ranging across seven categories from 0-5 to >100 mg/L O_2 (Table 2) (Kyoritsu, n.d.). pH was determined with Simplex Health (Simplex Health, Wollaston, United Kingdom) pH test strips which were held in the sample water for 3 seconds and subsequently matched to a colour chart. Electrical conductivity was measured using hand-held Lohand Biological (Hangzhou Lohand Biological Co., Ltd, China) conductivity meters dipped into the sample water for approximately 15 seconds until the reading in µS/cm stabilized (Table 2). Each participant received a copy of the instructions on how to conduct each test and recorded all their data on their own individual datasheet, covering both sites. Replicate samples were taken by citizens at each site – fourteen students sampled each parameter twice in Site 1 and three times in Site 2, while the other half of the participants did the opposite, thus taking a total of five measurements for each parameter across the two sites.

A total of 27 datasheets were received following sampling and one was rejected because it was incorrectly completed. Data analysis was conducted on the results collected by 26 participants in the study, resulting in a total of 66 measurements for most parameters at Site 1 and 64 measurements for each parameter at Site 2 (Table 5).

Table 2. Ranges of measurement of the equipment used by citizen scientists to analyse various water quality parameters at the River Deenagh and Folly stream.

Parameter	***Units***	**FWW Equipment Range**								
Orthophosphate	*mg/L P*	<0.02	0.02-0.05	0.05-0.1	0.1-0.2	0.2-0.5	0.5-1.0	>1.0		
Nitrate	*mg/L N*	<0.2	0.2-0.5	0.5-1.0	1.0-2.0	2.0-5.0	0.5-10.0	>10.0		
Chemical Oxygen Demand	*mg/L O2*	0.0-5.0	5.0-10.0	10.0-13.0	13.0-20.0	20.0-50.0	50.0-100.0	>100.0		
pH	*pH Unit*	< 4.5	4.5 – 5	5 – 5.5	5.5 – 5.75	Increments of 0.25 up to 7.5	7.5 - 8	8 – 8.5	8.5 - 9	> 9
Electrical Conductivity	*µS/cm*	10 - 1990 +/- 10 µS/cm precision								

2.5 Laboratory Analyses

At each site three samples were taken from the bucket of sample water and transported to the Southern Scientific Services laboratory at Farranfore, Co. Kerry within 20 minutes of collection for preservation and analysis. The laboratory holds ISO/IEC 17025:2017 accreditation for general requirements for the competence of testing and calibration laboratories (Southern Scientific Services, 2019). All methods used for the analysis of the various parameters are listed in Table 3. Orthophosphate and Nitrate were determined by spectrophotometry; pH and electrical conductivity were analysed using Rohasys MINILAB Multi Parameter robot (ROHASYS BV, Rijen, Netherlands); chemical oxygen demand was determined using a closed-reflux, colorimetric method (Table 3).

Table 3. Laboratory methods from Standard Methods for the Examination of Water and Wastewater 23rd Edition (Baird *et al*., 2017) used in the analysis of water samples as part of this study by the accredited laboratory.

Parameter	**Standard Reference/SOP**	**Range of Measurement**	**Accuracy of Measurement**	**Equipment/Technique**
Orthophosphate	APHA, 4500P-E, 23Ed., (2017) / SPC 027c	0.01-12 mg/L P	+/- 0.001	Spectrophotometry by Aquakem 250 Autoanalyser
Nitrate	APHA, 4500NO3-E, 23Ed., (2017) /SPC 027g	0.25-45 mg/L N	+/- 0.001	
Chemical Oxygen Demand	APHA, 5520D, 23Ed., (2017) / SPC 016	10-30,000 mg/L	+/- 0	HACH/Colorimetric
pH	APHA, 4500B-H+, 23Ed., (2017) / SPC 052	4 - 10 pH Units	+/- 0.01	Rohasys Minilab
Electrical Conductivity	APHA, 2510B, 23Ed., (2017) / SCP 052	14.7 -111,900 µS/cm @ 20°C	+/- 0.1	

