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Abstract

Fresh water is a limited resource under anthropogenic threat. Europeans are using an average of 3550 liters per capita per day and this amount is increasing steadily as incomes rise. Water saving options are being actively promoted, but these intensified measures do not yet come close to saving enough water to prevent water shortages that may seriously affect our way of life in the near future. With projected increases in demands for good quality fresh water, educating the public about sustainable personal water use and water quality threats becomes an absolute necessity. One way to achieve this is through engaging citizens in water issues, e.g. through citizen science projects. Using snowball convenience sampling, we distributed a questionnaire among 498 people in 23 countries to investigate whether people were aware of how much water they used, what they perceived as threats to water quality and whether they would like to help improve water quality. Our results showed that the amount of daily water

use was greatly underestimated among respondents, especially indirect use of water for the production of goods and services. Furthermore, the effects of climate change and detrimental habits such as feeding ducks were underestimated, presumably because of environmental illiteracy. However, eighty-five percent (85%) of our participants indicated an interest in directly working together with scientists to understand and improve their local water quality. Involving citizens in improving local lake quality promotes both environmental and scientific literacy, and can therefore result in a reduction in daily personal water use. The next iteration of the Water Framework Directive legislation will be launched shortly, requiring water managers to include citizens in their monitoring schemes. Engaging citizens will not only help improve surface water quality, and educate about cause and effect chains in water quality, but will also reduce the personal fresh water usage.

1. Introduction

1.1 Water scarcity now and in the future

In recent years, it has become evident that fresh water is a limited resource under anthropogenic threat. During the last century, the world population has tripled but freshwater use has increased 6-fold, paralleling increasing incomes and thus higher and different food demands (Alcamo 2000; Cosgrove et al. 2000). Although projected freshwater use by humans in 2016 already exceeded the global sustainable freshwater supply (Wigginton 2015), a staggering 1/5 of the world population does not have adequate access to safe drinking water (Cosgrove et al. 2000). Increasing human population will further intensify global pressure on available freshwater resources (Vorosmarty et al. 2000; Rijsberman 2006). Population growth not only directly increases freshwater demand but also affects the quantity and quality of fresh water in numerous ways via global change (Vorosmarty et al. 2000). More specifically, threats to water quality range from agriculture (nutrient pollution, pesticides, herbicides, and fertilizers), domestic domain (sewage, industry, pharmaceuticals and personal care products, and human activities such as feeding ducks), industry (energy, water abstraction, pollution) and climate change. Global change will increase freshwater demand by humans, but will also affect the freshwater demand by ecosystems through e.g. increased evaporation. Ecosystems are already affected by massive amounts of freshwater abstractions for drinking water, irrigation and power supply (dams), with half of the world wetlands disappearing in the twentieth century due to these abstractions on top of changes in land use (Cosgrove et al. 2000). Under warmer conditions, the ecological water demand of ecosystems will increase, further underlining the need to protect and smartly manage our water resources.

Furthermore, when the water demand by ecosystems is included in water scarcity calculations, the map of water scarce countries is drastically altered. If ecosystems' water demand is included, previously water-abundant western countries suddenly become water-scarce, belying the idea that water scarcity is mostly a problem exclusive to third world countries (Rijsberman 2006).

1.2 Water Policies

In order to meet current and future freshwater demands, water resources should be properly managed. For effective water management, both social aspects, e.g. public acceptance, regional culture and history as well as economic aspects, e.g. investments in water infrastructure and technology should be considered when planning for the sustainable protection of natural ecosystems (Shen and Varis 2000). In 1995, European citizens and environmental organizations demanded cleaner freshwater resources, resulting in the European Commission making water protection one of their priorities (European Commission 2016). The European Water Framework Directive (WFD) (Directive 2000/60/EC) replaced the Drinking Water Directive and Urban Waste Water Treatment Directive with the aim of cleaning polluted waters and ensuring that clean waters remain clean (The European Parliament and the Council of the European Union 2000). The WFD was the first guideline based on ecological principles, replacing previous legislations focusing solely on chemistry, using emission standards for water quality (Moss et al. 2003). To successfully protect the ecological quality of all Europe's water, the WFD promotes citizens' engagement in water quality assessment and solutions, encourages water managers and scientists to invest in outreach initiatives that deal with water awareness and further collaborations with non-government organizations (NGOs; Dickinson et al. 2012).

1.3 Water awareness

We define water awareness as being cognizant of how much water is used daily through direct use such as drinking and washing, and indirect use, e.g. how much water is used for the production of food items or clothing. Additionally, water awareness includes the realization of water quality threats such as agricultural run-off and the recognition that fresh water is a limited recourse. Engaging citizens in protecting freshwater resources encourages environmentally responsible behavior. This refers to “any action, individual or group, directed toward remediation of environmental issues/problems” as stated by Sivek and Hungerford (1990) and is nowadays popularly described by the term “citizen science” (Bonney et al. 2009). In this paper we defined citizen science as a form of environmentally responsible behavior in which individuals or groups learn about, monitor, preserve and improve lake water quality. Different attitudes, opinions and underlying personal experiences can attribute to a person’s water awareness.

The 2016 report of the Global Education Monitoring team indicated that the higher the level of education a person has received, the higher the value that person gives to the environment and addressing environmental problems (GEM Report Team 2016). In recent years, environmental education, with a focus on the impact humans have on the environment have been included in schools’ curricula around the world (GEM Report Team 2016), possibly making younger age classes more water aware.

Working in a scientific environment encourages critical thinking and provides an international, global perspective on the topic of choice. These traits can contribute to correctly identifying and interpreting environmental issues (Hayes 2001; Bybee, 2008).

The United Nations (UN) sustainable development goals specifically underline the importance of including women in addressing water (quality) issues. Globally, women are more involved with daily direct water use as they are generally primary responsible for housework and family care. This includes cooking and washing and even trips to the local water source, making women daily witnesses to water quantity and quality (United Nations

2016a). However, although much progress has been made since early 2000, 16 million girls will never receive an education, including environmental or scientific tuition (UNESCO 2018). Gender might therefore not have a clear relation to identifying threats to water quality.

Rurally located families might be more directly involved with their water source. Forty-six percent (46%) of the world's population lives in a rural area and many have their own water source (United Nations 2016b). Consequently, people raised in urban areas can be more disconnected to the source of their water compared to their rural counterparts. Personal experiences regarding water shortage (droughts) and water abundance (heavy rains and floods) might also influence a person's attitude towards the value of water. This difference could become apparent across Europe as, for example, southern Europeans will have experienced more chronic water shortage problems compared to northern Europeans, while northern Europeans are relatively more exposed to flooding incidents (European Environmental Agency 2015).

All the above-mentioned factors come together to determine one's view towards water: is it only a resource for human survival or does water mean more, i.e. the source of life in general, essential for ecosystem functioning? We hypothesize that differences in the perception of water might influence the water awareness of a person but possibly also their willingness to engage in water quality protection.

1.4 Other European surveys

In a large-scale survey commissioned by the European Union, 25,425 Europeans of age 15 years old and older were asked to state their opinion about fresh water and coastal issues (TNS Political and Social 2012). Whereas most participants felt ill-informed, they did believe water quality was a serious concern, with agricultural (90%) and chemical pollution (84%)

indicated as drivers of freshwater quality and quantity. Most participants were already taking individual actions to reduce their water use and believed that stronger efforts were needed to address water quality issues in general. Two-thirds (67%) of the EU survey participants thought that providing more information on the environmental consequences of water use is the most effective way to tackle water problems.

Within the first cycle of River Basin Management Planning for the EU WFD, a call was put out for a more bottom-up approach towards community-led actions in water management (The European Parliament and the Council of the European Union, 2000). In a survey distributed in the Republic of Ireland and the United Kingdom at the end of the first cycle of WFD plans (2015), 81% of respondents did not feel included in decision making about water resources. Only 32% of the participants had been invited to attend a community event regarding water issues, although the survey was already targeted towards societal groups interested in water resource management (Rolston et al. 2017). Both these surveys indicated that there is a strong interest in water quality related issues amongst European citizens, and room for improvement regarding communication on, and involvement in addressing water quality issues.

1.5 Hypotheses

In this study, we address three topics to assess the water awareness of citizens in 23 countries, predominately located in Europe. Using a survey, we identified how people [1] assess their own water use, and [2] perceive local water quality and its major stressors. Additionally, [3] we tested whether the motivation for environmentally responsible behavior co-aligns with water awareness. We hypothesized that:

- Participants who enjoyed a higher education are more water aware and thus assess their direct and indirect water use correctly, and identify more threats to water quality.

- Younger participants are more water aware.
- Participants working in the sciences are more water aware.
- Women are more water aware than men.
- Rurally located participants are more water aware than participants living in urban areas.
- Participants who are prone to flooding will assess more water quality threats participants who experience more drought (based upon country of residence).
- Participants who view water as an important factor for life itself, will be more water aware than people who view water to be a resource for humanity.
- Participants who view water with a more holistic view will be more willing to actively participate in improving their local water quality.

1. Materials and Methods

In order to assess water awareness among European citizens, a 40-question survey was distributed among water managers in different European regions and different stakeholder groups with a vested interest in water, such as diving associations and fisherman. These contacts further distributed the survey within their network using social media. In this questionnaire, three themes were addressed, [1] awareness of personal water usage, [2] the perception of water quality issues, and [3] the willingness to engage in environmentally responsible behavior. Both quantitative (multi-answer, multiple-choice questions, single answer, multiple-choice questions and ranking scale questions) and qualitative (open questions and comment boxes at multiple choice and ranking scale questions) questions were included (Supplement 1).

