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Water quality, biological quality, and human well-being: Water salinity and scarcity in the Draa River basin, Morocco

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ABSTRACT

River ecosystems are being threatened by rising temperatures, aridity, and salinity due to climate change and increased water abstractions. These threats also put human well-being at risk, as people and rivers are closely connected, particularly in water-scarce regions. We aimed to investigate the relationship between human well-being and biological and physico-chemical river water quality using the arid Draa River basin as a case study. Physico-chemical water measurements, biological monitoring of aquatic macroinvertebrates, and household surveys were used to assess the state of the river water, ecosystem, and human well-being, as well as the associations between them. Salinity levels exceeded maximum permissible values for drinking water in 35 % and irrigation water in 12 % of the sites. Salinity and low flow were associated with low biological quality. Human satisfaction with water quantity and quality, agriculture, the natural environment, and overall life satisfaction were low particularly in the Middle Draa, where 89% of respondents reported emotional distress due to water salinity and scarcity. Drinking and irrigation water quality was generally rated lower in areas characterized by higher levels of water salinity and scarcity. The study found positive associations between the river water quality and biological quality indices, but no significant association between these factors and human satisfaction. These findings suggest that the relationship between human satisfaction and the biological and physicochemical river water quality is complex and that a more comprehensive approach to human well-being is likely needed to establish relationships.

1. Introduction

In the past 50 years, the framing of nature conservation developed from conserving nature for its own good, to conserving nature for the benefit of people, to a shared human-nature environment (Mace, 2014). In this social-ecological system perspective human well-being is linked directly to the health of the ecosystem and includes mental and physical health of individuals (Andrews and Duff, 2020), social bonds between them, but also the relationship between humans and nature (Gergen, 2009). This implies that human well-being is related to the quality of resources and ecosystem services and consists of the fulfillment of different interdependent categories of material and non-material needs (Gergen, 2009; Mace, 2014). The access to nature and the existence of biodiversity in the vicinity was shown to increase well-being (Hartig et al., 2014; Marselle et al., 2019). Understanding the direct and indirect connections between ecosystem health and human well-being and satisfaction can deliver crucial insights that may inform future conservation efforts.

River ecosystems play a vital role in human well-being by providing freshwater and food, regulating climate, and offering cultural services (Akinsete et al., 2019). However, human activities such as hydromorphological changes, pollution, as well as changes in climate conditions increase salinity levels and can threaten human well-being (Akinsete et al., 2019; Cunillera-Montcusí et al., 2022). River ecological health (i.e., river water quality, water quality influencing factors, status of the river ecosystem) and human well-being were decreasing from up- to downstream in a study using the Happy River Index in China, where water scarcity, degradation of the ecosystem, soil erosion, and pollution,

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and unguaranteed ecological flow were restricting human well-being and ecosystem health (Zuo et al., 2020). Nature and riverscapes can impact mental and physical health (Kaplan 2001; Russell et al., 2013; White et al., 2010), with studies reporting a positive correlation between river naturalness and human well-being (White et al., 2010). Disconnectedness from nature can have negative effects on psychological health (Frumkin et al., 2017; Kals and Maes, 2002; Sandifer et al., 2015). However, most studies have been conducted in developed countries and focused on large perennial rivers (Cruz-Garcia et al., 2017). It remains open to which extent this can be extrapolated to intermittent, ephemeral, and dry rivers in countries of the Global South (Ferreira et al., 2022; Messager et al., 2021; Nicolás-Ruiz et al., 2021). As climate change and anthropogenic pressures continue to increase, these systems and regions may be particularly threatened by a deteriorating ecological and human health (Liu et al., 2022; Zuo et al., 2020).

In the Draa River basin in the South of Morocco, people depend directly on the river ecosystem, as it is providing water for irrigation and domestic use, and thus helps to survive in the arid conditions of the northern Sahara (Mahjoubi et al., 2022). In the upper reaches of the Draa River basin, salinity is primarily caused by geological factors, with rocks and soils releasing ions into the water (Warner et al., 2013). Depending on the rock types, some streams have salinity levels as high as 20 mS/cm (e.g., El Mellah River; direct translation: Mellah = salt), almost half the level of sea water. Salinity further increases, especially in the Middle and Lower Draa basins, due to lower rainfall and increasingly arid climate (Beck et al., 2018; Williams, 1999), which leads to a lack of dilution of water and high evaporation, respectively (Warner et al., 2013). Secondary salinization, such as the use of saline freshwater for irrigation (Hssaisoune et al., 2020; Williams, 1999) in the large date palm oases along the Middle Draa (Karmaoui, 2014), further increases salinity (Haj-Amor et al., 2016). The drying of intermittent streams during the summer and changes in the natural flow regime caused by the presence of a large dam between the Upper and Middle Draa impose additional stress to the river ecosystem (Karmaoui, 2014). The Draa River basin is characterized by several aridity and salinity gradients that allow to study associations between these gradients and potential responses of the river ecosystem and human well-being (Johannsen et al., 2016).

We assessed how river water quality and biological quality of rivers are associated with water salinity and scarcity in the Draa River basin and how these relate to human well-being. River water quality was assessed through physico-chemical water quality parameters to describe the state of rivers. Aquatic macroinvertebrate metrics were used to describe the biological quality, as macroinvertebrates fulfill important roles for the functioning of freshwater ecosystems and their presence in most aquatic habitats make them suitable to study the biological quality of rivers (Wallace and Webster, 1996; Covich et al., 1999). Human well-being was assessed through a standardized household survey targeting the topics of water and crop quality, people's health status, and satisfaction.

Based on the processes of primary and secondary salinization and their effects on the river ecosystem, we propose the following hypotheses: High water salinity is associated with (1) poor river water quality and (2a) low biological quality of rivers. We also expect (2b) reduced flow rate as a measure of water scarcity to be associated with low biological quality. Additionally, we hypothesize (3) human satisfaction to be associated with low river water and biological quality, as we expect a direct link between the river ecosystem and human well-being. These hypotheses were tested by analyzing the relationships between river water quality, biological quality, and human well-being indices.

2. Materials and methods

2.1. Study area

A total of 17 sites in the Draa River basin were selected for the assessment of river water and biological quality and visited in October 2021 and March 2022 (Fig. 1; Table S1). 13 of those sites were in tributaries originating in the High and Anti-Atlas Mountains that drain into the El Mansour Eddahbi dam. From there the Draa River flows south-east, here referred to as Middle Draa, before turning as Lower Draa towards the Atlantic Ocean. However, the Middle and Lower Draa are dry for most of the year, leading water only after heavy rainfall events or dam releases. Only one site was selected in the Middle Draa, because the dry state of the river during the study period did not allow further ecological assessments of aquatic macroinvertebrate life stages. Four sites were located in the Lower Draa sub-basin at a tributary from the Anti-Atlas.

