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Disentangling ecosystem services perceptions from blue infrastructure around a rapidly expanding megacity

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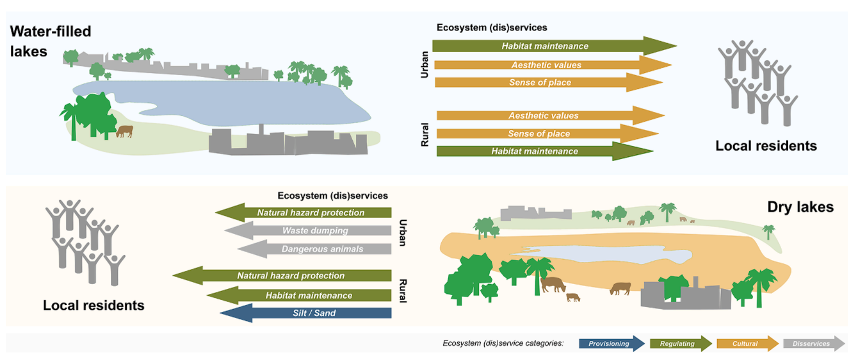
HIGHLIGHTS

- Urban lakes are key landscape elements, supplying manifold ecosystem services (ES).
- Lakes were valued more for regulating ES than for cultural and provisioning services.
- Provisioning ES were more important in rural areas, disservices more in urban areas.
- Urban planning needs to regard the disparate roles lakes play to residents.

GRAPHICAL ABSTRACT



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ABSTRACT

Restoring, maintaining, and developing green and blue infrastructure (GBI) in cities is a key strategy to safeguard ecosystem services and human well-being under conditions of rapid urbanization. Developing "blue infrastructure" is a new concept, but there are diverse historically grown water management systems that have the potential to inform contemporary debates about GBI. The aim of this study is to identify how local people perceive ecosystem services from a historically grown type of blue infrastructure (lakes), considering multiple interactions between ecosystem services categories, lake types, rural-urban environments, and sociodemographic characteristics of respondents. We performed a photo-elicitation survey among 536 residents along two urban-rural gradients in Bengaluru (Bangalore), India, asking about perceptions of ecosystem services from water-filled and dry lakes, challenges, and management options. Our results showed that blue infrastructures provide a multitude of ecosystem services that benefit people, with regulating and cultural services standing out. Both water-filled and dry lakes proved important for local people, but they supply different types of ecosystem services. While urbanisation level had a significant influence on how people perceive different ecosystem services

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from lakes, sociodemographic differences in the assessments were relatively low. Proposed management options departed substantially from those commonly proposed in the literature. We conclude that lakes are of high societal importance compared to their small surfaces, given their capacity to provide a host of ecosystem services. They should become keystone structures of GBI development for sustainable urbanisation in the Global South.

1. Introduction

With 55% of the world's population now living in cities, and a share of 68% of urban population estimated for 2050 (United Nations, 2019), urban areas play a central role in global sustainability (Elmqvist et al., 2021). While urbanization has been most expressed in Europe and the Americas in the 20th century, Asia and Africa are now the world regions where urbanization is advancing most rapidly (Nagendra et al., 2018). The massive expansion of urban areas, in particular of impervious surfaces that cover more than 40% of urban land (Benedict & McMahon, 2006), presents fundamental challenges to sustainability and environmental justice, such as decline in human well-being, alteration of ecosystems and their capacity to provide ecosystem services, or degradation of the basic physical and organization structures needed for society (Thapa et al., 2021). At the same time, urbanization also offers opportunities for the development of more liveable, healthy, and resilient cities (Elmqvist et al., 2015).

Restoring, maintaining, and developing green and blue infrastructure (GBI) in cities is frequently promoted as a key strategy to safeguard ecosystem services and human well-being under conditions of rapid urbanization (Elmqvist et al., 2015). GBI as an umbrella term comprises networks of natural and semi-natural areas, with other environmental features, designed and managed to deliver a wide range of ecosystem services (Hansen & Pauleit, 2014). It integrates "green" spaces and features, such as parks and street trees, with "blue" elements, such as watercourses and lakes (Amaral et al., 2021). The notion of a green infrastructure was first articulated by Benedict and McMahon (2002) as a strategic approach to land conservation that addresses the ecological and social impacts of urban sprawl in the USA. Worldwide, this approach has now become a planning strategy for the enhancement of urban ecosystems (Madureira & Andresen, 2014). It stresses a people-based perspective on planning and connecting cities with their peri-urban and rural surroundings (Gulsrud et al., 2018). GBI approaches hold immense promise for better communicating ecosystem services and biodiversity conservation as well as better prioritizing, integrating, and structuring implementation strategies (Beery et al., 2017; Lafortezza et al., 2013).

This study focuses on the water-related components of GBI. While the "green" components have been in the foreground of most GBI strategies, the "blue" infrastructure is also of utmost importance to cities, as many of these experience severe water-related sustainability challenges, such as drought, flooding, or shortages of clean water (Haase, 2015). Blue infrastructure in cities comprises lakes, ponds, brooks, rivers, wetlands, artificial channels, and other urban waterbodies (O'Donnell et al., 2021). Water-related sustainability challenges are particularly predominant in the Global South, where urban growth frequently outstrips sewerage infrastructure (Nagendra et al., 2018). As a consequence blue spaces play a major role, both as recipients of untreated sewage (and therefore in spreading disease and pollution) and as providers of biological treatment of sewage (Haase, 2015).