2.1 Recruitment and survey design

The survey was set up on SurveyMonkey (2015) and distributed via targeted contact persons to be able to get a general view of water perception among ‘water interested’ Europeans. The survey was distributed in professional and personal networks of the authors which included aquatic scientists (Global Lake Observatory Network (GLEON) and Networking Lake Observatories in Europe (NETLAKE) COST Action 1201), water managers from different levels of the government and stakeholder groups (citizen groups, angler associations, diving associations such as Project Baseline). From there on, the survey was distributed further throughout the network by the participants themselves, i.e. through snowball sampling (Goodman 1961). Through the use of social networks (LinkedIn, Facebook, Twitter) and virtual snowball convenience sampling we aimed to maximize the number of participants in this survey (Lake *et al.* 2018; Noga and Wolbring 2013; Mirzaei *et al.* 2019; Valerio *et al.* 2016). No inclusion or exclusion criteria were used to include as many people from as many different backgrounds as possible. Media attention was drawn to the survey by means of a press release. The survey was open to the public from 22 September 2015 until 1 March 2016. Questions were made available in English, Dutch and Italian, as well as versions specifically tailored for children (6 - 18 years old) and adults (>18 years old). We adhered to the Netherlands Code of Conduct for Academic Practice in which “Every academic practitioner demonstrates respect for the people… involved in scientific research. Research on human subjects is exclusively permitted if the persons concerned have freely given informed consent, the risks are minimal and their privacy is sufficiently safeguarded.” (Principle 1.2) (VSNU 2004). The introduction section of the survey included the following statement “The information you supply will be anonymous and you will not be identified in any report or article that is published as a result of this questionnaire”; Appendix 1). All survey versions retained the same questions in the same order. After closing the survey, quality of the data was assured by removing surveys without demographic information, or with demographic information but no other questions answered. We used no other inclusion or exclusion criteria. Dutch and Italian survey answers were translated to English by native speakers and combined in one database for further analysis, resulting in a database of 498 completed questionnaires. For each question, non-responders for that specific question were removed to create a new data file with which further analysis of that question was carried out.

Participants were grouped according to education, occupation, gender, age, country of residence, rural or urban located. Five age classes (<18, 19-30, 31-45, 46-55 and >56) ensured a sufficient number of participants per class for further analysis. For group size per survey question we refer to the supplement 2. Additionally, we grouped people according to their answer to the question “Can you describe what water means to you”. The answers to this open-ended question could be allocated to 4 different categories: [1] the “Water is Life“

group, where participants saw water as more than a human resource (i.e. "Essential to life", "important for nature"); [2] the "Water as a Resource" group (i.e. "Drinking", "washing"), [3] answers that entailed both "Life and Resource" (i.e. "Drinking and for nature") and [4] a group in which the distinction could not be made (i.e. "Water is water") (Figure 1). Three independent researchers allocated the answers to these 4 categories individually after which the average allocation was calculated and applied to form the definitive groups. If the answer was allocated to three different categories by the three researchers, the answer was allocated to group 4 (no distinction possible).

2.2 Data analysis

The semi-structured questionnaire consisted of quantitative (single answer, multiple choice questions, multi-answer, multiple choice questions and ranking scale questions), and qualitative (open questions and comment boxes at multiple choice and ranking scale questions) questions (Appendix 1). Different types of questions required specific statistical approaches as outlined in Table 1. Differences in gender, age, education, occupation, country, rural or urban, and "Water as Life" or "Water as a Resource" were tested by Pearson's Chi^2 test for count data (Pearson 1900) (*R* package 'stats'). To prevent inaccurate inference in the Chi^2 groups with counts smaller than 5 (Agresti 2007; McHugh 2013), these groups were combined with the adjacent group up to the point that >80% of groups had counts >5, and none had 0. To exemplify, few participants ($n < 5$) from the "Water is Life" or "Water is a Resource" group choose the 250 liter option in estimating their daily direct water use and thus these respondents were added to the 200 liter group to form the >200 liter option for further analysis. If more than two groups were present, i.e. age groups, education level and countries, a Fisher post hoc test was performed to compare all subgroups pairwise (Fisher 1935) (*R* Package 'fifer'). In these post- hoc tests, p-values were corrected using the False Discovery

Rate (FDR) correction method to correct for multiple comparisons (Benjamini and Hochberg 1995).

The multi-answer, multiple choice questions were analyzed in three ways. Firstly, by counting the number of ticked answers for each group and testing whether differences could be found using Pearson's Chi^2 test for comparing groups; e.g. do men identify more threats to water quality than women? A Fisher Chi^2 post hoc test with FDR correction was performed in case of multiple groups such as age classes (Pearson 1900; Fisher 1935; Benjamini and Hochberg 1995). Secondly, a 'Species Scatter plot'(CANOCO v5) was made to detect whether some indicated threats were more 'related' to each other, i.e. would be chosen together more often than others. The distance between the symbols approximates the dissimilarity of distribution of relative abundance of those threats across the samples as measured by their chi-square distance (Terbraak 1986; Braak and Šmilauer 2012). Thirdly, to get more insight in the relative importance of each factor (i.e. education level, occupation, gender, age, rural or urban located, country of residence and overall attitude ('Water is Life'/ 'Water as a resource')), we also carried out a Principal coordinates analysis (PCoA) including all factors in one model to analyze the number of threats indicated by the participants (Question 30). Relevant factors (groups) were identified using a permutation test for the Redundancy Analysis under reduced model, on the PCoA results, in which terms were added sequentially (ANOVA, 9999 permutations).

Questions where participants were asked to rank statements were transformed by dividing rank number by the sum of the ranks. Generalized linear models (GLM) were used to detect differences in group choice in determining the importance of a specific water quality threat (McCullagh and Nelder 1989). The GLM was performed on these proportional response variables using the binomial (link = logit) family, and included tests for overdispersion

(Crawley 2007). A constrained ordination technique was used to detect whether variations in ranking could be explained by the grouping, specifically a Canonical Correspondence Analysis (CCA) using CANOCO v5 (Terbraak 1986; Braak and Šmilauer 2012).

All analyses, except for CCA, were performed in *R* using functions of basic *R*, the Fifer package and the Vegan package (Fife 2014; R Core Team 2015; Oksanen 2017). All tests were performed against a 5% significance value.

3. Results

3.1 Demographics

A total of 603 people participated in the survey, 498 participants completed the survey to such an extent that statistical analysis was possible. No other inclusion or exclusion criteria were used. Of these 498 people, 229 identified as female and 265 as male, 4 people declined to answer. The age of participants ranged from 6 to > 65, with most participants in the 19-45 yr. group (n = 281, Figure 2A). Eighty-five percent of the participants indicated an education level of 'higher education beyond secondary school', 51% of all participants attended University. Additionally, 142 people (29%) identified themselves as working in a scientific environment, and 356 people (71%) working in a different field (Figure 2B). The survey respondents came from 23 countries, 302 people considered themselves to live in an urban and 194 in a rural environment (Figure 3). Further analysis towards country differences focuses on the top four represented countries in this survey, i.e. Spain (n = 29), Ireland (n = 29), Italy (n = 67) and the Netherlands (n = 302). Relatively more scientists were present among survey participants from Spain (38%), Ireland (41%) and the Netherlands (25%) compared to Italy (18%).

The participants used lakes in different ways for recreation, i.e. swimming (29%), aesthetic enjoyment (26%), hiking (15 %), boating (11%), scuba diving (9%) and fishing (5%) or in other ways (i.e. bird watching) (2%). Two percent of the participants did not use lakes for any form of recreation. The number of times the participants visited a lake or reservoir in the past year ranged from daily (5%) to never (7%). Most participants visited a lake at least once a month (28%), once or twice a year (25%), once or twice a week (19%) or every 2-3 months (17%). Perception of whether good environmental conditions existed for the lake that participants visited most often was answered “Yes” by 55%, ”No” by 20% and “I don’t know” by 26 %.

3.2 Water use

In this study, 80% of the participants underestimated their daily direct water use compared to the European average of 150 liters per day (European Environmental Agency 2014) (Question 24, Figure 4A). The level of education of the participants significantly influenced their daily direct water use estimate ($\chi^2 = 22.0$, $p = 0.019$). Participants with a secondary education indicated a lower direct water use than participants with a higher education other than university ($p = 0.009$) or university alumni ($p = 0.003$) (Figure 5A), while scientists estimated a higher direct water use than non-scientists ($\chi^2 = 11.3$, $p = 0.023$). Differences in daily water use assessment were also found among the four most represented countries in this study, i.e. the Netherlands, Italy, Spain and Ireland, ($\chi^2 = 22.7$, $p = 0.007$); of all pair-wise comparisons only the Dutch participants estimated a significantly higher direct water use than Italians (Chi^2 post hoc test, $p = 0.001$). The “Water is a Resource” group estimated a higher direct water use (in liters per day) than the “Water is Life” ($\chi^2 = 10.8$, $p = 0.013$). Gender, age, or residing in a rural/urban residence did not influence estimates about daily direct water use (Supplement 2).