Surveys with residents were conducted in October and November 2021 and April 2022, interrupted by a nationwide lockdown. Sites were located in 11 localities close to the ecological sites and in three further localities along the Middle Draa, where no ecological sites were located due to the dry state of the river during the study period, which resulted from a two to three years long drought (Fig. 1).

2.2. Physico-chemical parameters

Water temperature, pH, electrical conductivity, and dissolved oxygen were measured by using a multi-parameter (WTW MultiLine® Multi 3510 IDS) in the 17 ecological study sites (Fig. 1). Furthermore, river width and depth were measured. Flow velocity was measured using a hydrological impeller (SEBA Hydrometrie) and subsequently combined with the area of the cross profile to calculate flow rate. The ion composition was measured in field by using the MACHEREY-NAGEL VISOCOLOR reagent case with the photometer PF-12Plus and VISOCOLOR Eco colorimetric test kits. Measurements covered chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), orthophosphate (PO_4^{3-}), potassium (K^+), total hardness (TH) and carbonate hardness (CH). Concentrations of nitrate, nitrite, ammonium, orthophosphate, and potassium lower than 4, 0.02, 0.01, 0.6, and 2 mg/l, respectively, were below detection level. Concentrations of chloride above 6,000 were set to 6,000 as this stands for the upper water quality standard boundary and we refrained from higher dilution of samples for measurements to avoid inaccuracies. To account for temporal variability and measurement errors in data analysis, the measurements from October and March were averaged (except for dissolved oxygen and nitrite which were only measured in October). If a value was under detection level, we used half of the detection level to calculate the mean, a method commonly used (Uh et al., 2008, but see Clarke, 1998). Although more advanced methods are available, in our case with only few non-detects and few sites, the bias was supposed to be low (Helsel, 2006; Helsel, 2010). In the case of sulfate, we excluded two outliers as they were more than 18 times higher than the values of all other sites including previous measurements in the same sites. We attributed these outliers to measurement errors. Values were compared to Moroccan water quality standards for drinking water (Royaume du Maroc, 2006) and irrigation water (SEEE, 2007) to evaluate exceedance of maximum admissible values.

2.3. Water quality index

A river water quality index, hereafter WQI, was calculated to determine river water quality using a modified version of the Moroccan water quality index (Royaume du Maroc, 2008). We did not quantify 5-day biochemical oxygen demand (BOD_5), dissolved organic carbon (DOC), total phosphorus, and fecal coliforms, which are used to evaluate water quality of rivers in Royaume du Maroc (2002), while quantifying water temperature, pH, electrical conductivity, chloride, sulfate, and nitrate, which are described in Royaume du Maroc (2002) for the assessment of water quality. Dissolved oxygen and ammonium were included as in the original index. All parameters were scaled to a range from 0 to 100 using the class boundaries and calculation as described in

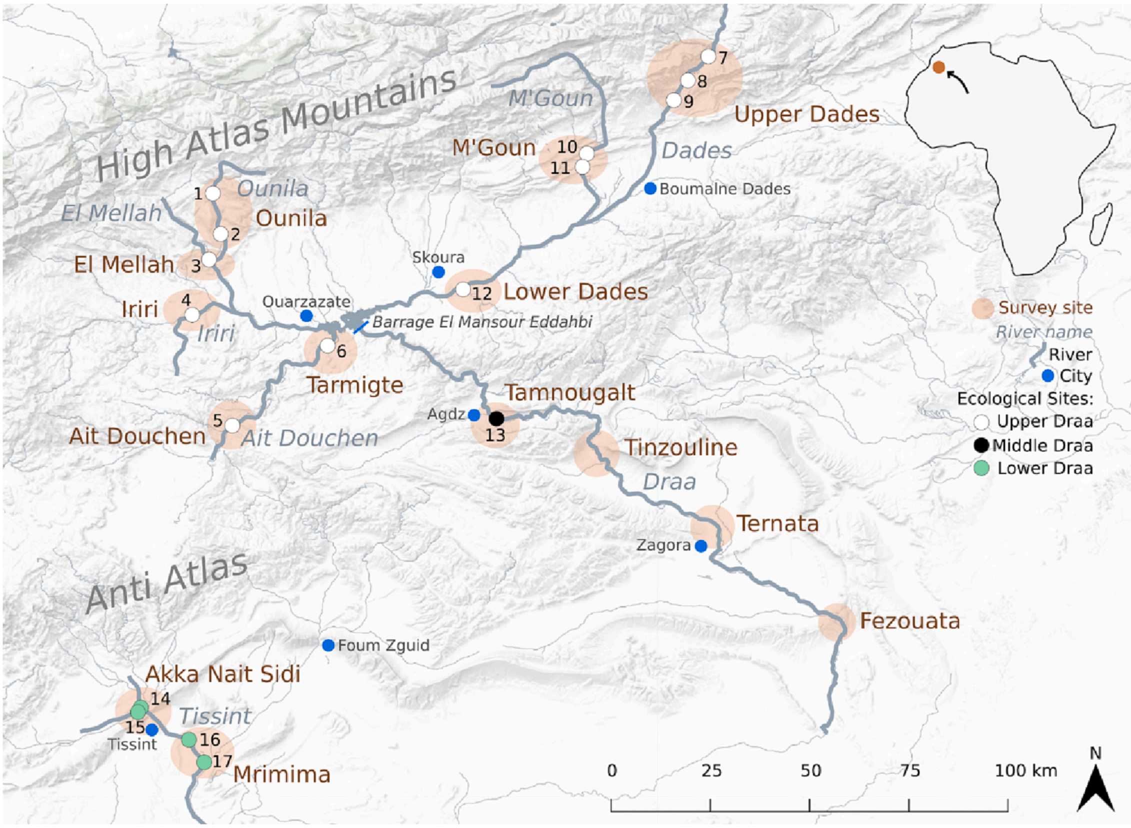

Fig. 1. Map of Draa River basin showing the 17 ecological study sites and 14 survey sites. Ecological sites in ellipses were assigned to survey sites. (terrain-basemap: © EOX).

Royaume du Maroc (2002; 2008; Table 1). For sulfate, nitrate, and ammonium, the minimum values were set to half the detection level (sulfate < 20 = 10; nitrate < 4 = 2; ammonium < 0.1 = 0.05), other parameters had all values above the detection level.

