Revealing Salient Aquatic Ecosystem Services Bundles: A Q-Methodology Application in South Africa

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Abstract

Preserving water quality, which has at least four of the ten characteristics of a “wicked problem”, is fundamental for economic development, ecosystems function, and human wellbeing. Consequently, identifying suitable public policies or technological solutions that can maintain or restore affected ecosystems, especially in river catchments, is a huge challenge. Understanding diverse stakeholder perspectives on important water related ecosystem services is critical to improving water governance and quality. This study uses the Q-methodology to identify and analyze perspectives about water-related ecosystem services in the Olifants river catchment, one of the most important and polluted in South Africa, across six diverse stakeholder groups competing for its limited water resources. The Q is a semi-qualitative methodology that can systematically recover detailed views of the subjective perceptions diverse stakeholder groups hold on a given topic. Our results suggest existence of three significant and conflicting perspectives. The “conservationists” privilege regulation and supporting services, the “water users” give highest priority to water for domestic and other private uses, while the “planners” rank mastering the environment for societal benefits highest. Equally importantly, our results also suggest solutions like ecological infrastructure investments, which deliver important services for some stakeholders without compromising the welfare of those who hold neutral perspectives towards them.

1 Introduction

Preserving water quality in river catchments is fundamental for economic development, ecosystems functions, and human wellbeing. In particular, low water quality can negatively impact aquatic ecosystems and biodiversity, and ultimately their ability to provide ecosystem services (Millennium Ecosystem Assessment, 2005), and this contributes to the erosion of resilience and adaptive capacity in the associated social-ecological systems. However, managing environmental resources is complex (Game, et al., 2014). This is because water-related ecosystems, with humans as a component, are inherently complex, and managers are often unable to predict all the consequences of their interventions at different spatial, temporal and administrative scales (DeFries and Nagendra, 2017). This observation probably explains why water quality management remains a major concern in many watersheds around the world (UN-Water, 2016), despite efforts to implement modern water management paradigms including more stringent water laws, Integrated Water Resources Management, and Sustainable Sanitation and Water Management.

Water quality management has at least four of the ten characteristics of a “wicked problem” (Rittel and Webber, 1973, Head and Xiang, 2016). First, changes in water quality could potentially affect everyone in society with different degrees of severity, although individuals have different mitigation options. As a result, such problems involve a large set of stakeholders who have different interests in water-related ecosystems services, who often hold different views about the definition of the problems, and their potential solutions. Second, there exists a wide range of causes and effects of poor water quality, and a multitude of ways in which water-related ecosystem services may be affected. Due to the multiplicity of pollution sources and the long lag times in system responses, it is often difficult, if not impossible, to identify and attribute the causes of pollution to a particular type of stakeholder or activity. Besides, the same amount of pollutants released in different environments may have different final impacts. Third, there is often a separation in space and time between the creation and consequences of pollution. Hence, polluters often do not have to bear the consequences of their own pollution, which reduces the likelihood of self-regulating feedbacks that would force them to change their management practices in the event of negative impacts. Finally, although we can learn how to manage water pollution and its effects on ecosystems by trial and error, the consequences of each trial are not only very large given the number of persons affected, but they are also not immediate. This limits the opportunities to experiment with different governance options.

Given these characteristics, identifying suitable public policies or technological solutions capable of rapidly reducing pollution and restoring affected ecosystems is a huge challenge, although this does not mean that we can do nothing about wicked problems. A number of solutions have been suggested in the literature (Conklin, 2006, DeFries and Nagendra, 2017, Kumlien and Coughlan, 2018, Carter, 2019), and two of these seem particularly relevant to water pollution issues. First, stakeholder involvement is seen as critically important (Camillus, 2008). In particular, a better understanding of the diverse stakeholder perspectives on the problem contributes to reducing the wickedness of ecosystem management (Head, 2008, Rissman and Carpenter, 2015, Head and Xiang, 2016). As noted by Rissman and Carpenter (2015), "*Ecosystem management decisions that may seem to be a simple matter of setting scientific limits on resource use frequently fail because of the political process of decision-making, differing values and norms, and power imbalances*". Camillus (2008) also suggested that "*The aim should be to create a shared understanding of the problem and foster a joint commitment to possible ways of resolving it. Not everyone will agree on what the problem is, but stakeholders should be able to understand one another's positions well enough to discuss different interpretations of the problem and work together to tackle it*". Second, the ecosystem services affected by pollution are often public and nonmarketed goods and changes in them are not factored into individual and governmental decisions. There is thus a need to make progress in the valuation of water-related ecosystem services, and a first step in that direction will be to identify which, among the different services provided by water ecosystems, are perceived as most important (Armatas, et al., 2014, Jensen, 2019).

Stakeholder perceptions about important water related ecosystem services are critical to improving water governance and quality, if they are to generate behavioral changes over the medium term (Game, et al., 2014, Carmenta, et al., 2017). Perceptions, which are composed of personal beliefs, perspectives, and meanings, are viewpoints about a particular topic of interest (Meissner et al., 2018). Yarar and Orth (2018) define perceptions as "lay theories" or the structured beliefs of laypeople to distinguish them from scientific theories, which are factual and based on scientific evidence. Lay theories are subjective, influenced by societal norms and individual experiences, and may even be ambiguous due to their subjective nature. Barry & Proops (1999) and Cross (2005) refer to perceptions as 'worldviews' or 'discourses' or 'attitudes'. They are usually diverse and subjective in nature, since they are based on an individual's personal, social, cultural and economic experiences (Pereira, Fairweather, Woodford, & Nuthall, 2016). From the standpoint of sustainable ecosystems management, points of stakeholder consensus and controversy across such diverse perceptions must be identified in order to help negotiate and address trade-offs among different ecosystem services.