Daily indirect water use (water used for the production of food, clothes, etc.) was underestimated by 86% of the participants when compared to the European average of 3400 liters per day (European Environmental Agency 2014) (Question 25, Figure 4B). The educational background of the participants played a significant role in influencing indirect water use ($\chi^2 = 32.2$ $p < 0.001$). Participants with an education up to secondary school estimated a lower indirect water use compared to participants with an education beyond secondary school. However, no significant differences were found when we zoomed in to education levels within the group of participants with an education up to or beyond secondary school (Figure 5B). Similar to direct water use, scientists estimated a higher indirect water use compared to non-scientists ($\chi^2 = 15.9$, $p = 0.003$). Participants from the Netherlands, Italy, Spain and Ireland estimated their indirect water use differently ($\chi^2 = 47.3$, $p < 0.001$). Specifically, the Irish ($p = 0.005$) and Dutch ($p < 0.001$) participants estimated a higher indirect water use than Italian participants, but still underestimated their use compared to the European average of 3400 liters per day (European Environmental Agency 2014). The other pair-wise comparisons did not indicate significant differences among countries. Gender ($\chi^2 = 5.9$, $p = 0.204$), urban versus rural residence ($\chi^2 = 5.7$, $p = 0.226$) and age ($\chi^2 = 14.0$, $p = 0.301$) had no influence on the estimation of indirect water use. When participants were grouped according to their perceptions of water ("Water is Life" versus "Water is a Resource"), groups did not influence their indirect water estimates ($\chi^2 = 3.0$, $p = 0.569$).

Additionally, we asked participants to compare their personal water use to the European average (Question 26). Forty-two percent (42%) of the participants estimated their water use to be below the European average of 150 liters, 47% estimated their water use to be comparable to the European average whereas 5% estimated an above average personal water use. Scientists versus non-scientists ($\chi^2 = 0.4$, $p = 0.820$), "Water is Life" versus "Water is a

Resource” (χ^2 = 5.0, p = 0.084) or area of residence (urban or rural, χ^2 =2.9, p = 0.24) did not influence estimated water use average, while education was marginally non-significant (χ^2 = 12.6, p = 0.051). Age groups differed in their opinion when comparing their water use to the European average (χ^2 = 17.3, p = 0.027). As post-hoc tests revealed, children (<18) choose “average” or “above average” more than adults (Chi^2 post hoc test p = 0.044). Additionally, more men than women thought their water use was below the European average (χ^2 = 6.2, p = 0.044). Participants from Italy, Spain, the Netherlands and Ireland also differed in assessing their water use compared to the European average (χ^2 = 14.1, p = 0.029). Pair-wise comparison indicated significant differences only between participants from the Netherlands and Spain (Chi^2 post hoc, p = 0.017). To test whether different attitudes towards water were related to willingness to save water, we asked participants which of the following actions they took in order to preserve water; “limit shower time”, “no car washing”, “limited watering of the garden”, “not letting the tap run”, “collect rain water” or “other” (Question 28, supplement 2). Participants from the “Water is Life” group indicated on average 3.0 water saving actions, which differed significantly with participants from the “Water is a Resource” group who indicated, on average, 2.6 water saving actions (χ^2 = 12.3, p = 0.016).

3.3 Perception of water quality

Many products or actions can threaten water quality (Vorosmarty et al. 2000). On average, every participant identified 6 out of 9 threats to water quality (66 %). The <30 and 31-45 age groups indicated more threats to water quality compared to >56 groups (χ^2 = 54.8, p < 0.001) as did participants with higher education (χ^2 = 41.8, p < 0.001) (Figure 6). Additionally, scientists identified more threats compared to non-scientists (χ^2 = 43.0, p < 0.001, Figure 7). Participants from the Netherlands and Ireland indicated more threats compared to participants living in Spain or Italy (χ^2 = 29.2, p = 0.004). Gender (χ^2 = 11.1, p = 0.192), area of residence (rural or urban $\chi^2 = 6.5$, $p = 0.586$) or “Water is Life” versus “Water is a Resource” ($\chi^2 = 3.4$, $p = 0.910$) did not influence the number of threats identified (Question 30, supplement 2). In general, pesticides and herbicides, fertilizers, sewage, industry, pharmaceuticals, personal care products and plastics were chosen as threats almost twice as much as climate change, water abstraction and feeding ducks. Explanatory factors (group allocation e.g. education level and gender) accounted for 13% of total variation (Supplement 3).

Additionally, we incorporated all explanatory variables in one RDA model for this question using all participants to estimate the relative importance of the individual explanatories. This resulted in the following order of relative explanatory power of the groups; country of residence, age, education level, gender, science or non-science occupation, rural of urban area and lastly overall attitude “Water is Life” or “Water as a Recourse” (Supplement 4).

When asked to rank threats to water quality (Question 29) dumping garbage was indicated as most threatening action, closely followed by dumping the contents of one’s aquarium, cleaning one’s boat, feeding fish and not cleaning up dog waste. Feeding ducks was seen as the least important action threatening water quality (Figure 8). No differences were found for education level, scientists vs non-scientists, gender, age, urban vs rural residence or “Water is Life” vs “Water is a Resource” when ranking water quality threats (GLM $p > 0.05$).

3.4 Motivation for environmentally responsible behavior

Interestingly, more than half of the participants (58%) were not familiar with the term ‘citizen science’ before the questionnaire, but saw its potential in raising environmental awareness, helping science and addressing scientific literacy. Only a small number of the participants thought citizen science’s only goal is to engage with nature (9%). Most participants (85%) saw a role for citizen science in monitoring and preserving water quality. Reasons for doing so included good citizenship (38%), taking care of the environment (29%) and helping scientists (20%). Making friends was predominately chosen among the <18 age category. Overall 8% of the participants indicated that being part of a community was the reason to become involved. Almost half of the participants (45%) saw themselves potentially playing a role in collecting data and raising environmental awareness. Most participants would invest time once a month (36%) or once a year (28%) to work towards better water quality. Education level, scientists vs non-scientists, gender, age, urban vs rural residence or "Water is Life" vs "Water is a Resource" did not influence participants' ideas about the role citizens can play in monitoring and preserving water quality (Supplement 2). Importantly, the "Water is Life" group is more willing to invest both time and money towards better water quality compared to only a time investment from the "Water is a Resource" group (Question 31, $\chi^2 = 8.8$, $p = 0.037$).

4. Discussion

Large scale changes linked to anthropogenic factors, for example nutrient enrichment and directional climate change (Jennings et al. 2009; Flaim et al. 2016; De Senerpont Domis et al. 2013) are negatively influencing freshwater supply and demand for both humans and ecosystems. These effects will likely continue and worsen in the coming decades (Randers 2012). Although several important actions such as the WFD (European Commission 2016) have been initiated to improve the quality of water resources, public participation in protecting and preserving our fresh waters is still low in Europe (Rolston et al. 2017; TNS Political and Social 2012). This despite the fact that Article 14.1 of the WFD specifically requires that Member States encourage the active involvement of all interested parties in the implementation of the Directive, and that the EU has published guidance on increasing public participation (European Commission 2003). Our study identified what 'water interested'

Europeans perceived their personal water use to be, what they perceived as threats to water quality and whether there was a willingness to address water quality issues. Provision of semi-quantitative data can help inform implementation of the WFD and similar water protection initiatives. Additionally, our study underlines the notion that addressing environmental and scientific literacy are important pillars to increase water awareness.

4.1 Water awareness, water use and threats to water quality

Our study clearly indicated that Europeans, who are actively engaged in water via work or personal interest, notably underestimated their direct water use. According to the European Environment Agency, 130-150 liters of drinking water is used by an average European citizen per day (European Environmental Agency 2014). Clearly, gaining insight into one's own direct water use through drinking, cooking and washing remains a difficult concept although it has been the focal point of many water saving advertisements and campaigns (United Nations 2015). Indirect water use is the water used for producing agricultural and industrial goods such as fruit, meat and clothing (Vanham and Bidoglio 2013). In Europe, average indirect water usage is approximately 3400-4200 L/person/day (Vanham and Bidoglio 2013) and is underestimated by most of the participants of our survey. We saw a clear difference among education level in water awareness, because direct and indirect water use, as well as threats to water quality, were estimated to be higher among more educated participants. Previous studies are in support of this relationship (Dolnicar and Hurlimann 2010; Willis et al. 2011; Hoy and Stelli 2016). Gregory and Di Leo (2003) found that Australians who received a higher education used more water per person because they could afford a more luxurious lifestyle, for example swimming pools and automated sprinkler installations. Although higher-educated Australians were more willing to buy water saving technologies and had greater intentions of saving water, less educated Australians were more prone to engage in behavioral changes and actually use less water (Gregory and Di Leo 2003).

Scientists in our study showed a higher water awareness compared to non-scientists, but still underestimated direct and indirect water use. Scientific literacy also promotes critical thinking and could lead to a more accurate assessment of the impact of one's personal habits on the environment (Dyck 2013; Forawi 2016). Addressing scientific literacy alongside with environmental literacy could thus add to increasing water awareness for the general population (Arslan 2012).

Gender is explicitly considered in the United Nations Water and Gender Equality statements (United Nations 2016a) because women usually take on more house work. Consequently, women are more closely involved in day to day decisions about water, especially in developing countries where women and children are the main water collectors (United Nations 2016a). Interestingly, we did not see a gender effect in water awareness, as direct and indirect water use and threats to water quality, were comparably assessed by both sexes (Supplement 2). Our participants were predominantly European, where household duties might be more equally distributed and living standards are higher with readily available tap water (European Environmental Agency 2014). In our study, age did not influence personal water use but did influence opinions regarding threats to water quality. Age groups 19-30 and 31-45 indicated more threats to water quality then the <18 and >56 groups. This is not in line with previous research in which older participants were more aware of water quality problems (TNS Political and Social 2012; Gregory and Di Leo 2003).

We expected a difference in water awareness between urban and rural residents as we hypothesized that the latter group might be more informed on the origin of their water, for instance because they have a private well. Several studies in Africa and China indicate that rural and urban water quantity and quality problems are different in origin: farmers in rural areas might struggle with irrigation issues, while urban water problems may constitute recreation restrictions (Anderson et al. 2007; Wang et al. 2008). However, we did not see differences between urban and rural participants, and we attribute this homogeneity to the fact that most participants are from Europe. Even most rural Europeans are connected to a regional water supply or if connected to a well, this well is generally checked and maintained regularly (WHO 2010). However, other research on the European population indicated a more informed rural population compared to urban residents regarding water quality issues (TNS Political and Social 2012).