2.4. Biological quality

2.4.1. Macroinvertebrates

At each ecological site, macroinvertebrates were sampled by using a 33 × 31 cm (0.1 m^2) Surber sampler (mesh size 500 μm) in October 2021. Quantitative samples were taken at ten spots per site which were selected to cover all microhabitats based on the proportion of microhabitats in a 100-m reach, resulting in a sample area of 1 m^2 per site. The samples were conserved with 95 % ethanol until sorting and identification of taxa in the laboratory. Taxa were identified to species level, except for Diptera (family or subfamily), Odonata (family or genus), Crustacea (order or species), Mollusca (genus or species), Annelida (subclass), and Tricladida (class).

Macroinvertebrate metrics describing biodiversity: taxon richness (number of taxa) and percentage of taxa of the orders EPT (%EPT; Ephemeroptera, Plecoptera and Trichoptera), and multi-metric biotic indices describing the biological water quality: IBMWP (Iberian biological monitoring working party, Jáimez-Cuéllar et al., 2002) and IBGN (Indice Biologique Global Normalisé, Archaimbault & Dumont, 2010), were calculated to describe biological quality of the rivers. These metrics have already been used in Morocco before (Feio et al., 2021). However, sampling methods differed from the protocols used for IBMWP and IBGN.

2.4.2. Biological quality index

We created a biological quality index (BQI). Therefore, we normalized the macroinvertebrate metrics (taxon richness, %EPT, IBMWP, IBGN) to a scale from 0 to 100 to match the WQI and calculated the mean of the metrics per site, for the purpose of comparing it to the other indices and to analyzing the impact of physico-chemical parameters on the biological quality of rivers.

2.5. Human well-being

To compare people's perception of drinking and irrigation water quality, their health and satisfaction, 181 interviews using a structured standardized questionnaire were conducted with residents in the 14 survey sites (Fig. 1), ranging from 7 to 23 interviews per site which lasted 5–12 min. Respondents were selected randomly. The survey used

Table 1
Moroccan water quality standards and intervals (Royaume du Maroc, 2002; 2008) for the used parameters water temperature (Temp), pH, electrical conductivity (Cond), dissolved oxygen (Oxygen), chloride, sulfate, nitrate, and ammonium.

Classification	WQI	Temp [°C]	pH	Cond [μS/cm]	Oxygen [mg/l]	Chloride [mg/l]	Sulfate [mg/l]	Nitrate [mg/l]	Ammonium [mg/l]
Excellent	100–80	0–20	6.5–8.5	100–750	7–10	0–200	0–100	0–10	0–0.1
Good	80–60	20–25	–	750–1300	7–5	200–300	100–200	10–25	0.1–0.5
Moderate	60–40	25–30	8.5–9.2	1300–2700	5–3	300–750	200–250	25–50	0.5–2
Bad	40–20	30–35	3.5–6.5, 9.2–10	2700–3000	3–1	750–1000	250–400	>50	2–8
Very bad	20–0	35–40	–	3000–7000	1–0	1000–6000	400–2000	–	8–50

a mixed qualitative-quantitative research approach using categorical multiple choice questions to identify the water sources used for drinking and irrigation, single-answer multiple choice questions to cover the perceived quality of river water, groundwater, and the produced crops in relation to different sources of water (river water, groundwater, ONEE (The National Office of Electricity and Drinking Water) tap water or truck delivered water), and rating scales to assess the effect of water quality and quantity on people's health status, and six aspects of satisfaction (health care, quantity and quality of water resources, agricultural production possibilities, conditions of the natural environment, and life overall). We additionally asked for gender, occupation, and age category (Table S2) to check for differences in responses between these categories.

To calculate a human satisfaction index (HSI) we used the values of the responses to the 4-point scale questions on satisfaction with health care, quantity and quality of water resources, agricultural production possibilities, and the conditions of the natural environment, ranging from very unsatisfied to very satisfied for the 14 survey sites applying equal-weights. Satisfaction with life overall was not used to calculate the index, as it represents already an aggregate measure of satisfaction. Individual respondent HSI values were taken to calculate a mean HSI per site (Fig. 1). We normalized the index to a scale from zero (very unsatisfied) to 100 (very satisfied) for the purpose of comparing it to the other indices. We analyzed the impact of physico-chemical parameters on the mean HIS values per site to check for possible associations.

2.6. Data analysis

For all data analyses we used R v.4.0.4 (R Core Team, 2021) and RStudio (version 1.2.5019) with the packages "car" (Fox et al., 2007), "dplyr" (Wickham et al., 2015), "rstatix" (Kassambara, 2020), "caret" (Kuhn, 2009), and "beanplot" (Kampstra, 2008).

Before regression analysis, we excluded the predictors nitrite, ammonium, and carbonate hardness, as most values were either the same (i.e., very low variance) or below the detection limit. Sulfate was excluded because of two errors as mentioned above. We omitted chloride ($r = 0.93$), potassium ($r = 0.89$), and total hardness ($r = 0.82$) due to high bivariate correlation with electrical conductivity (Dormann et al., 2013). To analyze the associations between physico-chemical parameters (i.e., water quality) and biological quality, and human satisfaction, we employed the regularized regression method elastic net that simultaneously does variable selection and shrinkage of regression parameters. The elastic net can be viewed as a generalization of the lasso with a combination of the lasso and ridge penalty (Zou and Hastie, 2005). This regression method can be used even if the ratio of observations (17 sites) to predictors (6; flow rate, water temperature, pH, electrical conductivity, dissolved oxygen, and orthophosphate) is low (Zou and Hastie, 2005). To check for significant differences of the survey responses between the survey sites and between demographic groups (i.e., gender, occupation, and age), we used the response values for the perceived quality of drinking water, irrigation water, and crop production, as well as mean satisfaction for each site. We used ANOVA for homogeneous and Welch's ANOVA for heterogeneous variances, followed by a Tukey's HSD or Games-Howell post-hoc test, respectively. Associations between WQI, BQI, overall satisfaction HSI as well as its elements were analyzed using Pearson's and Spearman's correlation coefficients. See Fig. 1 for match between ecological and survey sites.