This study investigates the management of water pollution and other water related ecosystem services in the South African section of the Olifants river catchment, one of the most important and most polluted in South Africa, with multiple stakeholders competing for its water resources. Despite South Africa having one of the most progressive legislations formulated to ensure sustainable water use, maintaining water quality in this catchment is proving to be a major policy challenge. Decreasing water quality is negatively impacting its ability to deliver water related ecosystem services. Given the diversity of stakeholders benefiting directly or indirectly from these ecosystem services, water pollution in this catchment has many of the characteristics of a wicked problem. The Government mainly coordinates water quantity and quality issues: national and provincial governments articulate laws and regulations to mitigate water pollution. While some hard data on water flows and water ecosystem services in the catchment exist (Nel and Driver, 2015, Hein, et al., 2020), there is a dearth of information about stakeholder perceptions. In particular, we could find no information about the ecosystem services that stakeholders find most important, their perceptions on the current state and levels of ecosystem services, and their perceptions on how the ecosystem service levels relate to water quality.

Inspired to remedy this gap, we developed an application of the Q methodology (subsequently referred to as Q) to identify and analyze diverse perspectives about water related ecosystem services in the Olifants catchment across six broad stakeholder groups (regulators, water users i.e. farmers and households, water suppliers, water boards, conservationists, and private sector). The Q is a semi-qualitative methodology used to systematically identify a detailed view of the subjective perceptions that a diverse group of people hold on a given topic (Watts and Stenner, 2012). It is a highly useful tool to analyze individually held perspectives within stakeholder groups (e.g., Cuppen, et al., 2010), and it has been used in a range of “wicked problems” applications associated with environmental issues (e.g., Curry, et al., 2013, Bredin, et al., 2015, Lehrer and Sneegas, 2018). For example, it has been used in health economics to elicit preferences and economic behavior (Baker et al., 2006), and more recently in environmental economics to rank ecosystem services (e.g., Armatas, et al., 2014, Jensen, 2019). It is based on individual interviews during which respondents are asked to sort a set of items, here the water related ecosystem services, into a predefined distribution. A by-person factor analysis is then used to identify groups of individuals sharing distinct latent factors (Webler, et al., 2009, Watts and Stenner, 2012). In this study, these factors correspond to ranking of water ecosystem services from an extensive pre-defined list. Stated otherwise, we elicited perceptions and identified groups of individuals sharing distinct perspectives about important ecosystem services provided by the Olifants river catchment.

The rest of the article is presented as follows. Section 2 discusses the water quality and water related ecosystem services provided by the Olifants catchment. Section 3 is on the methodology, wherein we present the study area, data collection, and data analysis. The results are presented in Section 4, and the conclusions and recommendations in Section 5.

2 Water Quality And Water Ecosystem Services In The Olifants River

South Africa is a water scarce country and the South African government acknowledges that water is a critical ingredient for growth and development (Funke, et al., 2007). The National Water Act – NWA (Act 36 of 1998) regulates all water uses in the country and its main goal is the sustainable management of the water resources. It states that water should be protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner for the benefit of all. In addition, the National Water Resource Strategy (NWRS) serves as the primary framework to guide the sustainable management of water across all sectors, by focusing on the role of water in supporting economic growth (Maharaj and Pietersen, 2004). These regulatory efforts are aimed at protecting water resources and improving the state of the country's water quality.

The Olifants river catchment is one of the six major Lowveld river systems of South Africa, occupying an area of around 54,000 km^2 (Gyamfi, et al., 2016). It has also been identified as the most polluted water management area in the country (Kyei and Hassan, 2019). About 3.5 million people live on the South African side of the catchment. Its waters must meet the competing demands of mining, commercial farm irrigation, residential development, industrial use, and the maintenance of ecological balance (Nieuwoudt, et al., 2004). The country is also experiencing a general decline in the operation and management of waste-water treatment infrastructure, especially sewage treatment (Department of Water Affairs, 2010). This pollution is reducing the Olifants rivers water-related ecosystems' capacity to provide important ecosystem services.

De Villiers and Mkwelo (2009) and Ashton (2010) described the Olifants river as one of the most threatened river systems in South Africa with a declining population of fish, crocodiles and other aquatic life, which could be related to the increasing levels of pollution. Dabrowski and De Klerk (2013) found high nutrient concentrations, a condition likely to support dense plant populations leading to the death of aquatic animals by depriving them of oxygen. The nutrients were emanating from sewage discharge from wastewater treatment works and run-off fertilizers from irrigation farms. Nutrient-enriched water bodies are susceptible to mass growth of toxic aquatic vegetation, which is a health risk to humans and aquatic life alike, and reduces water resources available for drinking, irrigation and leisure activities (Codd, 2000). Acid mine drainage (AMD) also constitutes an important source of pollution in the Olifants. AMD has been described as the “single greatest threat to South Africa's water-scarce environment” (Sharife, 2011; Kinna, 2016):

Four types of stakeholders, most of whom live in the Olifants catchment, rely on the river and its natural biodiversity for their livelihoods – either directly or indirectly. First, rural households rely on its provisioning services like traditional medicine, grazing, fuel, food and housing materials. Riverside communities harvest reeds, draw water, and use it for recreational and spiritual practices. Second, large mining companies and associated industries mainly situated in the upper catchment use its water for their intensive mining activities. Third, large-scale agriculture also depends on Olifants waters to irrigate orchards and maize fields. The large scale farms are also non-point pollution sources via their use of chemical fertilizers and pesticides. Fourth, South Africa's diverse wildlife economy (nature reserves, national parks, etc.) also relies on the Olifants water and its healthy ecosystems. In addition to South-African stakeholders, and due to the trans-boundary nature of the catchment, subsistence farmers in Mozambique also rely on the catchment's flood plains. As such, South Africa faces the double incentive to better manage the quality of the Olifants waters: the first one is to improve the well-being of its own citizens; the second one is to avoid polluting neighboring countries (Kinna, 2016).