The majority of the survey participants lived in northwestern European countries, i.e. The Netherlands and Ireland, and southern European countries, i.e. Spain and Italy. Personal experiences, local values and climate could contribute to the different attitudes towards water and its problems. Droughts and floods can affect people's lifestyle to such a degree that they can result in behavioral changes, including reducing water use or becoming more water aware. Overall, Dutch and Irish participants seemed to be more water aware compared to Spanish and Italian participants, although the unbalanced group size among countries makes this distinction tentative. The observed difference could be due to the higher lake surface area to land surface area ratio present in the Netherlands (7%) and Ireland (4%) compared to Spain (1%) and Italy (1%) (European Environmental Agency 2012). Presumably, a higher lake to land surface ratio indicates a higher chance of encountering water-related problems ("Seeing is believing"). In fact, Dutch and Irish participants visited their lakes more often (data not shown). Additionally, Dutch water quality is among the worst surface water quality of Europe, resulting in more news items concerning water quality problems throughout the year (EEA 2018). This could also lead to a higher water awareness among its inhabitants.

These differences among participants from Ireland, the Netherlands, Spain and Italy do not, however, coincide with the results from a large scale European survey (TNS Political and Social 2012). There, more Italian (91%) and Spanish (72%) participants indicated water quality problems to be a serious problem in their country compared to Irish (67%) and Dutch (45%) participants. Additionally, more participants from Italy and Spain indicated drought and floods as a serious problem, compared to participants from Ireland and the Netherlands (TNS Political and Social 2012). Of course, our survey included more parameters about water awareness (water use estimates combined with identifying water quality threats) compared to the TNS Political and Social survey (2012) which asked if certain threats are a serious problem in your country, underlining the different conclusions drawn. Lastly, relatively more of our Spanish (38%), Dutch (25%) and Irish (41%) participants worked in the scientific field compared to Italian participants, of whom worked more in other fields (82%). As our results show, a higher education combined with a scientific background could potentially be associated with a higher water awareness, which could influence our results regarding country- based differences in water awareness.

People who identified “Water as a Resource” versus the broader “Water is Life” option indicated different personal water use estimates, water quality issues and willingness to resolve water quality issues. Although the “Water as a Resource” group estimated a more realistic direct water use, “Water is Life” participants applied more water saving actions in day to day life. Saving water, being water aware and a willingness to address water issues constitutes a behavioral change (Gregory and diLeo 2003).

Our survey evidenced a distinct division between the perception of direct visible threats and indirect threats. The later would comprise climate change, feeding ducks and water abstraction, which were perceived as smaller problems with respect to the impact of direct visible threats agriculture, industry, personal care products and plastics. It is encouraging that people identify personal care products and plastic as threats, as research towards the effects of these anthropogenic products on the environment is relatively new (Eerkes-Medrano et al. 2015). Despite this, both threats have been widely taken up by media and (citizen) environmental groups as a serious issue threatening ecosystems, which might explain its placement in the major threats group (e.g. “Beat the Microbead”). Threats to freshwater systems that are harder to visualize or not immediately obvious, such as the effects of climate change, feeding ducks and water abstraction. These were perceived to be less threatening to water quality among participants. Scaling threats from most important to least important is, of course very difficult, and will change from system to system (Brown and Froemke 2012). But overall climate change is regarded as one of the most influential factors affecting fresh water quality and quantity now and in the future (Michalak 2016, Woodward et al. 2010, Jennings et al. 2009, Flaim et al. 2016, De Senerpont Domis 2013). The gap between scientists and citizens in assessing the relative importance of climate change on water quality has to be addressed in future research and legislation.

4.2 Citizen Science

Citizen science projects can be an excellent tool for citizens to learn about and/or even monitor lake water quality (Bonney et al. 2009, Seelen et al. 2019). Our study identified a great willingness to engage in citizen science activities among Europeans. In addition, our results show that by emphasizing the critical role water plays in sustaining life on earth (“Water is life”), citizen science programs could potentially reach a larger audience. Improving and deepening citizens’ understanding of water quality issues might lead to more environmental responsible behavior and thus a higher motivation to preserve and improve water quality (Jollymore et al. 2017, Rudd 2015). As stated by Storey et al. (2016), participation in water quality monitoring also leads to increased scientific literacy, as well as increased awareness of the local environment and broader environmental issues (Kin et al. 2016). Additionally, citizen science (groups) can built stronger relationships between citizens and local government that might lead to a more effective community engagement with local, regional and national government in freshwater decision making (Storey et al. 2016, Sinner et al. 2016, Kin et al. 2016). Article 14.1 of the WFD encourages “active involvement” in the implementation of the directive which includes access to background information and the collecting and processing of the public’s input. Together with three rounds of written consultation in the planning process, public participation is solidly cemented in the WFD (Mosterd et al. 2003). According to our results this transparency will be embraced by EU citizens who are happy to provide input, expertise, time and even money to help protect our fresh waters. This willingness to public participation as revealed by our study provides a great opportunity to enhance environmental and scientific literacy among these volunteers.

4.3 Other European surveys

In the large scale European survey (TNS Political and Social 2012), 25,425 Europeans of age 15 years old and older were asked to state their opinion about fresh water and coastal issues. The major water quality threats identified in the TNS survey coincide with the results from the current survey as agriculture, was indicated to be the biggest threat to water quality. Climate change was identified as a threat to water quality by 55% of the participants in the TNS survey; in our survey climate change placed 7th among threats to water quality.

The EU survey participants indicated that providing more information on the environmental consequences of water use is the most effective way to tackle water problems. Providing this information can be most effectively achieved by active participatory learning, i.e. citizen science. The scope for doing citizen science was not included in the EU survey, but 51% of their participants stated they would be interested in lending their opinion and insights for the next revision of the River Basin Management Plan. These findings are confirmed by the 498 participants in the current survey, of whom most indicated an interest in actively helping to improve water quality.

Previous surveys have focused their effort towards pinpointing the impact of citizen science engagement on the environmental behavior of the participants (i.e. Bonney et al. 2009, Jones et al 2013, Jollymore et al. 2017). They underlined the importance of community building between academia, the water professional sector and citizens and conclude that especially long-term involvement with citizen science increases environmental awareness (Jones et al. 2013). Even engaged citizens have trouble finding opportunities to be included in water management plans, although such inclusion is also mandatory in the second cycle of WFD plans (Head 2007, Rolston et al. 2017). Bottom up approaches towards water management should therefore be encouraged even if WFD legislation is still controlled top-down by the EU (Rolston et al. 2017). We suggest that this will to be one of the greatest challenges in the coming years among scientists, water managers, citizens and policy makers.

4.4 Opportunities, limitations and recommendations

The internet provides researchers with an almost unlimited platform to sample opinions and is used widely to gather various types of information without time-consuming personal meetings (Karpf 2012). However, this on-line platform could potentially lead to an age or education skewed response because of the necessary computer skills needed, but these skills are increasingly being encouraged and taught throughout the age classes (European Commission 2014). Although, the majority of participants completed the survey online (n = 406), we provided paper versions of the questionnaire on events like the Dutch Ecology Days (NERN 2016 Lunteren, the Netherlands) and at the World Water Day organized by Aquatic Knowledge Center Wageningen (AKWA), NIOO-KNAW, in Breda, the Netherlands, to counter this potential bias. We favored snowball convenience sampling for its simplicity and to obtain the greatest number of participants in a short period of time. This widely applied method allows for understanding key perceptions from a wide variety of participants. We are aware that this methodology is not representative of the entire population, preventing the 1 on 1 extrapolation of the results obtained in this survey to Europeans in general. The first recipients of the survey have had a large impact on the sampling design as they are the first link in distributing the survey further. We therefore distributed the survey starting with as diverse as possible initial informants (Valerio *et al.* 2016) which resulted in reaching not only scientists and water managers but a diverse group of participants, of whom most are actively involved with water, either through personal of professional interests (see paragraph 3.1). Snowball convenience sampling thus results in the exclusion of certain societal groups and over-representation of individuals that already have an interest in water (Noga and Wolbring 2013) as the distribution of the survey was started within our professional and personal circles. Our results indicated both an underestimation of water use as well as the direct effect we humans have on water quality among Europeans who were highly educated, and already interested in water issues.

Further research is needed to pry apart the regional differences emerging from this survey. Are southern Europeans less aware of water quality issues compared to Northwestern Europeans, and does this coincide with previous experiences regarding water quality and quantity issues? For example, Italian participants were predominantly from Alpine regions less subject to droughts and the survey results would not necessarily reflect responses for Italy as a whole. Future research could focus upon a different sampling methodology, such as random sampling, to be able to differentiate between European regions and the effect of climate on the water awareness of Europeans. Additionally, translations of the survey in multiple languages will be needed to achieve this goal. The current study was translated to

Dutch, and Italian (alongside the English version) which might have limited responses from other countries such as Spain. This has contributed to the unbalance between participants based upon country of residence. Lastly, additional research is needed towards what kind of education makes people more water aware. Is addressing environmental literacy, including the effects of climate change, enough to make people more water aware, or should scientific literacy be addressed at the same time for maximal effect?

5. Conclusion

Participants greatly underestimated their personal direct and indirect water use and showed some lack of insight into which factors can threaten water quality. There is much ground to cover in communicating water quality issues to citizens, especially on the effects of climate change, the consequences of duck feeding, and the effects of water abstraction on water quality. On the positive side, people were very willing to help improve their local lake quality i.e. by means of citizen science. This is a positive sign for the next cycle in the implementation of the Water Framework Directive legislation, which requires water managers to include citizens in their monitoring schemes.