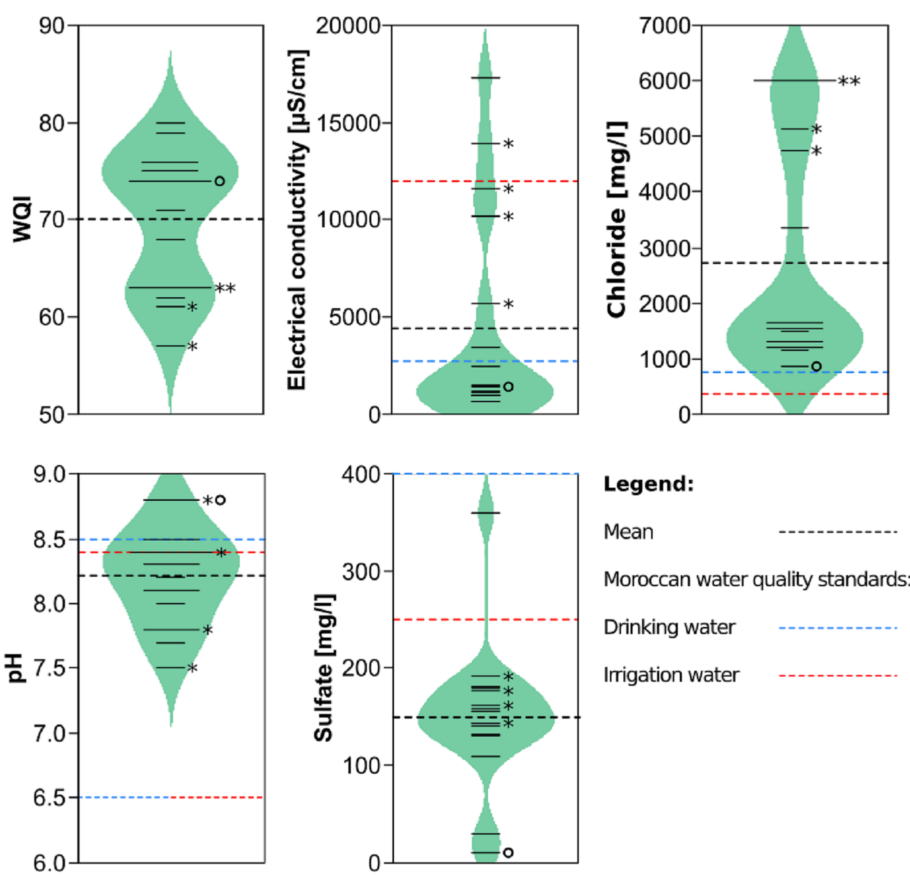

Fig. 2. Beanplots (Kampstra, 2008) showing the distribution of values for the WQI and the parameters where water quality standards were exceeded (electrical conductivity, chloride, pH, and sulfate). The circle indicates the site located in the Middle Draa; asterisks indicate the four sites in the Lower Draa, remaining sites are in the Upper Draa.

3. Results

3.1. River water quality

River water quality, as defined by the WQI, was good in 16 and moderate in one site (Table S1). Water quality was lowest in the Lower Draa (Fig. 2), and two tributaries in the Upper Draa. Low WQIs were mainly caused by very high electrical conductivity levels exceeding maximum admissible values by Moroccan water quality standards for drinking water (MAVDs) in six, and for irrigation water (MADIs) in two of those sites (Fig. 2). Chloride exceeded MAVDs and MADIs in all sites, with highest values in the same abovementioned sites, while pH exceeded both standards in two sites (Fig. 2). Sulfate exceeded MADI in one site. All other parameters met water quality standards, with values often close to or under detection level (Table S1).

3.2. Biological quality

3.2.1. Macroinvertebrates

Sites located in the Middle and Lower Draa showed low values for most metrics, as reflected in the BQI (Fig. 3). Only for %EPT the value of the Middle Draa is located above the mean.

In the best-fit model as selected by the elastic net (lambda = 4.52, intercept 51.2), altitude and flow rate showed a positive, electrical conductivity negative association with the biological quality index (BQI), explaining 60 % of the variation (Table 2).

Table 2
Results of elastic net for the biological quality index (BQI) and human health index (HSI) showing parameter estimates of all included variables, lambda, and coefficient of determination (R^2).

Parameter	Estimate BQI	Estimate HSI
Intercept	51.2	53.4
Altitude	6.6	4.1
Flow rate	6.4	0
Water temperature	0	−0.8
pH	0	−5.2
Electrical Conductivity	−0.04	−1.8
Dissolved oxygen	0	0
Nitrate	0	3.5
Orthophosphate	0	0
lambda	4.52	5.3
$\mathbf{R^2}$	0.6	0.75

3.3. Human well-being

Responses were similar across gender and occupation (Table S3). Higher age was associated with a lower rating of drinking water quality, lower health status, and lower satisfaction, however, showing very low effect sizes for drinking water quality and satisfaction (Table S3).

3.3.1. Water and crop quality

Water quality for drinking and irrigation as well as crop quality were rated generally good in the Upper Draa (Fig. 4). In the Middle Draa, people were rating irrigation water and crop quality less good than in the Upper Draa. People using treated groundwater through taps rated drinking water quality 48 to 60 percent higher in the Middle and Lower Draa respectively compared to untreated groundwater, whereas the quality of truck delivered water was rated lower than untreated groundwater. There were no differences in the rating of irrigation water and crop quality between the use of groundwater and water from rivers and springs in the Upper and the Middle Draa (Table S4). Clearer differences between the ratings were observed in the two villages of the Lower Draa (Table S4).

Water was perceived by people to be sometimes salty in 27 % of the sites of the Upper Draa, whereas the others did not perceive water to be salty. In the Middle and Lower Draa, 59 and 50 %, respectively, perceived water to be salty, with in total 39 and 29 %, respectively, stating that they experience it to be salty often.

3.3.2. Health status

No differences were found in how people perceived their health status throughout the Draa River basin, with a total mean of 7.3 (SD = 1.4) on a scale from 1 to 10 (Table S4). Of the respondents 8, 18 and 54 % in the Upper, Middle, and Lower Draa, respectively, indicated that the quality of water influences the health of people, of which 75, 89 and 46 % said that this effect is predominantly bad for the health status. Only four percent of people in the Upper Draa, but 25 and 54 % in the Middle and Lower Draa, respectively, reported physical diseases that they attributed to water salinity. While in the Upper Draa, physical diseases were only experienced sometimes, 14 and 54 % of those who experienced it in the Middle and Lower Draa stated that they occur often. 34%, 89% and 38% reported emotional distress due to water salinity and/or scarcity in the Upper, Middle, and Lower Draa, respectively.