2.6 Data Analyses and Considerations

The test kits provided by FreshWater Watch produced a categorical classification for the concentration of various water quality parameters within a sample of water. The categories for each parameter are outlined in Table 2. The outcomes of citizen scientist sampling are displayed in a frequency distribution table – the most frequently chosen concentration range, as well as the range containing the "true" laboratory value, are shown (Table 5). As the data is categorical, the concentration range containing the laboratory value could be considered the "correct" result, while results in all other categories could be considered incorrect. However due to the nature of the testing kits and the colorimetric method by which a value is determined, difficulty can arise for users when deciding between concentration ranges, as there is no distinctive colour difference between one concentration range and the next. When the "true" laboratory value falls close to the border of one of the concentration ranges it is understandable for citizen scientists to struggle with choosing the correct result. For this reason, results recorded one concentration range outside the "correct" concentration range are included in the discussion on percentage agreement and the accuracy of citizen science monitoring of ambient water quality. Opinion is also divided on an adequate level of percentage agreement in research. To one researcher 70% agreement is adequate, whereas another would not consider 70% agreement a sufficient level to answer their research questions (Aceves-Bueno *et al*., 2017). A general rule of thumb describes an agreement level of 75% as a minimum acceptable level of agreement (Graham *et al*., 2012; Hartmann, 1977; Stemler, 2004). This was the acceptance level adopted by this investigation.

3. Results

3.2 Water Quality Testing

Table 4 shows the results of water quality analyses conducted by an accredited laboratory in Kerry on samples taken from the River Deenagh (Site 1) and Folly stream (Site 2). Results of analyses of the same water quality parameters by citizen scientists are displayed in Table 5, and the percentage of their results in agreement with those obtained by the laboratory are highlighted in bold (Table 5). Of the five ambient water quality parameters analysed, citizen scientists demonstrated good agreement in their measurements of three – Orthophosphate, Nitrate and Electrical Conductivity. The other two parameters, pH and Chemical Oxygen Demand, showed less agreement with the laboratory results (Table 5).

Across both sites the majority of volunteer results for Orthophosphate were either in agreement with the laboratory value or else fell into a concentration range just above or below this (Table 5a). A similar result can be seen for Nitrate where between 81.3-84.8% of results across both sites fell within or just outside the concentration range corresponding to the laboratory value for Nitrate (Table 5b). However, greater variation can be seen in the distribution of results outside this concentration range (Table 5b). The results of electrical conductivity tests by citizen scientists at the River Deenagh were also positive, with 77.4% of results falling within or just outside the laboratory value of 180 µS/cm. At the Folly stream the results showed less agreement, with many citizen scientists overestimating the conductivity value at that site (Table 5e).

The results of Chemical Oxygen Demand tests were less compatible with the laboratory results; citizen scientists showed poor agreement of COD values in both the River Deenagh (0.0%) and Folly stream (2.6%) (Table 5c). The percentage of citizen scientist results recorded within or just outside the laboratory result was lower at 28.8% and 11.0% for sites 1 and 2 respectively. Citizen scientists were unable to measure pH accurately to within or just outside the concentration range agreeable with the laboratory result in either the River Deenagh (0.0%) or Folly stream (21.9%) (Table 5d).

The contrasting nature of the River Deenagh and Folly Stream is reflected in the results obtained by both citizen scientists and the accredited laboratory. Though Nitrate and pH levels did not appear to differ much between the two sites, Orthophosphate, Chemical Oxygen Demand and Electrical Conductivity levels were noticeably higher at the Folly Stream than in the River Deenagh (Tables 4 and 5). Irrespective of the levels of agreement between citizen and laboratory results, the volunteers and FWW testing kits were capable of revealing a difference in water quality between the two sites that supports current conclusions on the nature of these waterbodies.

Table 4. Results of analyses of water samples taken from the River Deenagh (Site 1) and Folly stream (Site 2) by an ISO/IEC 17025:2017 accredited laboratory. The means of the three laboratory analyses was calculated for each parameter and used for comparison with results gathered by citizen scientists.