Our results underlined the importance of addressing scientific and environmental literacy. Scientists, managers and policy makers should engage more with the public to inform citizens (and themselves), who are the ultimate decision makers in European society, about water quality issues, water saving, and water quality improving actions. Our study provides first guidance on capitalizing on the potential of citizens to engage in water quality issues, by emphasizing the crucial role water plays in sustaining life on earth.

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Figure

Figure 1: Word cloud compiled from answers to Question “Can you describe what water means to you” of the survey. A word cloud giver greater prominence to words that appear more frequently among the answers given by the participants (created through https://wordart.com/)

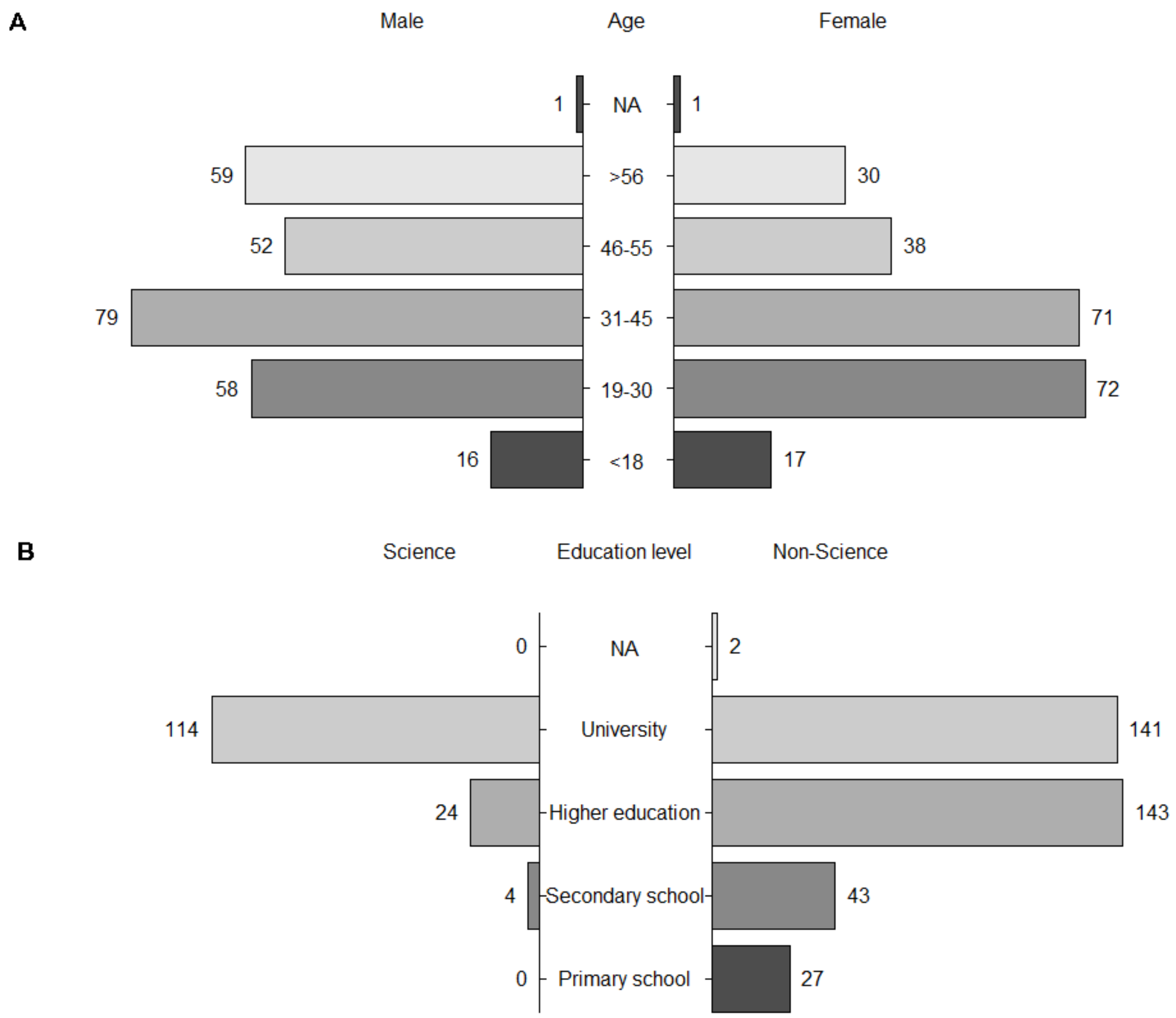


Figure 2: Demographics of survey participants, gender and age distribution (A), and level of education and science of non-science occupation (B).

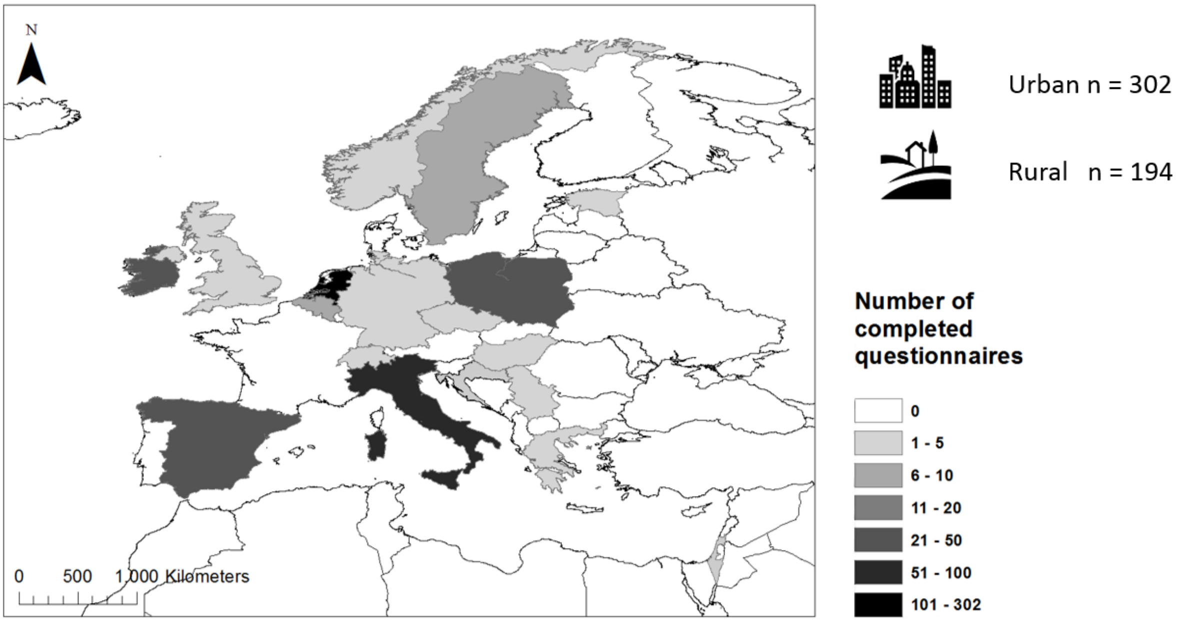


Figure 3: The survey was distributed through snowball sampling via social networks, originating in the Netherlands and Italy. At time of participation, participants lived in Belgium [n = 9], Brazil [2], China [1], Colombia [1], Croatia [2], Czech republic [3], Estonia [2], Germany [5], Greece [1], Hungary [2], Ireland [29], Israel [1], Italy [67], Malaysia [1], Norway [2], Poland [21], Serbia [2], Spain [29], Sweden [7], Switzerland [3], The Netherlands [302], UK [3] and USA [3] residing either in rural of urban areas.