3 Methodology

3.1 Study area

We drew stakeholders for this study from the Maruleng and Fetakgomo municipalities of Limpopo province, South Africa. The map below shows the location of Limpopo province on the left, the distribution of local municipalities in the province on the right and the flow of the Olifants river through Maruleng and Fetakgomo municipalities.

The motivation behind purposively selecting these municipalities was three-fold. First, they lie in close proximity to the Olifants River, implying that stakeholders are exposed to its water pollution challenges and thus knowledgeable about them. Second, both municipalities are classified as rural areas, with high dependency on the catchment's water related ecosystem services (WES) (Radingoana, et al., 2020). Stakeholders would likely hold strong perceptions about the relationship between water pollution and WES. Finally, the two municipalities neighbor Mozambique, making the Olifants River an internationally shared resource, with its water resources not only governed under different jurisdictions and laws, but also stakeholders operating under differing economic, social and cultural incentives.

3.2 Data collection

Prior to the data collection exercise, approval to conduct this research was sought and granted from the Ethics Committee of the Faculty of Natural and Agricultural Sciences at the University of Pretoria (Ethics Application NAS256/2019).

Following Watts and Stenner (2012), the data collection process followed a typical Q-methodology four-step procedure that includes concourse development, selection of statements to be sorted (or construction of the Q-set), selection of respondents (or construction of the P-set) and finally interviews in which respondents sorted the Q-set into Q-sorts, and completed exit interviews.

We initially developed a number of statements related to WES in the Olifants through a review of ecosystem services studies in the academic and gray literatures (e.g., for the academic literature Millennium Ecosystem Assessment, 2005, Boyd and Banzhaf, 2007, Haines-Young and Potschin, 2010, TEEB 2010), and a stakeholder engagement process. The latter began with a stakeholder mapping exercise informed by literature reviews and expert opinions, and resulted in six broad stakeholder groups: regulators, water users (farmers and households), water suppliers, water boards, conservationists, and private sector. This was followed by informal interviews with representatives of each stakeholder group, in which all possible opinions about WES in the Olifants were collected, to assemble the concourse. From the initial statement set, we selected 27 statements corresponding to the WES identified as relevant by at least a stakeholder representative to create the Q-set (Table 1). It is important to note that a statement included in the Q-set does not have to be factual; it only has to represent a participant's subjective view to qualify for inclusion. It follows that WES that would be deemed irrelevant in the context of the Olifants were not screened-out. Finally, the statements included in the Q-set were pre-tested with 18 stakeholders and representatives, before data collection.

Table 1
The ecosystem service title and definition used in the Q-set.

No.	Q statement as it appeared on cards	Accompanying explanation given to respondent	Type[a]
1	Maintenance of water quality by diluting pollutants.	Dangerous pollutants dissolve in the river to make them less harmful.	R
2	Preventing floods.	The river helps to redirect excess water from land.	R
3	Control of soil erosion.	Preventing surface run-off of soil and supporting vegetation whose roots hold the land/soil together.	R
4	Conservation of ecosystem.	By supporting the life of insects, plants and animals.	R
5	Natural storage for water.	A reservoir to store water.	R
6	Habitat for fish and wildlife.	The river as a home/conducive environment for fish and other animals.	R
7	Water for irrigation.	Water used to irrigate plants in farms and gardens.	P
8	Water directly from the river for domestic use (washing bathing etc.).	Water for day-to-day use by households.	P
9	Water for power generation.	The water used by Eskom (national power supplier) in hydropower stations to produce electricity.	P
10	Water transport (boats and canoes).	Water used as a means of transport.	P
11	Catching fish to eat or sell.	Fish from the river, which is sold by the roadside or eaten by households.	P
12	Plants herbs and natural products.	The river supports the growth of plants, which have different uses.	P
13	Water for municipality use to supply tap water.	The municipality uses the water from the river to provide tap water for residents.	P
14	Water for industrial use (mining and manufacturing).	Water used for commercial purposes.	P
15	Boat cruise water viewing and water games.	The river being used for enjoyment activities.	C
16	Tourism for wildlife.	The river supports animals and people can enjoy viewing those animals in the national parks.	C
17	Traditional and religious rituals.	Activities such as baptisms and initiation ceremonies.	C
18	Fishing for fun.	Fishing just to enjoy and pass time.	C

No.	Q statement as it appeared on cards	Accompanying explanation given to respondent	Type[a]
19	Research and education purposes.	Scientists and pupils can learn different things about the river.	C
20	A nice view to look at (aesthetic values).	Just enjoying how beautiful the river looks.	C
21	National pride of owning a clean river.	Feeling proud and happy that the country has a clean river.	C
22	Recycling nutrients.	Useful nutrients are dissolved and trapped in the water and when the water is used again, those nutrients are reused.	S
23	Preventing damage to the environment (ecosystem resilience).	The river helps the environment to survive even when there is pollution or other disturbances to the environment.	S
24	A special environment for rare species of plants and animals (refugia).	Supporting those plants and animals, which can only survive in moist areas like near the river.	S
25	Making the landscape more beautiful.	The river can make the surroundings more beautiful.	C
26	Support plant growth processes (pollination and photosynthesis).	Plants need water to grow, to produce flowers and to make fruits.	S
27	Water cycle.	Water from the river evaporates into clouds and comes back as rain.	S

[a] The different ecosystem services were classified into four types: C: cultural services; P: provisioning services; R regulatory services; S: support services (This classification was inspired from the classification proposed by the Millennium Ecosystem Assessment (2005))

Subsequent to developing the Q-set, we purposively selected fourteen participants representative of the six stakeholder groups to form the P-set (participants to be involved in the Q-sorting exercises). The selection of fourteen participants was informed by Watts and Stenner (2012), who recommend recruitment of a minimum of one participant for every two Q-set items, meaning we had to use half as many participants as there were Q-set statements.