3.3.3. Human satisfaction

Except for satisfaction with health care, with which respondents were generally unsatisfied, all other aspects of satisfaction followed a similar pattern of between-subbasin differences (Fig. 5, Table S5), with differences being less strong in overall life satisfaction. The Upper Draa had the highest mean response values for people being predominantly satisfied, significantly higher compared to the Middle Draa where they are predominantly unsatisfied to very unsatisfied. Mean response values of the Lower Draa were in between the other subbasins, however showing a very high variance caused by highly different response values

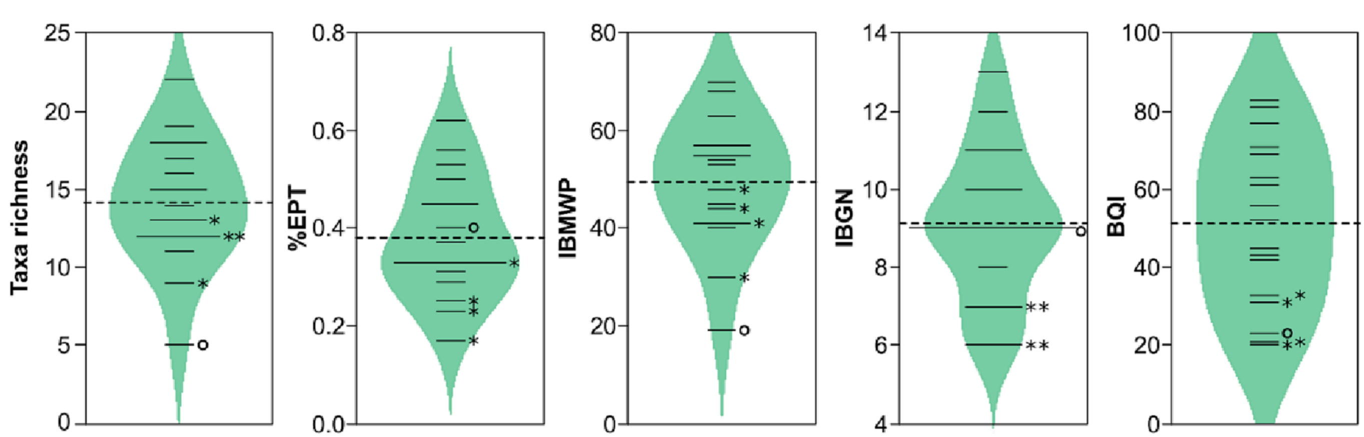

Fig. 3. Beanplots showing the distribution of values for the biological quality metrics and the BQI. The dashed line shows the mean. The circle indicates the site located in the Middle Draa; asterisks indicate the four sites in the Lower Draa, remaining sites are in the Upper Draa. For abbreviations see section 2.4.

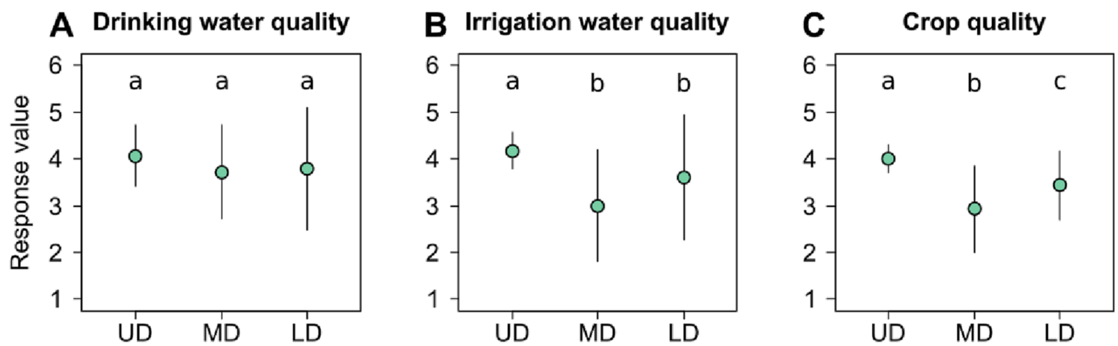

Fig. 4. Response values from 1 (very bad) to 6 (excellent; see Table S2) with SD for the Upper (UD, n = 101), Middle (MD, n = 56), and Lower Draa (LD, n = 24) for drinking water quality (A), irrigation water quality (B) and crop quality (C). Mean values of sub basins not sharing a lower-case letter are significantly different ($p < 0.05$).

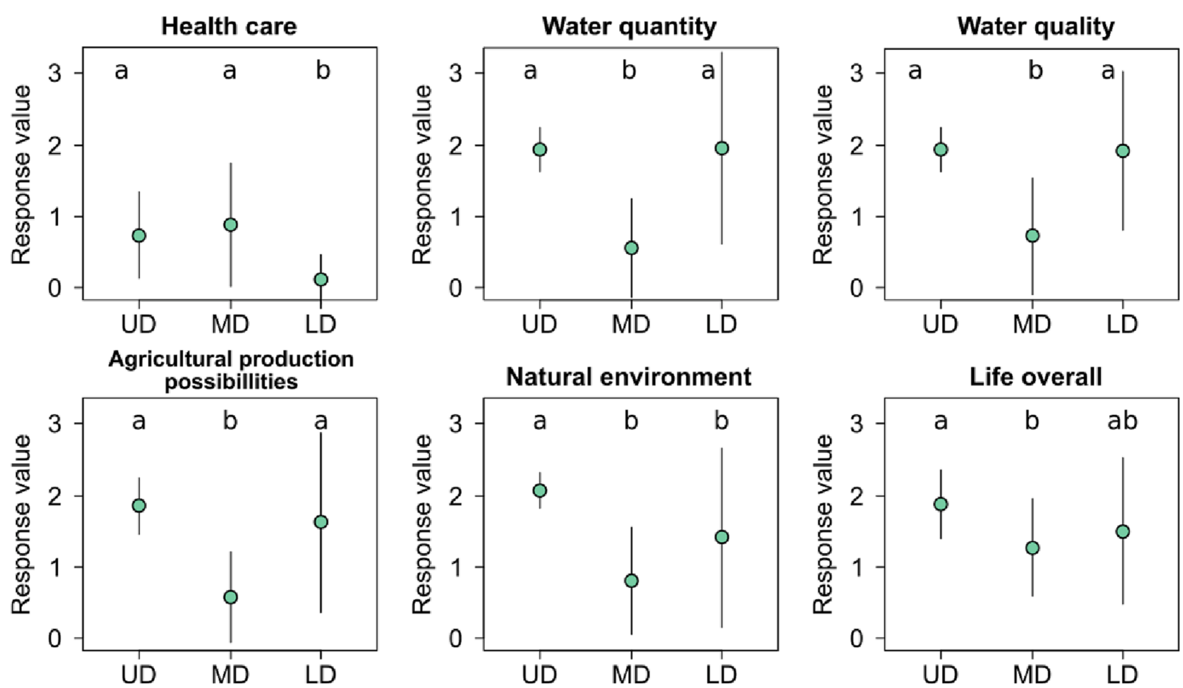

Fig. 5. Response values from 0 (very unsatisfied) to 3 (very satisfied; see Table S2) with SD for the Upper (UD, n = 101), Middle (MD, n = 56), and Lower Draa (LD, n = 24) for satisfaction with different aspects. Mean values of sub basins not sharing a lower-case letter are significantly different ($p < 0.05$).