Parameter	*Units*	**Site 1**				**Site 2**			
		Sample1	**Sample 2**	**Sample 3**	**Mean**	**Sample1**	**Sample 2**	**Sample 3**	**Mean**
Orthophosphate	*mg/L P*	0.02	0.01	0.02	0.02	0.10	0.10	0.10	0.10
Nitrate	*mg/L NO3-N*	2.4	2.5	2.6	2.5	2.5	2.4	2.4	2.4
Chemical Oxygen Demand	*mg/L O2*	<10	11	10	11	15	14	17	15
pH	*pH Unit*	7.5	7.5	7.5	7.5	7.2	7.1	7.1	7.1
Electrical Conductivity	*μS/cm @ 20˚C*	180	179	180	180	427	434	432	431

Table 5. Results of citizen scientist water quality sampling at the River Deenagh (Site 1) and Folly stream (Site 2) using the FreshWater Watch water quality testing kits. The number and percentage of results obtained by citizen scientists within each concentration range are shown. The citizen scientist results in agreement with the results obtained for each parameter by an accredited laboratory are highlighted in bold.

a) Orthophosphate			b) Nitrate			c) Chemical Oxygen Demand		
Range (mg/L P)	**Site 1 Results**	**Site 2 Results**	**Range (mg/L N)**	**Site 1 Results**	**Site 2 Results**	**Range (mg/L O2)**	**Site 1 Results**	**Site 2 Results**
<0.02	29 (43.9%)	0 (0.0%)	<0.2	0 (0.0%)	0 (0.0%)	0.0-5.0	46 (69.7%)	22 (34.4%)
0.02-0.05	***35 (53.0%)***	13 (20.3%)	0.2-0.5	1 (1.5%)	6 (9.4%)	5.0-10.0	19 (28.8%)	35 (54.7%)
0.05-0.1	2 (3.0%)	*27 (42.2%)*	0.5-1.0	9 (13.6%)	5 (7.8%)	10.0-13.0	***0 (0.0%)***	4 (6.3%)
0.1-0.2	0 (0.0%)	***23 (35.9%)***	1.0-2.0	12 (18.2%)	4 (6.3%)	13.0-20.0	0 (0.0%)	***2 (3.1%)***
0.2-0.5	0 (0.0%)	1 (1.6%)	2.0-5.0	***42 (63.6%)***	***31 (48.4%)***	20.0-50.0	1 (1.5%)	1 (1.6%)
0.5-1.0	0 (0.0%)	0 (0.0%)	0.5-10.0	2 (3.0%)	17 (26.6%)	50.0-100.0	0 (0.0%)	0 (0.0%)
>1.0	0 (0.0%)	0 (0.0%)	>10.0	0 (0.0%)	1 (1.6%)	>100.0	0 (0.0%)	0 (0.0%)
Total	66 (100.0%)	64 (100.0%)	Total	66 (100.0%)	64 (100.0%)	Total	66 (100.0%)	64 (100.0%)

d) pH		
Range (pH Units)	**Site 1 Results**	**Site 2 Results**
< 4.5	0 (0.0%)	0 (0.0%)
4.5 – 5	0 (0.0%)	0 (0.0%)
5 – 5.5	10 (15.2%)	0 (0.0%)
5.5 – 5.75	45 (68.2%)	2 (3.1%)
5.75 – 6	8 (12.1%)	14 (21.9%)
6 – 6.25	2 (3.0%)	26 (40.6%)
6.25 – 6.5	1 (1.5%)	4 (6.3%)
6.5 – 6.75	0 (0.0%)	2 (3.1%)
6.75 - 7	0 (0.0%)	1 (1.6%)
7 – 7.25	0 (0.0%)	***6 (9.4%)***
7.25 – 7.5	*0 (0.0%)*	7 (10.9%)
7.5 - 8	***0 (0.0%)***	2 (3.1%)
8 – 8.5	0 (0.0%)	0 (0.0%)
8.5 - 9	0 (0.0%)	0 (0.0%)
> 9	0 (0.0%)	0 (0.0%)
Total	66 (100.0%)	64 (100.0%)

e) Electrical Conductivity			
Range (µS/cm)	**Results Site 1**	**Range (µS/cm)**	**Results Site 2**
110	1 (1.6%)	410	1 (1.6%)
130	4 (6.5%)	420	8 (12.9%)
150	3 (4.8%)	430	***10 (16.1%)***
160	6 (9.7%)	440	11 (17.7%)
170	*15 (24.2%)*	450	20 (32.3%)
180	**30 (48.4%)**	460	9 (14.5%)
190	3 (4.8%)	470	1 (1.6%)
Total	62 (100.0%)	480	2 (3.2%)
		Total	62 (100.0%)