Each member of the P-set was interviewed during a one-on-one meeting in their own premises (home or office), without monetary compensation. In these meetings, the interviewee completed the Q-sorting exercises and an exit interview. For the Q-sorting exercises, they were required to rank the statements presented to them on a Q-board. For the ranking, they were initially instructed to carefully read all statements marked on the cards they received, and sort them into three stacks reflecting “importance”, “neutrality”, and “non-importance”. They were then asked to do a more fine-grained sorting by rank ordering the three stacks into the slots of an 11-point forced-choice quasi-normal distribution printed on a score sheet ranging from +5 (extremely important), through 0 (neutral), to -5 (not important at all) (Figure 1). The Q-sorting exercises were followed by informal discussions, in which the interviewer sought to understand the interviewees' rankings, and give them an opportunity to express views that were not captured in the Q-set. Notes taken during these interviews helped the authors interpret the factors revealed by the statistical analysis.

The Q-sorts were then recorded and coded with the help of the PQMethod software (Schmolck and Atkinson, 2014). Internally, the software codes the Q-sorts as a matrix where the columns correspond to a statement and the rows correspond to the respondents. Each cell corresponds to the rank given to the statement $ST\ x$ by the respondent r. Therefore, a line corresponds to all the ranks given by one respondent.

3.3 Data analysis

The statistical procedure underlying Q is a factor analysis where the variables to be classified are the Q-sorts (i.e., the sorting of the persons who did the ranking). This by-person factor analysis identifies the Q sorts that are highly correlated. Highly correlated Q sorts will indicate respondents who share the same view on how the WES should be ranked. Therefore, each shared ranking group is represented by one factor, and Q helps finding groupings of similar WES rankings.

Among the possible factor extraction methodologies, we chose the principal component analysis. The unrotated output maximizes the variance accounted for by the first and subsequent factors. However, this often results in having many items load substantially on more than one factor. In order to make the output more understandable, it is a common practice to conduct some rotation of the factors to obtain "clearer" loadings, that is a solution where each item loads strongly on only one of the factors, and much more weakly on the other factors. Factor analysis allows for different types of rotation. In our case, we opted for a varimax rotation.

To select the number of factors, we looked at two common criteria used in Q analyses: the minimum number of significant Q sorts and the Kaiser-Guttman criterion (Brown, 1980). Following the Brown rule, a Q-sort was considered significantly loaded on a factor at $p < 0.01$ if its loading on that factor was greater than $2.58/\sqrt{N} = 0.496$, where N=27 is the number of statements (Brown, 1980). The Kaiser-Guttman criterion retains factors with eigenvalue greater than one. In addition, factor solutions ranging from two to four factors were extracted and inspected for a final decision on the number of meaningful factors to be extracted.

Following the varimax rotation, we selected the Q-sorts representative of each factor. To associate a Q-sort with a factor, we relied on the concept of communality h^2 defined as the sum of squared loadings along each row. The PQMethod proposes a pre-flagging algorithm to flag the purest cases only. A Q-sort with a loading a on the factor is pre-flagged if its loading is significant at $p < .05$, and if $a^2 > h^2/2$, i.e. the factor explains more than half of the common variance. In addition, the PQMethod allows the researcher to manually flag or un-flag Q-sorts.

For purposes of interpreting Q sorts associated with one factor, it is a common practice to create factor arrays, which represent how a weighted average member of that group would have arranged their statements (Watts and Stenner, 2012, Yarar and Orth, 2018). Factor arrays are based on Zscores of each statement for a particular array (See Brown, 1980 for a detailed explanation of the Z-score calculations). The Z-scores make possible direct comparisons with scores for the same statements in the different factors, since all factor arrays have identical means (zero) and standard deviations (one). Since statements were forced into a quasinormal distribution during the interviews, it is possible to select the item with the highest Z-score and assign it the value of +5, the nexthighest item the value of +4, etc. in order to reproduce the initial format of the Qsorts. These rounded scores introduce a small amount of error due to the arbitrary grouping involved, but they are usually preferred for interpretation, since they conform to the format in which the data were originally collected. Qualitative interpretation will then be based on the analysis of these factor arrays.

In order to discuss the relative importance of different types of ecosystem services, we classified the different services into three categories: provisioning, regulatory and supporting services, and cultural & recreational services (Table 1). This classification was inspired by the Millennium Ecosystem Assessment (2005). Then, we estimated the salience ascribed by the factors to the three categories of ecosystem services in which statements were grouped. Salience was calculated by adding the absolute value of Z scores of the statements in each categories and normalizing that sum to the number of statements in that category. We also obtained a mean absolute Z-score per category. Normalization allows for comparisons across categories. It is also a way of validating the inclusion of each type of ecosystem services in the study, since themes with low salience are less relevant for the stakeholders interviewed.

4 Results

The results of the principal component analysis without rotation are presented in Annex A. The first three factors had at least two significantly loading Q-sorts at the 1% threshold whilst the Humphrey's rule suggested two factors. Therefore, we ran the 3,000 bootstrap using qmethod successively with two and three factors and a varimax rotation to obtain indicators of internal validity, such as the standard deviation of the loadings and the frequency of flagging (Zabala and Pascual, 2016), and check the interpretability of the results. We retained the solution with three factors, which together explained 57.9% of the variance. The factor loadings and the Q-sorts flagged to define the factors are presented in Annex B. The table includes the Q-sorts loading standard deviations and frequency of flagging obtained from the bootstrap resampling to test the robustness of the Q-sorts on the factors.

One regulator and one commercial user were not flagged on any factor because they had high loading on at least two factors. The first factor included six out of 16 Q-sorts, and was composed mainly of conservationists and regulators, but included also one water supplier and one domestic user. However, the domestic user had the lowest loading and a higher standard deviation to loading ratio. Therefore, it carried less weight in the definition of this factor. The second factor included five Q-sorts and was mainly composed of people related to the provision or use of treated water (domestic user and suppliers), but it also included the views of one conservationist and one water board (bulk water). The third factor included three Q-sorts, two of them being representative of the private sector.