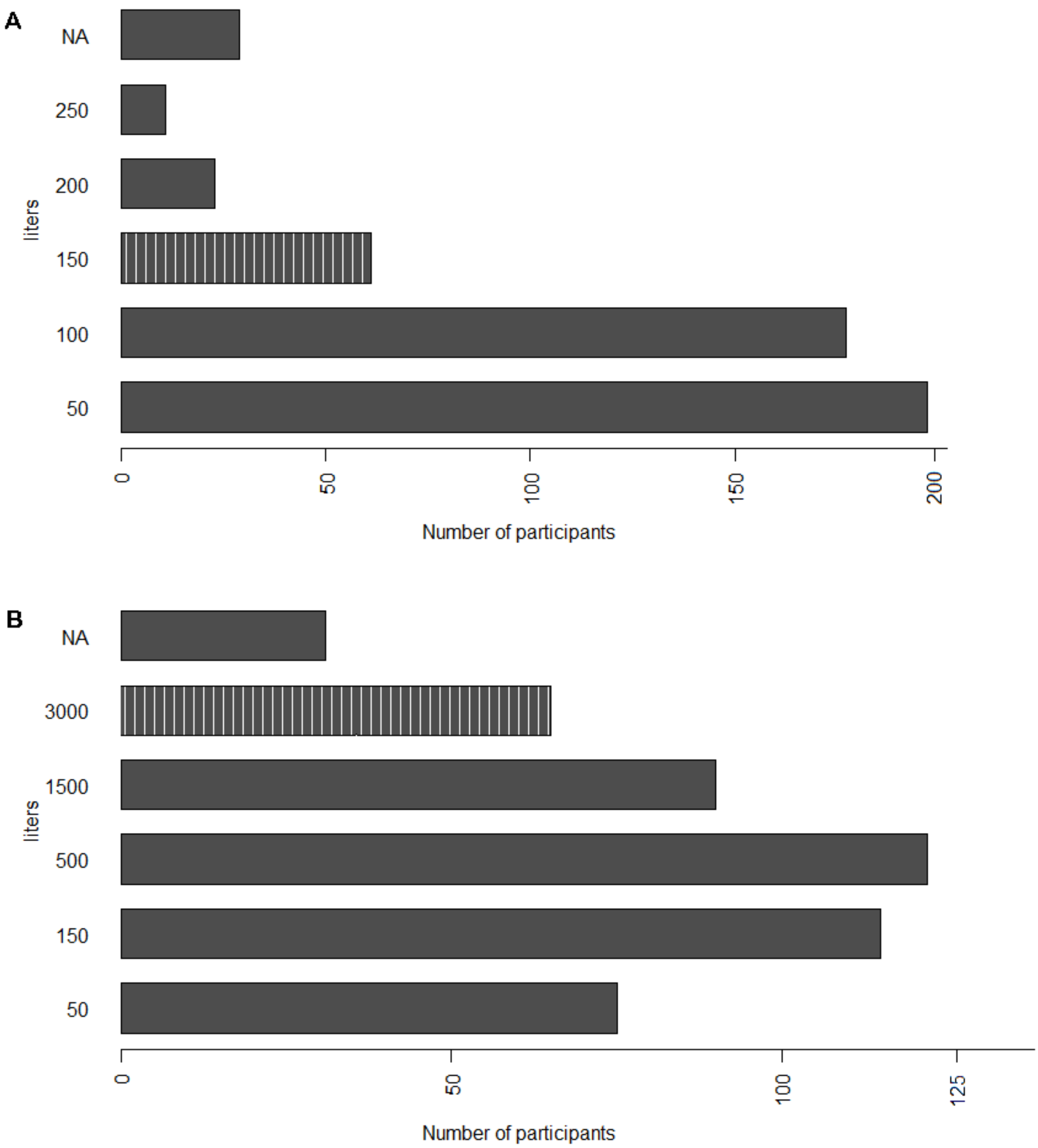


Figure 4: Distribution of answers given by participants to multiple choice question 24: How many liters of water do you think you use directly daily?"(A) and question 25: How much water do you think it takes to produce the goods, food and beverages you use on a daily basis? (B). Hatched bar indicates correct answer (EEA 2014).

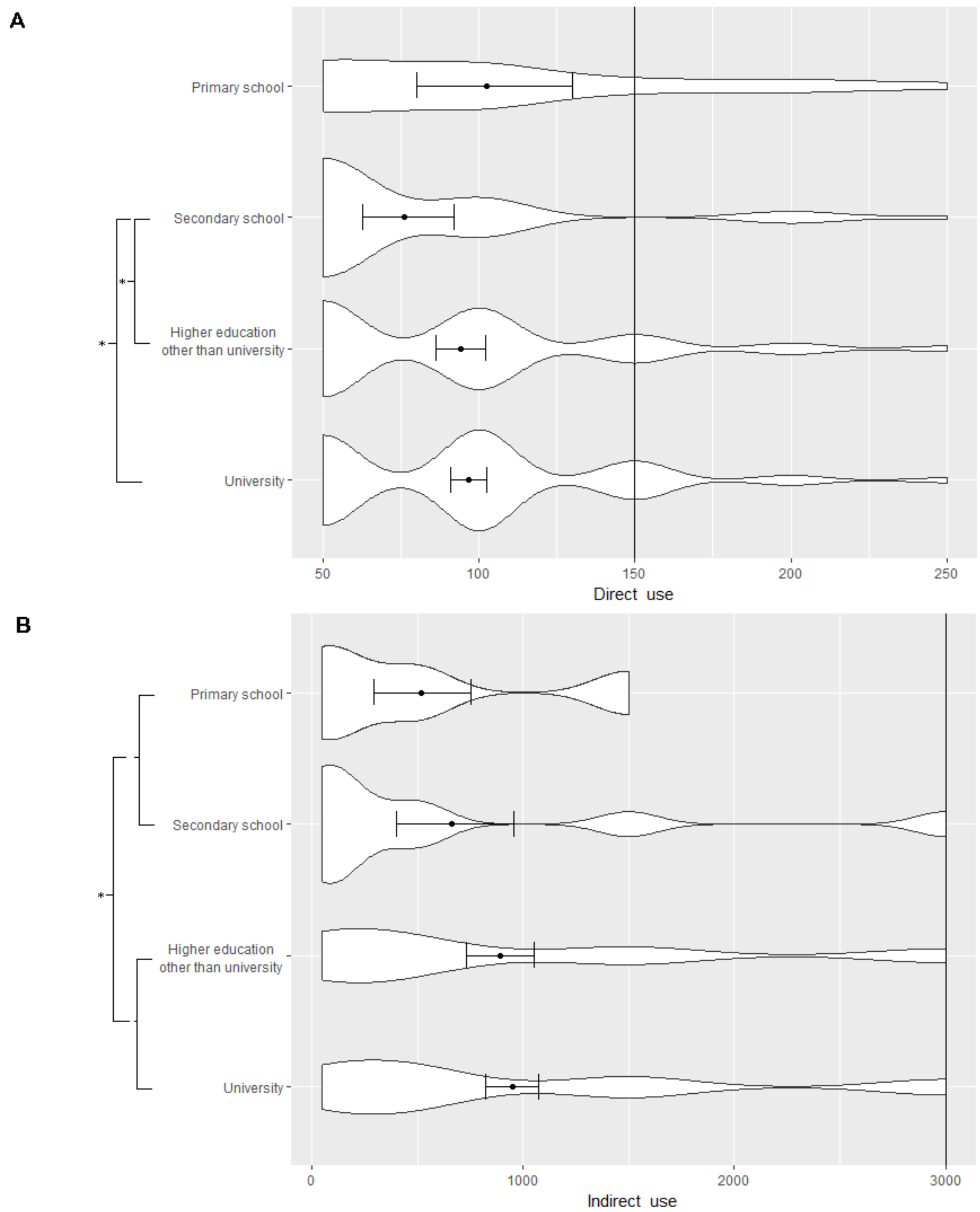


Figure 5: Violin plot indicating distribution of answers by participants to questions "How many liters of water do you think you use directly daily?" (A) and "How much water do you think it takes to produce the goods, food and beverages you use on a daily basis?" (B) according to age classes. Width of the density plot indicates frequency, whiskers 95%

confidence interval and dot median, the vertical line indicates correct answer (EEA 2014), * indicate significant differences between education levels ($p < 0,05$).

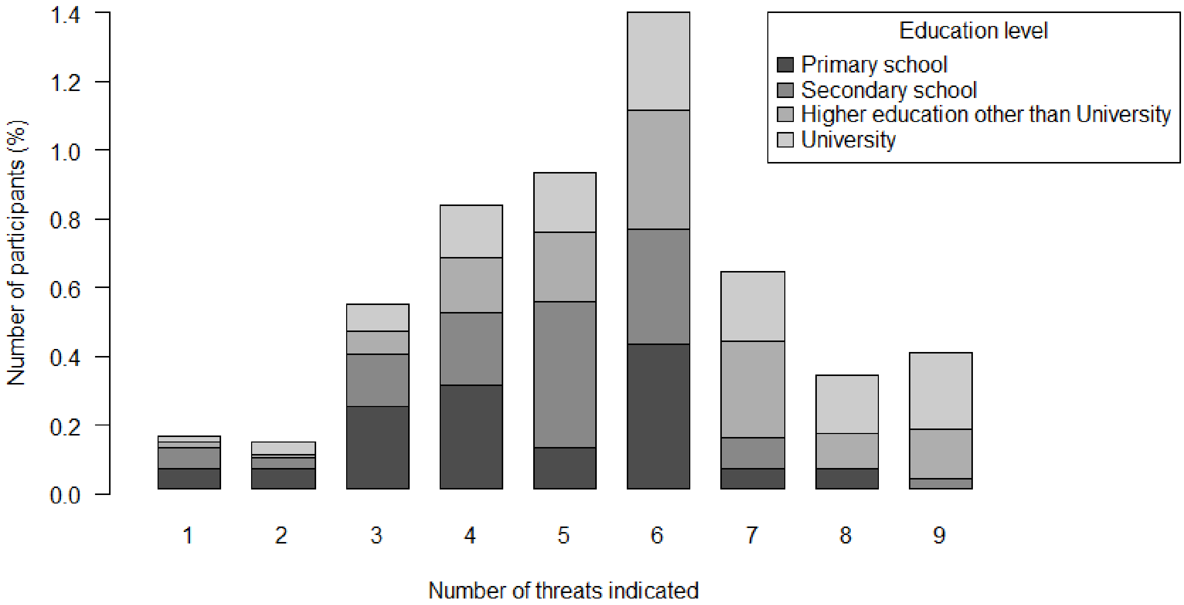


Figure 6: Number of water quality threats indicated by participants with various different educational backgrounds scaled to the number of participants belonging to each educational group (%).