4. Discussion

4.1 Can citizen science help support monitoring for SDG Indicator 6.3.2?

Overall the results of the water quality analyses indicated that citizen scientists were able to measure water quality parameters to within or just outside the laboratory value for between 79.7% and 99.9% of measurements for Orthophosphate and Nitrate, establishing them as two of the parameters most compatible with the laboratory results (Table 5a-b). Electrical conductivity measurements were a little more variable, with between 46.7% and 82.3% of results falling within or just outside the laboratory value (Table 5e). Chemical oxygen demand and pH were the parameters showing the least agreement with the laboratory results (Table 5c-d). Concentration ranges just outside the concentration range containing the laboratory result were taken into account when discussing percentage agreement and the overall accuracy of results. While this was deemed necessary to account for the difficulty volunteers experienced in choosing between concentration ranges due to the colorimetric nature of the testing kit, it must be recognized that this method likely overestimates the percentage agreement due to the inclusion of results at the extreme, opposite ends of the outer concentration ranges which were not in any way misinterpreted.

The five water quality parameters chosen for inclusion in this research study form the basis of the most basic monitoring level for ambient water quality under SDG Indicator 6.3.2, the ambient water quality indicator for SDG 6 (UNEP, 2018). Results of citizen testing of Orthophosphate, Nitrate and Electrical Conductivity proved reasonably accurate based on the percentages of results in agreement with laboratory analyses for these parameters (Table 5a-b & 5e). This was partly expected for both nutrient tests given the positive conclusions drawn by other researchers who have used the Kyoritsu PackTest water chemistry kits provided through FreshWater Watch to allow citizen scientists to measure Orthophosphate and Nitrate (Levesque *et al.*, 2017; Loiselle *et al.*, 2016; McGoff *et al.*, 2017; Scott & Frost, 2017; Shupe, 2017; Thornhill *et al.*, 2017; Thornhill *et al.*, 2018; Xu *et al.*, 2017). Two of these studies (Levesque *et al.*, 2017; Thornhill *et al.*, 2017) noted that between 65.8% and 81% of results obtained by citizen scientists for both parameters were in agreement with laboratory results, a slightly higher level of agreement than was noted in this investigation. Interest level has been identified as an important motivational variable in a student's academic performance and an influencing factor in how much attention is paid to a particular activity (Hidi & Harackiewicz, 2000; Schiefele, 1991, 1996). It is therefore possible that the slightly lower level of agreement with laboratory results witnessed in this study compared to others involving FreshWater Watch volunteers could be attributed to lower interest levels on the parts of the students, compared to those of volunteers giving time out of their everyday schedule. An investigation into whether differences in interest levels influence the accuracy of results obtained using the kits may prove beneficial for recruitment purposes for future citizen science projects. Other published research studies focusing on testing water quality using citizen scientists have opted for the use of total reactive phosphorus (Hach Aquacheck Cat. 27571-50) and nitrate field test strips (HACH, 2745425; Hach Aquacheck Cat. 27454-25) (Loperfido *et al*., 2010; Muenich *et al*., 2016) and observed mixed results. No other published studies could be found on citizen science water quality testing involving the use of the Lohand Biological meters for conductivity. The performance of the meters in the field and their agreement with the laboratory results was very good at the River Deenagh (Table 5e), though they did not perform as well at Folly stream, potentially indicating that they are less reliable in more polluted environments. Other published studies have made use of YSI Professional Plus multi-probes (Shelton, 2013), EuTech ECTestr™ 11 probes (Storey *et al*., 2016), Oakton PCtestr meters (Shupe, 2017), and the LaMotte PockeTester meter (Wilderman & Monismith, 2016) for measuring electrical conductivity and have reached mostly positive conclusions on their use. However, while also useful, these instruments are considerably more expensive than the Lohand Biological meters provided through FreshWater Watch.