The statements Z-scores and factor scores are presented in Annex C and the correlation between factors are presented in Table 2. The correlation between factors one and two was high but still below the threshold of 0.496 used to determine significant correlations at $p< 0.01$ (Brown, 1980). We concluded that the three factors represented sufficiently distinct views to be analyzed, but with possible convergence of views on some aspects especially between the first two factors.

Table 2
Correlation between factors

	Z1	**Z2**	**Z3**
Z1	1.0		
Z2	0.408	1.0	
Z3	0.253	0.089	1.0

For the sake of space, we show only a graphical representation of the factor arrays for the three factors (Figure 2). We also present the average Z-scores and the salience per factor and per type of ecosystem services in Table 3. In what follows, information between brackets in the descriptions of the factors include the statement number (from 1 to 27) and the normalized value assigned to the statement (from −5 to +5).

Table 3
Salience and Mean Z-scores per type of ecosystem service and per group

Type	**N**	**Salience**				**Mean Z-score**			
		Group			Overall	Group			Overall
		1	2	3		1	2	3	
Provisioning	8	0.84	1.11	0.80	0.92	-0.04	0.71	0.24	0.31
Regulatory & Support	11	0.77	0.77	0.82	0.79	0.61	-0.17	0.27	0.24
Cultural & Recreational	8	0.83	0.60	0.83	0.75	-0.80	-0.48	-0.62	-0.63

4.1 Description of the factors

4.1.1 Factor 1: The conservationists

For this group, the main function pertains to the regulation and support services. In particular, they put the conservation of ecosystems (#4: +5) and the dilution of pollutants (#1: +4) as the main services of water related ecosystems of the catchment. Other supporting services were ranked high, such as support plant growth (#26: +3), recycling nutrients (#22:+3), habitat for fish and wildlife (#6: +2) and to a lesser extent an environment for rare species (#24:+1).

While the regulation and support types of services were clearly set as most important, this group also recognized the importance of supplying water for human consumption, as showed by the ranking of water for domestic uses (#8:+3), and to a lesser extent by the water for municipalities (#13: +1). However, the bootstrap scores of these provisioning services were more variable indicating these services were meaningful but that its relative position given by the different members was more variable. As a result, these provisioning services are less representative of this group.

This group ranked the cultural and recreational services as least important. All these services got a factor score lower than zero. This was especially the case of aesthetic values (#20: -3), recreational fishing (#18: -3), and boat cruises (#15: -4). Finally, water transport that we classified as a provisioning service was ranked lowest (#10: -5).

Overall this group is strongly defending the regulation services associated with water-related ecosystems of the catchment. This is consistent with the composition of the group composed largely of conservationists and regulators.

4.1.2 Factor 2: The water users: water for domestic and other private uses

Stakeholders holding this perspective gave priorities to major provisioning services with the highest priority given to domestic uses. The highest importance was given to the water extracted to supply potable water to residents (#13: +5) and the water directly extracted from the river for domestic use (#8: +4), both referring to water for domestic uses. It was followed by water for irrigation (#7: +3). Two regulation services were ranked relatively high: the maintenance of raw water quality by diluting pollutants (#1: +3), and the provision of a habitat for fish and wildlife (#6: +2). The diluting service can be linked to support the provision of water for domestic and other private uses, since they expect the water related ecosystems to clean-out the water before their private use. This group also placed importance on the Olifants river being able to provide plants, herbs and natural products for use in different activities (#12: +2). Overall, we see that this group bundled a mix of provisioning and regulatory services that are all related directly or indirectly to a final private use of the natural resources of the catchment. Water for industrial uses received a high rank (#14: +2), however, the variability of this ranking was also higher indicating a less consensual view about this service within the group.

This group also did not see the cultural and recreational services as important. The least important WES for stakeholders holding this perspective was sport fishing (#18: -5). These stakeholders were also of the view the Olifants river could not contribute to make the landscape more beautiful (#25: -2). Among the provisioning services, water for power generation was also ranked very low (#9: -4).

A general characteristic of this group was also the low rank given to regulation services, especially the protection of rare species (#24:-3) and the control of soil erosion (#3:-3), and the recycling of nutrients (#22: -2) mainly because these stakeholders did not see how these services would be beneficial to people. Prevention of floods (via dams or wetlands) (#2: -1) were not considered important services.

Overall, this group is attached to domestic and private uses of natural resources. As a result, the regulation services and provisioning services that have no direct influence on the capacity to beneficiate from the resources are not seen as important. This group is mainly composed of water suppliers in charge of delivering water to end-users, but also include the member of the water board in charge of delivering bulk water, these priorities are to be expected. This importance given to water provisioning services, especially for domestic uses, could be expected since the defining stakeholders for this factor were mainly water suppliers (both bulk and domestic) and domestic users. The domestic users, suppliers and water boards enjoy the Olifants river for the goods and services it provides directly.

4.1.3 Factor 3: The planners: an environment to be mastered for societal benefits

This factor included three loaders, two from actors of the private sector and one regulator. It is unique in its importance given to the power generation (#9: +5), the storage of water (#5:+4) and regulatory functions associated with erosion (#3:+3) and flood control (#2: +2). The use of water for industries was given a lower rank (#14:+1) but this rank was not variable within that group. All these services somehow relate to the regulation of water flows, most likely via the construction of dams. These services also relate to the production of more public goods (power generation, water for households, prevention of floods, and prevention of erosion). However, the provision of public goods associated to the maintenance of natural ecosystems are not given the priority. In particular, all regulatory services related to the conservation of natural habitats and species were given low and consistent ranks. (#24: -1, #22:-1, #6:-2, #4:-2).

Most of the cultural and recreational services were given a low rank, except the generation of national pride of owning a clean river (#21:+2).