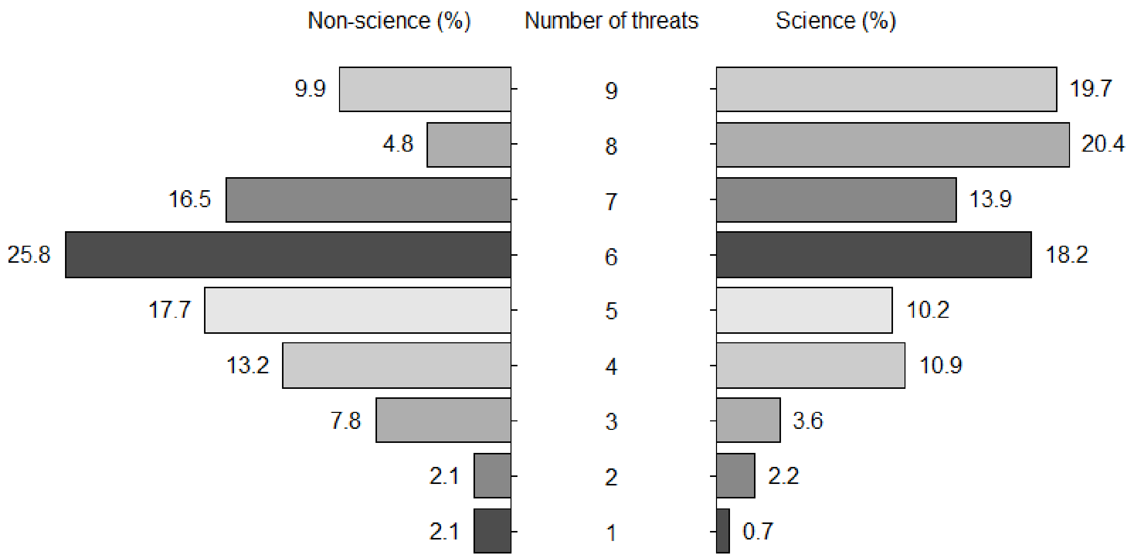


Figure 7: Number of water quality threats indicated by the participants working in science compared to other fields of employment scaled to the number of participants belonging to each group (%).

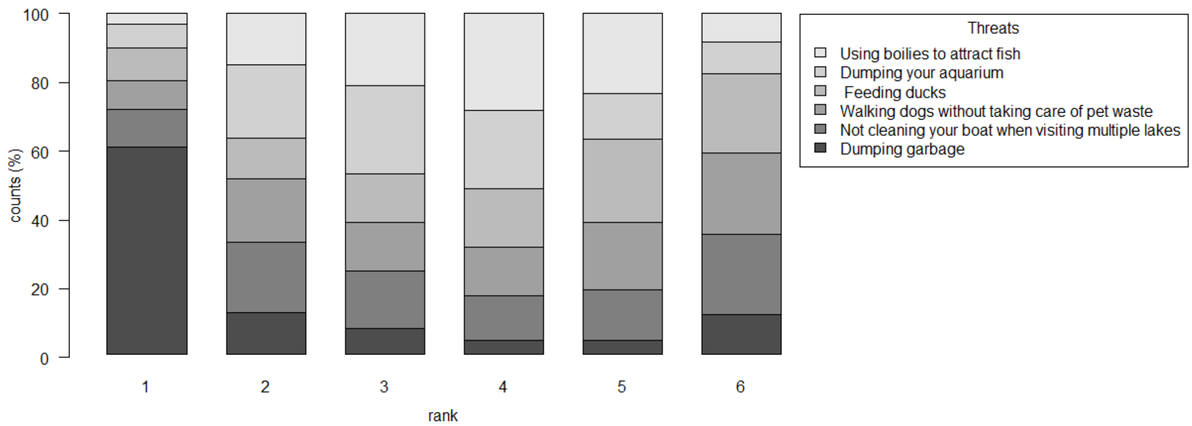


Figure 8: Overall pattern in ranking water quality threats of all participants from 1: most threatening to water quality to 9: least important factor threatening water quality. No differences among groups were found (GLM p > 0.05).

Tables

Table 1: Overview of statistical methods used per question type. “Groups” refer to participants belonging to either gender (2 groups, male or female), age class (multiple groups), residence in rural or urban area (2 groups), education level (multiple groups), science or non-science occupation (2 groups) or “Water is Life” versus “Water is a Resource” group (2 groups).

Table 1

Question type			Analysis	Predictor variable	Response variable	Question in survey
Multiple choice	single answer	Two groups	Pearson’ Chi^2 test for count data	Group member	Counts per choice	24-26, 31, 33
	single answer	Multiple groups (>2)	Pearson’ Chi^2 test for count data + Fisher Chi^2 post hoc test	Group member	Counts per choice	24-26, 33
	multi answer	Two or multiple (>2) groups	Pearson’ Chi^2 test for count data	Group member	Counts per choice	28, 30
	ranking scale		GLM	All groups	Relative ranking	29
	multi answer		CCA (biplot)	All groups	Counts per group	30
	multi answer		PCoA	All groups	Threats indicated per individual	30
Open questions		Two groups		Group member	Counts per choice	12

Supplement 1

NETLAKE Citizen Engagement Water Survey

Thank you for participating in our survey. Your feedback is important.

As part of a project on monitoring water quality by citizens, we are undertaking a questionnaire on water awareness and the role of citizens in monitoring, preserving and improving lake water quality. There are 40 questions, and the survey will take about 15 minutes to complete. Once you have started the questionnaire it needs to be completed.

The information you supply will be anonymous and you will not be identified in any report or article that is published as a result of this survey. Thank you for your time and for helping us towards engaging citizens in monitoring, preserving and improving lake water quality.

More information on this project can be found on https://nioo.knaw.nl/en/world-water-monitoring-challenge

Demographics

Q1: Are you male or female?
Q2: What is your age?
Q3: What country are you from?
Q4: What province do you live in?
Q5: Are you from a rural or urban area?
Q6: What is the highest level of school you have completed or the highest degree you have received?

- primary school
- secondary school
- University
- Higher education other than university

Q7: Which of the following best describes your current field of occupation?

- Agriculture
- Construction
- Education
- Finance and Commerce
- Forestry and Fisheries
- Healthcare
- ICT
- Industry
- Public service
- Pupal
- Science
- Tourism and Hospitality
- Transport
- Student
- Other, please specify….

Q8: How many people currently live in your household?
Q9: Do you have any children aged 0-6 years?

Q10: Do you have any children aged 6-12 years?
Q11: Do you have any children aged 12-18 years?

Knowledge on water and water management

Q12: Can you describe what water means to you?
Q13: What source does your water come from?

- Ground water
- Bottled water
- River water
- Lake or reservoir
- I don’t know

Q14: How do you use water in your day to day life (more than one answer is allowed)?

- Drinking water
- Sanitation
- Irrigation
- Recreation
- Power supply

Q15: For what type of recreation do you use lakes and reservoirs (more than one answer is allowed)?

- Fishing
- Aesthetic enjoyment
- Boating
- Swimming
- Scuba diving
- Hiking
- None
- Other, please specify…

Q16: How close are you to a lake or reservoir?
Q17: In the past year, how often did you visit a lake or reservoir?

- Daily
- Once or twice a week
- At least once a month
- Every 2-3 months
- Once or twice a year
- Never

Q18: Do you think that the lake or reservoir you visit most often is in good environmental condition?

- Yes
- No
- I don’t know

Q19: What would prompt you to visit a lake or reservoir (more than one answer is allowed)?

- Good water quality
- Beautiful landscape
- Weather conditions
- Proximity to home
- Recommendations by other people
- Media attention

Q20: How do you get your information on water issues (more than one answer is allowed)?

- Newspaper
- Social media/internet/email
- Snail mail/local newsletters
- Word of mouth

Q21: Which of the following stops you from using a lake or reservoir for recreational purposes (more than one answer is allowed)?

- Murky water
- Bad odour
- Scums
- Debris
- Dead animals
- Swimming bans
- Fast currents
- Weather conditions
- Steep banks (inaccessible waterfront)

Q22: If you are concerned about water quality how would you rank the following issues (1:most important to 9:least important issue)

1. Murky water
2. Bad odour
3. Debris or waste dumping
4. Dead animals
5. No fish to catch
6. Few plants or animals
7. Industrial pollution
8. Agricultural pollution
9. Waste water pollution

Q23: If you detect an environmental problem in your lake or reservoir who do you contact?

- Environmental agency
- Municipality/local authority
- Drinking water company
- Fishing club
- Police
- Water protection agency

Water awareness

Q24: How many liters of water do you think you use directly daily?

- 50
- 100
- 150
- 200
- >200

Q25: How much water do you think it takes to produce the goods, food and beverages you use on a daily basis?

- 50 liter
- 150 liter
- 500 liter
- 1500 liter
- 3000 liter

Q26: How do you think your daily water usage compare to the national average?

- Below average
- Average
- Above average

Q27: Do you think we have to preserve water?

- Yes
- No
- I don't know

Q28: What action do you take to preserve water (more than one answer is allowed)?

- Limit shower time
- No car washing
- Limited watering of the garden
- Not letting the tap run
- Collect rain water
- Other, please specify….

Q29: How do you rank these actions in threatening water quality? (1:most threatening to 6: least important)

1. Walking dogs without taking care of pet waste
2. Feeding ducks
3. Dumping your aquarium
4. Using boilies to attract fish
5. Dumping garbage
6. Not cleaning your boat when visiting multiple lakes

Q30: What do you think are threats to water quality (more than one answer is allowed)?

- Fertilizers
- Pesticides/herbicides
- Feeding ducks or fish
- Sewage
- Climate change
- Industry
- Water abstraction
- Pharmaceuticals and personal care products
- Plastic
- Other, please specify…

Q31: What are you willing to invest in better water quality?

- Time
- Money
- Time and Money
- Nothing, water is a basic commodity

Q32: How much do you pay for a cubic meter of water?

Citizen engagement

Q33: Do you see a role for citizens in monitoring and preserving water quality?

- Yes
- No
- I don’t know

Q34: What is your reason for becoming engaged in monitoring, preserving and improving lake water quality (more than one answer is allowed)?

- Make friends
- Learn more about science
- Learn more about the environment
- Good citizenship
- Other, please specify…

Q35: What role could you play in monitoring, preserving and improving lake water quality (more than one answer is allowed)?

- Collecting information on water clarity, water colour and other info on water quality
- Raising environmental awareness
- Coordinating activities
- Analyzing data
- Developing tools/equipment
- Other, please specify…

Q36: What time investment would you give towards monitoring, preserving and improving lake water quality?