between the two survey sites of Akka and Mrimima. This is also reflected in the HSI values (Fig. 6), with the people in the Upper Draa showing generally higher HSI values, except for the high variance in the Lower Draa (Figure S1).

In the best-fit model as selected by the elastic net (lambda = 5.3, intercept 53.4), altitude and nitrate showed a positive, water temperature, pH, and electrical conductivity a negative association with the human satisfaction index (HSI), explaining 75 % of the variation (Table 2).

3.4. Comparison of WQI, BQI, and HSI

The WQI was correlated with the BQI (Pearson's $r(15) = 0.6$, $p = 0.01$) in the 17 ecological sites (Fig. 7). In the 11 survey sites, the HSI was only weakly, i.e. not significantly, correlated with BQI (Pearson's $r(9) = 0.5$, $p = 0.11$), and not with WQI (Pearson's $r(9) = 0.25$, $p = 0.45$). Values for the Upper Draa were generally high compared to the other sites (Fig. 7). The individual components of satisfaction included (mean values per site) in the HSI were not significantly correlated to the WQI and BQI, either, except for satisfaction with the environment that correlated with BQI (Table S5).

4. Discussion

4.1. Water quality and quantity

We found that the water quality index of rivers in the Draa River basin is mainly determined by salinity. Sites with higher electrical conductivity and higher chloride concentrations scored lower in water quality index values and concentrations often exceeded maximum admissible values for human consumption (Royaume du Maroc, 2006) and irrigation (SEEE, 2007). This is in accordance with our first hypothesis. Low values of other parameters like phosphate indicate low pollution of the river water. This may be explained by fertilizers being rarely used in the mainly traditional farming that is conducted in the Draa River basin (Ou-Zine et al., 2021). This result should be interpreted with caution as other components of water quality that may indicate pollution such as BOD5, DOC, total phosphorus, and fecal coliforms, were not determined. With further primary salinization due to increasing aridity (Beck et al., 2018; Williams, 1999) and ongoing secondary salinization, especially in

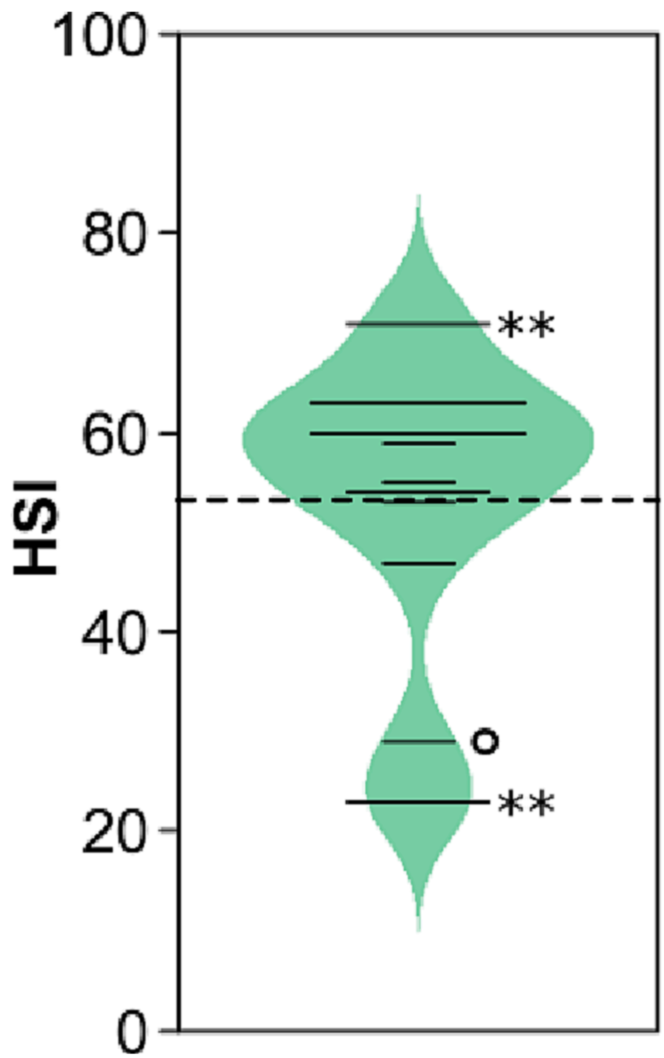

Fig. 6. Beanplot showing the distribution of values for the mean HSI (Human Satisfaction Index) per site. The dashed line shows the mean overall. The circle indicates the site located in the Middle Draa; asterisks indicate the four sites in the Lower Draa, remaining sites are in the Upper Draa. Compare Figure S1 for individual respondent HSI values.

the Middle and Lower Draa area (Warner et al., 2013), river water quality is likely to further degrade in the future.

The rating of the quality of water resources by respondents was largely consistent with the measured river water quality in terms of salinity, with most people in the Lower Draa region reporting poorer water quality and perceiving the water to be salty. Besides river water, groundwater can be affected by high and increasing salinity (Warner et al., 2013), limiting access to usable drinking and irrigation water. However, treatment of drinking water (e.g., ONEE tap water, mainly pumped from aquifers to water towers where it is treated) could explain the little differences of perceived drinking water quality in the three sub-basins. Perceived irrigation water quality was lower in the more saline and dry Middle and Lower Draa. Salinity levels well below the maximum admissible values for irrigation water of 12 mS/cm (SEEE, 2007) can already drastically reduce the growth and yield of salt-tolerant plants such as date palms (Tripler et al., 2011). While river water is used for irrigation in the Upper Draa, groundwater is mainly used in the Middle and Lower Draa, because river water is only available after dam releases or rain events or is too saline. Wells are deepened, or new ones are constructed (Berger et al., 2021), leading to increasing over-exploitation of aquifers (Hssaisoune et al., 2020). The increased water salinity and scarcity, among other factors (Dessu et al., 2014), may explain the dissatisfaction with water quality and quantity in the Middle and Lower Draa, as we saw associations of the human satisfaction with altitude, electrical conductivity, and water temperature, though not with flow rate. However, as water quality was only investigated at one site in the Middle Draa and the other sites were dry during the sampling period, the transfer of this result to the entire sub-basin should be treated with caution. With increasingly dry climate (Beck et al., 2018; Tramblay et al., 2018), and intensive cultivation of water-demanding crops such as watermelons (Hssaisoune et al., 2020; Karmaoui et al., 2016), river ecosystem health and human well-being may be further compromised in the coming decades (Karmaoui et al., 2019).