The test for Chemical Oxygen Demand followed an identical procedure to those used for Orthophosphate and Nitrate, albeit with a slightly longer time for colour development before reading the result, yet the accuracy of the results was vastly different (Table 5c). The test procedure for pH was also extremely simple, involving dipping a Simplex Health test strip into the water for 3 seconds and determining the result after 15 seconds, yet despite this simplicity great variability can be seen within the results. As the participants were already familiar with the testing procedure for Chemical Oxygen Demand due to its similarity to other parameters, and the simplicity of the pH test left little opportunity for error, variability in the results of both parameters would suggest that less accurate and precise measurements potentially stemmed from a difficulty in interpreting the results rather than a difficulty in correctly carrying out the tests themselves to avoid contamination and reduce error (Table 5c-d). Further investigations using these tests may prove beneficial in determining their accuracy, and the ease with which results can be interpreted, before they could be applied to routine monitoring of ambient water quality for the Sustainable Development Goals. Other published studies have investigated pH using pH field test strips (Sigma-Aldrich, P-4411; Aquaspex™ pH-Fix 4.5-10.0) (Muenich *et al*., 2016; Storey *et al*., 2016) and Oakton PCtestr meters (Shupe, 2017) with mixed reviews. Citizen science studies to date measuring dissolved oxygen have made use of the YSI Professional Plus multi-probes (Shelton, 2013) and LaMotte Direct Reading Titrator kits (Storey *et al*., 2016) with mixed results. This study measured Chemical Oxygen Demand as an alternative to dissolved oxygen, yet also recorded mixed results on the test's accuracy, possibly suggesting that the technology behind citizen science tests has not yet advanced to the stage where accurate measurements of oxygen or oxygen demand can be taken (Table 5c). However, given the multitude of published studies revealing positive results for orthophosphate, nitrate and electrical conductivity with the use of various citizen science equipment, finding affordable and reliable testing equipment for these parameters especially should not be too great a challenge. This may allow for the initial establishment of citizen science as a core source of support for ambient water quality monitoring as part of the SDGs.

As noted above, the percentage agreement between citizen scientist and laboratory results was slightly lower in this investigation than in others involving FreshWater Watch volunteers using identical testing equipment (Levesque *et al*., 2017; Thornhill *et al*., 2017). While the lower interest levels of the students may have had an effect on the accuracy of the results, neither study carried out by Levesque *et al*., (2017) or Thornhill *et al*., (2017) revealed a 100% agreement rate between volunteer and laboratory results. This may suggest that while interest and training levels do hold some influence over operator error and the accuracy of results (Fore *et al*., 2001), technology is the main limiting factor when it comes to the accuracy and success of citizen science. Though technology has been a huge contributor to the advancement of citizen science in recent decades (Silvertown, 2009) it also remains as a barrier in certain circumstances where it is considered unreliable or unaffordable. Other published studies have opted for the use of more accurate equipment with positive results (Shelton, 2013), though this is unrealistic for most citizen science programmes due to the substantial associated cost. Though extremely affordable, a limitation of the equipment provided by FreshWater Watch for the purpose of monitoring for the ambient water quality indicator is the colorimetric method by which the range of values is determined. This rather subjective process provides difficulty for the user when determining whether the result lies within one range or another when the true result may in fact lie on the border of the kit ranges. This happened at both sites in this study when analyzing Orthophosphate, for example (Tables 2 & 4).

Other studies using the same equipment provided by FWW have also cited difficulties in determining results where the existence of low nutrient concentrations means results falling into the two lowest concentration categories limit finer scale analysis of nutrient patterns (Levesque *et al*., 2017; Scott & Frost, 2017). A review by Newman *et al*., (2012) into the future of citizen science using emerging technologies concluded that future citizen science programmes will need to "choose appropriate technology" for the project participants. Based on these observations, it is clear that further advancements in technology, whether to produce a more precise and accurate result that cannot be misinterpreted, or to allow for easer interpretation of a more ambiguous result, are still necessary before citizen monitoring may be accepted as reliable enough to support data collection on ambient water quality as part of SDG 6: "Clean Water and Sanitation".