4.2 Consensus and divergence of views

4.2.1 Consensual ecosystem services

Ten out of the 27 services were consensual, i.e., they had Zscores that were not significantly different across factors at $p < 0.05$ (Annex C). Out of these ten services, water for industrial uses was the only consensual provisioning service. In contrast, most cultural and recreational services were consensual (5 out of eight services in that category); they were seen by all factors as less important than the other services. Finally, only four of the eleven regulation and maintenance services were consensual.

Overall, the consensus was more about services that were not deemed important (mostly cultural services) or of moderate importance (mainly selected supporting services), but there was less consensus on what were the most important services. In particular, none of the cultural and recreational services were ranked higher than one in any group. It suggests a consensus among the persons who participated to the Q that these services will not be important for the Olifants. This was an unexpected result given the presence of the Kruger National Park, a highly touristic place for its wildlife, in the Olifants catchment.

Therefore, the difference in point of views between the groups will be about the mix of provisioning and support services.

4.2.2 A simple classification of the ecosystem services

To better understand the diversity of point of view towards these WES, we calculated the mean and the standard deviation of the scores obtained on the three factors. The scatterplot of the statements along these two dimensions is shown in Figure 4. We separated the mean score into three classes: highly negative, close to zero, highly positive, and the standard deviation into small and large. This delineated six classes of statements identified in the different quadrants of the Figure 4.

The lower part of the graph identified more consensual WES because the standard deviation is small. In the lower-right quadrant (highly positive mean score and small standard deviation), there is a consensus among factors to consider these services as very important. The services found in this category are water for municipal uses, water for irrigation and to a lesser extent water for industrial uses. We also find two regulation services, i.e. maintenance of water quality and support of plant growth processes. The upper-right quadrant (highly positive mean score and large standard deviation) includes the direct extraction of water for household consumption. The standard deviation is high because one factor had a score close to zero, while the other two gave high scores. While not completely consensual, this also suggests that this service will not be highly controversial as two groups are highly in favor of this ecosystem while the remaining group is neutral towards it. Therefore, the observation of these two quadrant suggests that provisioning services related to the use of water by households (either directly or through municipal delivery), by agriculture and by industries are consensual or at least not controversial. For example, this is the case of water for agriculture that is seen as important by one group (factor 2), but is given highly negative ranks by others. This leaves room for obtaining solutions that can potentially satisfy the different types of stakeholders.

In the lower-middle quadrant (low mean score and low standard deviation), there is a consensus to consider these ecosystem services as neither important nor unimportant services. They include the prevention of damage to the environment and water cycle. These two services were probably not sufficiently defined to be easily evaluated, explaining a relative consensus to rank them in the middle part of the distribution. Research and education purpose falls also in that category. In this case, the lack of direct or rapid benefits might explain this lack of interest for this service. Finally, the tourism for wildlife also falls in that category. This general lack of recognition for this service is surprising given the importance of tourism for this catchment as attested with the presence of the Kruger National Park, one of the largest national parks in South Africa.

In the lower-left quadrant of the graph (highly negative mean value and small standard deviation) there is a consensus for considering WES of very low importance. This quadrant includes only cultural and recreational services (recreational fishing, aesthetic value, and religious values). The upper-left quadrant (highly negative mean value and large standard deviation) includes services that with highly negative scores for some groups, and better scores by other group. This quadrant only contains two services related to the use of boats either for transport or for tourism. However, for both these services, the scores were highly negative for two groups and close to zero for the last group. Considering this, we can conclude that the upper- and lower-left quadrants contain services that will not be defended by any of the stakeholders. Again, this provide useful information for the management of the ecosystems.

In the upper-middle quadrant (small mean score, large standard deviation), we will find the controversial services. They are controversial because the combination of the high standard deviation and low mean can only be obtained if scores are negative for some groups and positive for other groups. This is particularly the case of the water for power generation and the two regulation services (control of soil erosion and conservation of ecosystems). Power generation was seen by some stakeholders as not realistic given the water flows and the configuration of the basin. However, one group considered it as an important service, in this case potential service. This difference of views may originate from a different level of information about the real potential of this service. The “conservation of ecosystems” particularly opposed the conservationist views (factor 1) with the planners (factor 3). On the other hand, the planners saw the “control of erosion” as an important service while the conservationist did not see them as important. These opposing views underline a different approach of the services potentially obtained from water-related ecosystems in the catchment. The first ones see them as an opportunity to conserve important ecosystems and species. The other ones highlight the services that have a direct or indirect impact on the production of tangible services.

4.3 Discussion: implications for the management of ecosystems in the Olifants

Ecosystem management is often difficult because of uncertainties and conflicting stakeholder views. Although the Q method cannot address the uncertainties about the consequences of another policy or governance structure on ecosystems, it has proven useful in identifying the views of different stakeholders. We have identified three contrasting views on the important ecosystem services derived from water-related ecosystems in the Olifants river basin.

An initial description of the three factors suggested conflicting and irreconcilable views on the hierarchy of services. In particular, we did not find any consensus about the most important provisioning services, indicating conflicts regarding the possible direct benefits society should extract from these ecosystems. It highlighted a divide between “conservationists” who give priority to ecosystems and ranked low the provisioning services, “water users” who give priority to private extractive uses of the resource and the services that would help keep it clean, and “managers of the environment” who are ready to transform natural ecosystems if it provides more public goods.

However, a more careful observation of the rankings by the different groups also suggests that some trade-offs and win-win solutions could be discussed. More specifically, the Q method allowed for the identification of services very important for at least two groups and considered more neutrally by the remaining group. For example, the contribution of ecosystems to the dilution of pollutants and the maintenance of water quality was seen by conservationists (#1: +4) and water users (#1: +3) as important, while the developers did not rank it low (#1: +1). In the same way, direct extractions from the river for domestic uses showed the same pattern (#8: +3, +4, 0), where conservationists and water users recognized these direct extraction as important for the population well-being as some households do not have access to treated water delivered in the villages or in their homes. The water extracted by municipalities to supply tap water follow a symmetrical pattern (#13: +1, +5, +3), the water users and the developers seeing municipal water uses as more important.