4.2. Biological quality

Biological quality of rivers in the Draa River basin was positively correlated with river water quality, with a general decline from up- to downstream. Additionally, biological quality was, in accordance with our second hypothesis, negatively associated with high electrical conductivity and low flow rate. High salinity limits the survival of non-adapted species (Kaczmarek et al., 2021), with only saline specialist or generalist species surviving (Arribas et al., 2019; Samraoui et al., 2021). Consequently, sensitive taxa such as various ephemeropterans, plecopterans, and trichopterans (EPT) were absent in the saline sites of the Lower Draa, which is reflected in the IBGN (Archaimbault and Dumont,

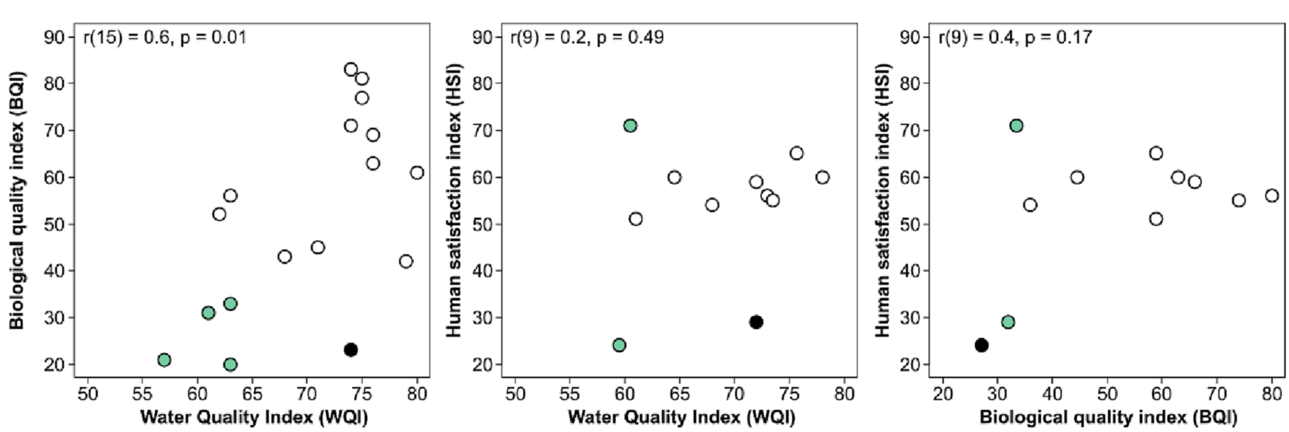

Fig. 7. Scatter plots showing correlations of river water quality index (WQI), biological quality index (BQI, and human satisfaction index (HSI). Green points = Upper Draa, black point = Middle Draa, white points = Lower Draa. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2010). Low flow rate and the periodical drying of rivers further reduce macroinvertebrate richness (Beauchard et al., 2003), as many species are adapted to high flow velocities (Samraoui et al., 2021) and cannot tolerate stress caused by low flow or standing waters, cannot withstand desiccation, or are unable to complete their life cycles during shorter wet periods of the river (Stubbington et al., 2017). The Middle Draa is separated from the Upper Draa by the El Mansour Eddahbi dam. Because the Middle Draa only leads flowing water after dam releases or heavy rain events, adaptations to short reproductive cycles and stagnant flow are required (Kaczmarek et al., 2021; Samraoui et al., 2021). An increase in salinity and aridity in the coming decades (Hssaisoune et al., 2020, Terink et al., 2013) and the construction of dams (Zarfl et al., 2015) may lead to the loss of salt-sensitive or non-adapted species (Kaczmarek et al., 2021), compromising biological quality of rivers.

As a specific multimetric macroinvertebrate index for assessing river water quality, biological quality, or ecosystem health is lacking in most of Africa (Edegbene et al., 2019), we decided to combine several metrics. Overall, the biological quality index had the lowest values for the high salinity sites in the Lower Draa and the stagnant pool in the Middle Draa, suggesting that it is suitable for indicating generally poor conditions for human use in saline and arid sites. This is also reflected in the low scores for these sites in the IBMWP and IBGN, which were created to assess biological water quality using indicator organisms (Jáimez-Cuéllar et al., 2002; Archaimbault and Dumont, 2010). While measured river water quality in the site of the Middle Draa was better than in the Lower Draa, as also reflected in the IBGN, intermittency and stagnant flow resulted in poorer biological quality values compared to the saline sites. Overall, the IBMWP and the IBGN seemed to be useful to detect poor biological water quality in saline and low flow sites of the Draa River basin compared to the other sites of the Draa, though they do not account for the reference state in terms of the natural state of saline streams and their communities. Although we found a correlation between river water and biological quality, we did not achieve a differentiation between the impact of primary and secondary salinization. Naturally saline streams may be unsuitable for human use and score low in commonly used multimetric macroinvertebrate indices, still, they can harbor unique communities. This indicates the need of specific indices and indicator organisms for saline and intermittent streams (Arias-Real et al., 2022), especially to detect anthropogenic impacts in natural stressed ecosystems (Gutiérrez-Cánovas et al., 2019). However, more research is needed to define indicator organisms for yet less studied regions (Gutiérrez-Cánovas et al., 2019) and to further develop indices to monitor climate change and anthropogenic impacts on naturally saline streams (Gutierrez-Cánovas et al., 2008).