- Once a week
- Once a month
- Once a year
- One-time only
- Never

Q37: Have you heard of citizen science?

- Yes
- No

Q38: What is the goal of citizen science (more than one answer is allowed)?

- Raising environmental awareness
- Helping scientists
- Raising scientific literacy
- No goal other than loving nature
- Other, please specify…

Q39: Do you have a science partner? If yes, who is it?

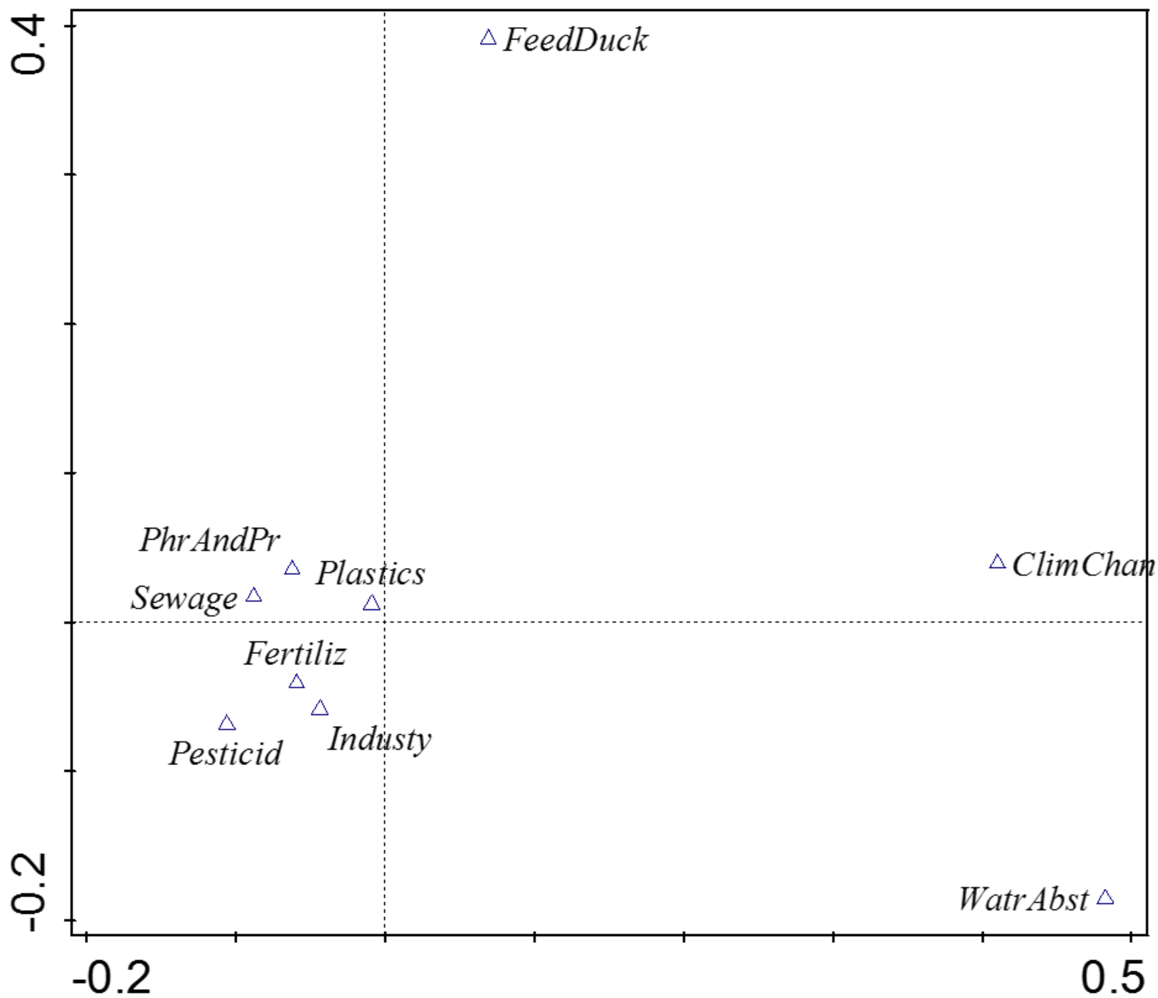
A science partner is your contact point for monitoring of water quality by citizens

Q40: If you have any other comments or suggestions on this questionnaire, please indicate them here:

Supplement 3

“Species scatter plot”

Score scaling is focused on number of indicated ‘possible factors threatening water quality’ by participants to threaten water quality (Question 30). All groups (gender, age, residential area etc.) are included as supplementary variables to explain possible variation. The distance between the symbols approximates the dissimilarity of distribution of relative abundance of those threats across the samples as measured by their chi-square distance. Points in proximity correspond to threats often occurring together.

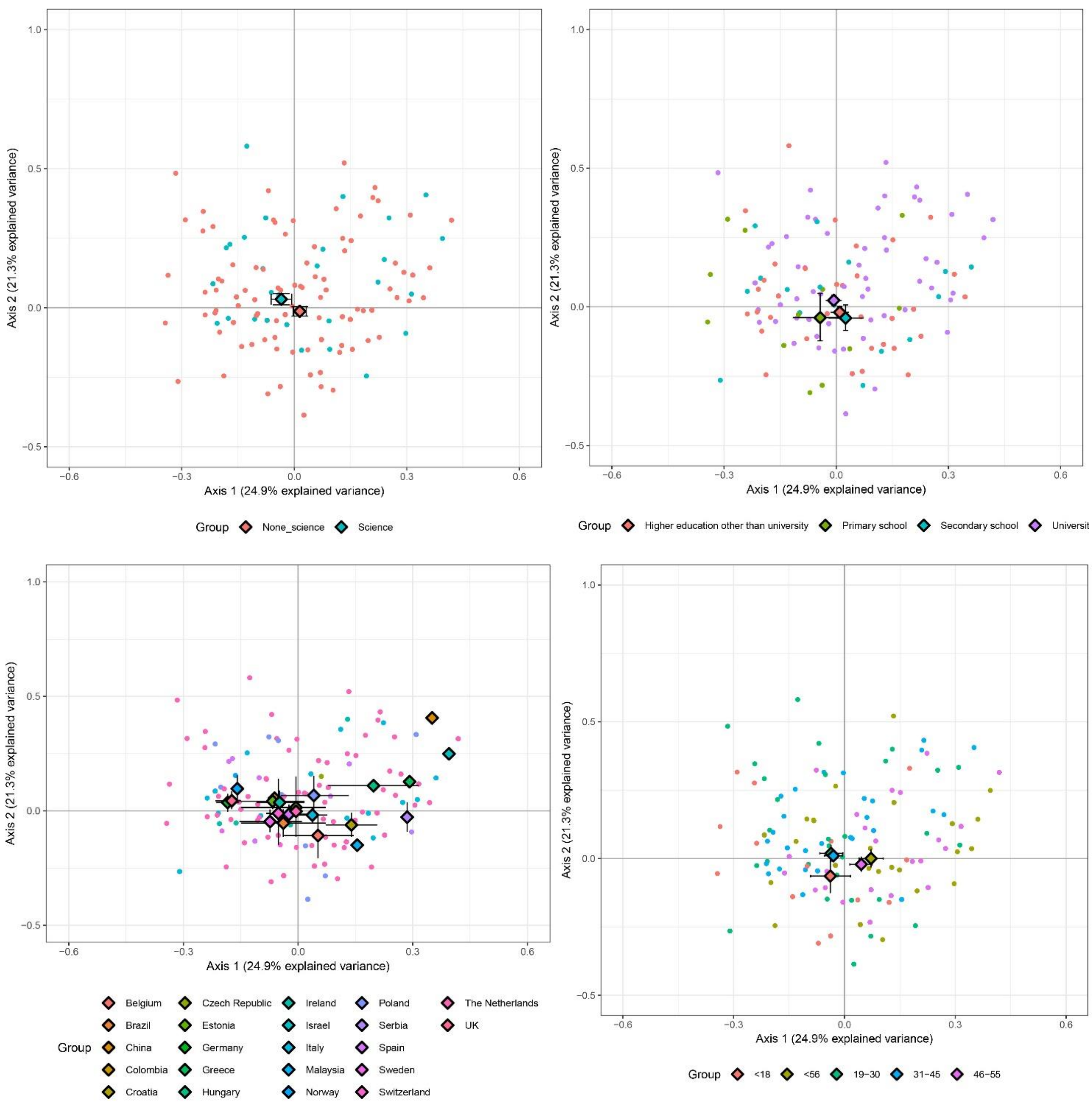


Supplement 4

RDA Question 30

Results permutation test for RDA under reduced model for question 30, terms added sequentially (first to last), with 9999 number of permutations.

Groups	Df	Variance	F	Pr(>F)	
Gender	2	0.00095	1.7503	0.0611	.
Age	4	0.0054	4.9767	0.0001	***
Country of residence	21	0.01084	1.904	0.0001	***
Rural or urban	1	0.00035	1.2712	0.2456	
Education level	3	0.00133	1.6316	0.0283	*
Occupation	1	0.00067	2.4614	0.0113	*
Life/Recourse	1	0.00021	0.7845	0.6217	
Residual	432	0.11711			


Axis 1 (24.9% explained variance)
Axis 2 (21.3% explained variance)
Group None_science Science
Group Higher education other than university Primary school Secondary school Universit
Group Belgium Brazil China Colombia Croatia Czech Republic Estonia Germany Greece Hungary Ireland Israel Italy Malaysia Norway Poland Serbia Spain Sweden Switzerland The Netherlands UK
Group <18 <56 19–30 31–45 46–55