On the other hand, adjustments to the assessment methods themselves may further increase the ease with which citizen and professional data may be integrated for the purpose of ambient water quality monitoring. During the global roll-out of the ambient water quality SDG Indicator 6.3.2 a number of challenges regarding the methodology were identified, namely issues surrounding the establishment of target values to determine whether a waterbody has good ambient water quality or not. The current method of determining an absolute measure of water quality through the comparison of measured values with target values is greatly influenced by the target values selected, and thus could result in misleading interpretations of water quality depending on whether the target values selected are lenient or strict (UNEP, 2018). As this study has revealed, while citizen science cannot provide numerical measures of the parameters for the ambient water quality indicator that are as accurate as those obtained by an accredited laboratory, it can indicate a concentration range for each parameter (Table 5a-b & 5e). Citizen science may therefore be more applicable to a monitoring methodology in which the focus shifts from target values to target ranges, allowing for the easier integration of citizen science data with that of professionals. A less specific assessment method, in which the results of water quality tests may encompass a range of values rather than conforming to a black-or-white target value may therefore prove more approachable and applicable for citizen science monitoring networks hoping to aid in the determination of ambient water quality. Assessing the appropriateness of potential methods for applying citizen science monitoring to target ranges in support of the ambient water quality SDG Indicator 6.3.2 should prove an important focus of future studies. Another factor which must be considered is the comparability of citizen science data worldwide. Differences in study design and data validation procedures have oftentimes resulted in difficulty when determining the accuracy of citizen science (Storey *et al.*, 2016). This study therefore chose to assess the quality of citizen data through comparisons made with professionally-generated laboratory data, a validation procedure common in citizen science water quality monitoring programmes (Muenich *et al.*, 2016; Levesque *et al.*, 2017; Loiselle *et al.*, 2016; Scott & Frost, 2017; Thornhill *et al.*, 2017; Thornhill *et al.*, 2018). When it comes to applying citizen science monitoring programmes to the collection of data on ambient water quality for SDG Indicator 6.3.2, guidelines and protocols will have to be clearly established in order to allow for the generation of comparable data, as is the case with laboratory results worldwide through the use of Standard Operating Procedures (SOPs). At the time of writing FreshWater Watch had collected 22,092 datasets on water quality throughout the world, over 10,000 in Europe alone. While this database is a wonderful resource for comparing water quality worldwide through the use of FreshWater Watch testing equipment, comparisons and the integration of data with other citizen science programmes will prove complicated should the advantages offered by the collection of vast amounts of data be overcome by the unavoidable biases introduced via the use of different testing kits and procedures. Careful consideration must therefore be given to how citizen science may be used to effectively support the monitoring of ambient water quality for the Sustainable Development Goals when there currently exists so many options for testing equipment, as evidenced above. While greater leniency is called for through the use of target ranges for monitoring under the ambient water quality indicator, stricter regulations will need to be put in place in order to establish the guidelines and protocols necessary to ensure that high-quality and intercomparable volunteer data is generated on ambient water quality. These considerations would allow for the production of more comparable data in both developed and developing nations with well-established citizen science communities. Applying citizen science in an approach as such should also allow for the more effective integration of volunteer monitoring programmes with current professional activities in developing nations where a lack of capacity to collect and analyse water quality data required for SDG Indicator 6.3.2 hinders their ability to report on ambient water quality (United Nations, 2018).

5. Conclusions

This study assessed the applicability and feasibility for citizen science to contribute towards monitoring activities supporting SDG Indicator 6.3.2 on the “Proportion of bodies of water with good ambient water quality". It showed that citizen scientists can produce data on Electrical Conductivity and on Orthophosphate and Nitrate concentrations, in two Irish waterbodies that agreed with the analysis of these parameters at an accredited laboratory. However, the precision and accuracy of the tests used for Chemical Oxygen Demand and pH need further development. Through the positive conclusions drawn for three of the five water quality parameters analysed, this study has demonstrated the potential of citizen science to contribute to water quality monitoring for the Sustainable Development Goals. The limitations in accuracy of the field kits used here may present challenges for how the data can be integrated into existing monitoring activities.

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