Besides macroinvertebrates, other organisms such as riparian plant species (Mostakim et al., 2022) and vertebrates (Riesco et al., 2020) are affected by increasing primary and secondary salinization, as well as increasing aridity in the Draa River basin. A loss of species and a change of assemblage composition can disrupt ecosystem functioning (Lecerf and Richardson, 2010) and reduce ecosystem resilience to disturbance (Peterson et al., 1998). Conservation efforts should, however, not only focus on perennial freshwater rivers (Cañedo-Argüelles et al., 2016), but also take naturally saline and intermittent rivers and their adapted communities into account (Benamar et al., 2021; Velasco et al., 2006), as these species may have the potential to colonize anthropogenically salinized and intermittent rivers (Kefford et al., 2016). When important species are lost, other species, like invasive alien species, may proliferate (Clavero et al., 2015), potentially reducing human well-being (Jones, 2017) by for example an increase in species that transmit diseases to humans, such as mosquitoes (Ramasamy and Surendran, 2012) and pathogenic microorganisms (Keesing and Ostfeld, 2021). The aim to reduce the impact of secondary salinization on the river ecosystem and thereby safeguard human well-being may be compromised by future efforts to provide freshwater resources for drinking and irrigation water, like the cross-basin water transfers to other regions (El Moçayd, et al., 2020).

Asked about satisfaction with the natural environment, respondents were particularly dissatisfied along the mostly dry Middle Draa River. Other studies showed that healthy environments have a positive impact on satisfaction (Hartig et al., 2014). However, we found no correlation between human satisfaction overall and biological quality, which contradicts our third hypothesis. As the Middle Draa was mostly dry during the study period, we could not study water and biological quality in this area, where satisfaction was low. Data from more sites along the Middle Draa might have resulted in clearer trends. However, the missing differentiation between naturally saline and anthropogenically salinized rivers in biological quality indices, could have led to higher biological quality in natural high saline sites. Nevertheless, we found high levels of satisfaction mainly in the Upper Draa area where biological quality was typically good. While respondents in Akka in the Lower Draa showed highest satisfaction although living in an area showing low biological quality, we expect that this is related to their situation of high water availability with relatively low salinity levels for the Lower Draa region compared to their direct neighbors.

To maintain biological quality of rivers, measures are needed to limit increasing water demand and salinity. This can be achieved through water strategies, including improving irrigation efficiency (Hssaisoune et al., 2020; Jeddi et al., 2021) and reducing agricultural areas (Johannsen et al., 2016), especially for water-demanding crops such as watermelon (Karmaoui et al., 2016). Further intensive use of water resources would limit ecosystem functioning, leading to a loss of ecosystem services (Jakubínský et al., 2021) and thus may compromise river ecosystem health and human well-being.

4.3. Human health

Respondents reported generally good health conditions, while being unsatisfied with health care. Although differences in health status were low between sites in the whole basin and a clear association with biological quality was lacking, every tenth person reported negative effects from water, such as fecal-oral diseases and tooth discoloration. However, these effects are not necessarily caused by river water directly, as the bacteriological quality of water could be reduced between source and point-of-use (e.g., during central storage in water towers or storage in households; Wright et al., 2004). About half of the respondents from the Lower Draa reported physical diseases attributed to water salinity (e.g., kidney problems). Similarly, it was stated that salinity in drinking water might have a connection with kidney diseases like kidney stones and Rheumatism (SRTT (Sir Ratan Tata Trust Navajbai Ratan Tata Trust), 2011).

Besides physical diseases, nine out of ten respondents in the Middle Draa reported emotional distress caused by both water salinity and scarcity, whereas it was reported by about a third of respondents in the Upper and Lower Draa. Previous studies suggested that a low predictability of supply is a contributor to emotional distress (Stevenson et al., 2012, Wutich et al., 2016, Wutich and Ragsdale, 2008,). Several factors may explain the low predictability: natural factors include the decreased precipitation in the area, whereas the management-related ones mainly include flow regulation through the dam which is contributing to the intermittent characteristic of the Middle Draa. Other contributors to emotional distress could be caused by witnessing wetland degradation or destruction over the years (Larsen, 2012).

4.4. Human well-being

Aspects of human well-being covered in this analysis, namely water and crop quality, health status, and satisfaction (which includes satisfaction with health care, water quality and quantity, agriculture possibilities, environment, and life overall in the area) are partly provided by the river ecosystem in the three Draa sub-basins. However, we did not find a significant correlation of human satisfaction with the water and biological quality indices, with only the satisfaction with the conditions of the natural environment showing a positive correlation with the biological quality. River naturalness positively affects health and well-being among individuals, while a disconnection from nature may have detrimental effects on human satisfaction, as well as contributing to an unhealthy environment (Kaplan et al., 1989, Kaplan, 2001; Nasar, 2000; White et al., 2010). Similarly, our results indicate that respondents in the Upper Draa were predominantly satisfied with the natural environment, in contrast to the Middle Draa where respondents expressed missing the riverscape for years. While we found a correlation of the satisfaction with the conditions of the natural environment and aspects regarding water quantity and quality as well as agriculture, satisfaction with health care showed no correlation with those aspects. Other important intangible aspects of human well-being require further research for the Draa and other areas (e.g., spirituality, identity, cognition). When considered, these may provide stronger associations between the state of the ecosystem and human satisfaction and well-being. Our knowledge could be advanced by studies with a more comprehensive perspective that assesses how the different constituents of well-being benefit from nature.

4.5. Conclusion

Our findings indicate that high salinity levels and low water flow are reducing the water and biological quality of rivers in the Draa River basin. However, as current biological indices fail to discriminate between naturally saline and anthropogenically salinized rivers and, thus, potentially assigning a too low biological quality to naturally saline rivers, specific indices would be required for better assessment of their status. Our study suggests direct and indirect relationships between the state of the river ecosystem and human well-being, such as saline river water directly causing human emotional distress and decreasing satisfaction. However, several correlations were much weaker than hypothesized or non-existent. We suspect that the relationship can be masked by additional factors such as the cultural background or specific local needs or water usages so that more comprehensive surveys with more detailed and open interview questions and complex statistical tools may be required to find those associations. In addition, a larger sample size would increase the capacity to detect relationships. Targeting countries of the Global South is crucial, as these are particularly vulnerable to the effects of climate change on their nature, economy, and society, in particular on water supply for nature and humans. In this context, to improve human well-being, policies and action plans should consider the interdependence between ecosystems and their inhabitants.

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CRediT authorship contribution statement

Nils Kaczmarek: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Imane Mahjoubi:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing. **Mokhtar Benlasri:** Investigation. **Maren Nothof:** Methodology, Validation, Formal analysis, Investigation. **Ralf B. Schäfer:** Methodology, Validation, Formal analysis, Writing – review & editing, Supervision, Funding acquisition. **Oliver Frör:** Methodology, Validation, Writing – review & editing, Supervision, Funding acquisition. **Elisabeth Berger:** Conceptualization, Methodology, Validation, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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