This leaves room for the implementation of some Pareto solutions, in the sense that they would contribute to the delivery of services important for some stakeholders, while not affecting the others, since they have a more neutral attitude towards them. One possible candidate is the development of ecological infrastructures (EI). EI refers to nature-based equivalents of built infrastructure designed to deliver valuable ecosystem services like water and climate regulation, soil formation, and disaster risk reduction (Von Bormann and Gulati, 2014). Protection, restoration, or maintenance of targeted wetlands would serve the double purpose of ecosystem preservation and water quality maintenance (via the filtering of pollutants) so that households extracting water directly from rivers would be less affected by pollution. In fact, this would also supplement built infrastructure for water such as water treatment plants or dams (SANBI, 2014, United Nations Environment Programme, 2014, Palmer, et al., 2015, UNESCO, 2018). Indeed, these ecological infrastructures would need to be crafted so they deliver the expected services; this requires that their efficiency in delivering these services are validated by science-based evidence, and the local trade-offs are accepted by the different local stakeholders. While this exploratory study was deliberately made at a large scale to explore the different views, similar methodology could be employed when evaluating a specific change such as an investment into ecological infrastructures. A particularly interesting research track will be to combine mapping tools with the Q-methodology to map stakeholder perceptions and preferences regarding the possible outcomes of such investments (Forrester, et al., 2015, Elbakidze, et al., 2017, Sigwela, et al., 2017, Sy, et al., 2018).

5 Conclusion

We used Q methodology to understand stakeholder perceptions about WES in the Olifants River. Our results led us to identify three perspectives, each with a unique take on the research question. The first perspective was held by a group of stakeholders that we classified as conservationists based on their prioritization of the use of WES to conserve the environment. The second perspective revealed a focus on WES for domestic use. The third perspective revealed a focus on using WES to maximize societal welfare.

This study demonstrates that in the multi-stakeholder governance and use of a resource, there are converging and competing priorities. Such information can serve as a useful starting point for the design of strategies for effective management of trade-offs. It is our view that a similar study on the Mozambique side of the Olifants River could generate complementary information that could inform transboundary strategies for the management of this shared resource.

Declarations

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Figures

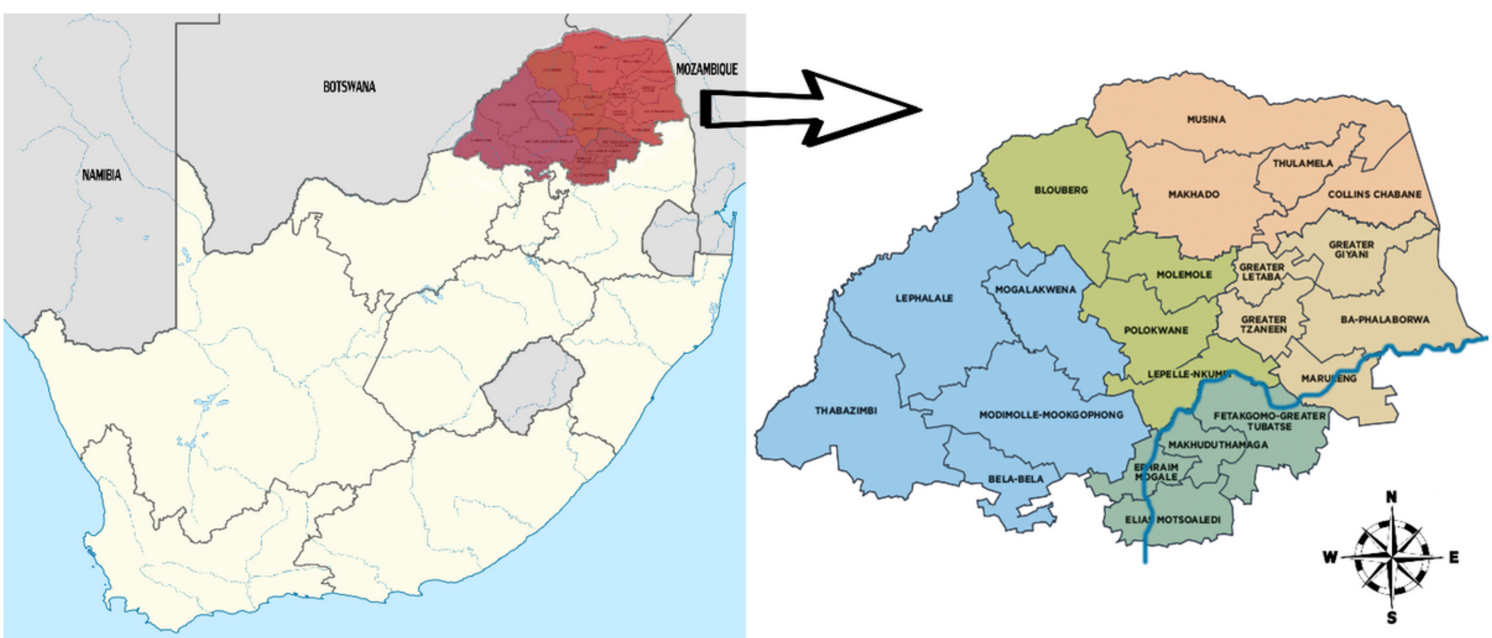

Figure 1

Map of South Africa (on the left) and Limpopo province (on the right) showing the position of the Olifants river

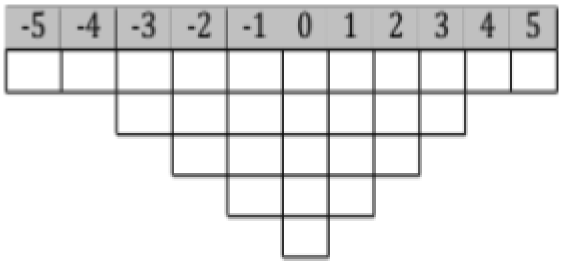

Figure 2

Pre-arranged distribution for ranking of water-related ecosystem services

Rank	ES1	SE1	bias.1	ES2	SE2	bias.2	ES3	SE3	bias.3
5	4	***	0	13	***	1	9	***	0
4	1	*	2	8	***	-1	5	***	0
3	26	*	0	7	**	0	3	***	0
3	8		1	1	*	1	13	*	1
2	22	**	-2	6	**	-1	2	**	-1
2	6	*	-1	12	***	0	21	*	0
2	7		1	14		0	26		1
1	13		0	26	*	0	1		0
1	24	*	-1	27		0	14	*	-1
1	14		1	19		1	23		0
1	5		1	15		0	7		0
0	23		-1	11		0	12		0
0	11		-1	16		0	27		0
0	27		0	10		-1	8		0
0	2		0	20		0	16		0
0	19		0	23		1	25		0
-1	21		0	4		-1	19		0
-1	17		0	5		0	17	*	0
-1	25		0	17		0	24	*	1
-1	12		1	2	*	1	22	*	0
-2	16		-1	21	*	1	6	**	1
-2	9	**	1	22	***	0	4	*	0
-2	3	*	0	25	*	0	10		-1
-3	20	*	-1	24	**	0	15	*	-1
-3	18	**	0	3	**	1	11	**	1
-4	15	***	1	9	**	1	18	*	-1
-5	10	***	-1	18	*	-4	20	**	0

Figure 3

Summary of the average weighted-average Q-sorts; for each factor the column ES present the ecosystem services numbers. ES were color-coded: grey for provisioning services, blue for regulation and maintenance services, yellow for cultural and recreational services. The columns SE and bias give an indication of the stability of the statement. For SE, '***','**', '*' indicates that the score of the statement is greater than, respectively, 2, 1.5 and 1 times the standard error calculated from the bootstrap sample.

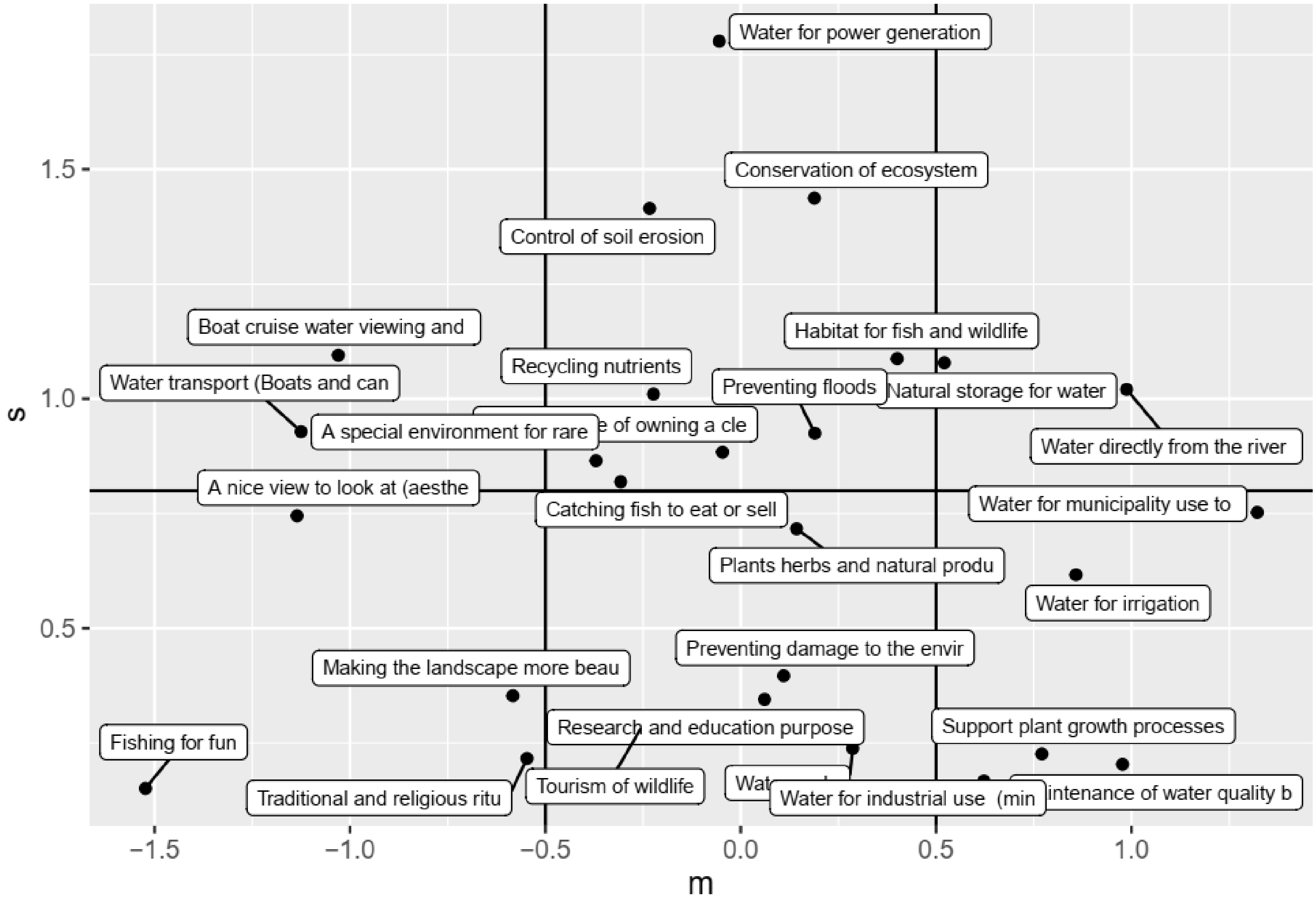

Figure 4

Scatterplot of the statements along the mean (m), standard deviation (s) axis

Supplementary Files

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- Annexes.docx