A core underlying feature of GBI is multifunctionality. Multifunctionality (the ability to provide several ecosystem services on the same area, Hölting et al., 2019) is expected to contribute to different sectoral policy aims and meet the demands of a diversity of actors (Roe & Mell, 2013). For example, blue infrastructure approaches open up new ways to cope with the challenges of adapting urban landscapes to climate change, rapidly changing land-use patterns, and changing societal perspectives on biodiversity and ecosystem services (Lovell & Taylor, 2013). Blue infrastructure has great potential to foster biodiversity, ecosystem services such as climate regulation, air cooling, water storage, flood prevention, water purification, growth of particular crops, and the prosperity of cities, for instance by providing business opportunities (Haase, 2015; Lamond & Everett, 2019). The contributions of urban blue infrastructure to cultural ecosystem services such as outdoor recreation, tourism, sense of place, and aesthetic values have received particular attention (O'Brien et al., 2017). However, mere increment of water surfaces may not be helpful, as strategic placement of GBI components is needed, for example for flood prevention purposes (Nickel et al., 2014).

To better understand the role of GBI for improving human well-being in cities, this paper addresses people's perceptions of the ecosystem services that GBI provide. Perceptions define whether and how people recognise the supply of ecosystem services (Spangenberg et al., 2014; Veerkamp et al., 2021; Zoderer et al., 2019) and play a critical mediating role between the actual supply of services and people's demand and use thereof. From an environmental justice perspective, it is vital to take variations in people's perceptions into account. Without a disaggregated picture that makes differences in perceptions visible, urban planning processes are likely to exclude relevant stakeholders and produce unfair outcomes (Andersson et al., 2019). The study of perceptions across different social groups thus not only provides a direct contribution to "recognition justice", but also creates an important foundation for achieving "procedural" and "distributive" justice in the planning of GBI (Langemeyer & Connolly, 2020). Depending on levels of knowledge, use, experiences, and needs, there can be substantial differences in how individuals perceive ecosystem services (Claris Fisher et al., 2021; Haase, 2015). Previous research has demonstrated that such differences may further be accentuated by factors such as age, gender, ethnicity, and other socio-cultural and socio-economic conditions (Andersson et al., 2019). In addition, perceptions of ecosystem services may also vary across space, most notably across rural–urban gradients (Larondelle & Haase, 2013), and are therefore strongly affected by urbanization processes.

While social-ecological research has studied urban GBI in many parts of the world, several important research gaps remain. First, GBI has overwhelmingly been conceptualized as a contemporary approach, while the legacies of historically grown GBI remain neglected (Deak & Bucht, 2011). Exploring these time-tested indigenous land and water management systems across the world has potential to inform contemporary GBI development (Vierikko et al., 2016). Second, existing studies have been dedicated much more intensively to "green" and less to "blue" components of GBI. They also more frequently addressed the Global North than the Global South, where planning and policymaking are often ignorant of the benefits of GBI (Amaral et al., 2021; Nagendra et al., 2018). Third, much of the research on GBI has centred on urban areas (Li et al., 2017), while its role to connect urban to rural areas has been less intensively studied. Fourth, studies have been dedicated to understanding spatial–temporal dynamics, design, planning, stewardship, and governance of GBI (Andersson et al., 2019), and much less on individual perceptions of ecosystem services and related aspects of ecosystem services recognition (Veerkamp et al., 2021). The present study aims to fill these gaps by identifying the capacity of lakes to provide important ecosystem services (and disservices) as perceived by diverse stakeholders across a rural–urban gradient around Bengaluru, India. We ask the following research questions:.

- Which ecosystem services do local people associate with lakes?

- How do people's perceptions of ecosystem services differ between rural, transitional, and urban areas?
- Which factors, such as age, caste, or education, do influence the perceptions of ecosystem services among local people?
- Which personal challenges and management options do local people express around lakes?

While our study site Bengaluru is reaching an advanced stage in the rural–urban transition process, many other emerging megacities in India and elsewhere are undergoing similar developments (D'Souza & Nagendra, 2011). The insights from this case study may thus be useful for understanding and managing the ecosystem services of blue infrastructure in similar settings in other parts of the world.

2. Material and methods

2.1. Study area

Bengaluru is India's third largest city and the capital of the state of Karnataka. The city (12°58′N, 77°35′E) is located on the Deccan plateau of South India, with an average altitude of 920 m above sea level. Its Eastern part is flat, while the Western region of Bengaluru is undulated. Mean annual rainfall is around 700–900 mm, and the monsoon season extends from June to October. The greater Bengaluru area has a population of 12.8 million, with an annual growth rate of around 3.6%. The administrative boundaries of the city have similarly increased, from 69 km^2 in 1949 to 761 km^2 in 2007 (Mundoli et al., 2015). Once known as a "City of lakes" and the "Garden city", urbanization has put strong pressures on the natural spaces in the area (Nagendra & Ostrom, 2014). Bengaluru city is surrounded by transitional and rural villages that form a low-density sprawl. Substantial growth has also been experienced by several secondary towns around Bengaluru that developed industries, services, and market infrastructure (Steinhübel & von Cramon-Taubadel, 2021). Such development, together with rapid establishment of IT hubs, a subsequent speculative growth in real estate prices, and a persistence of agriculture and other rural land uses, has led to rural, transitional, and urban lifestyles existing side by side (Mundoli et al., 2015). These processes resulted in highly unequal growth rates and contested access to the GBI of the region (D'Souza & Nagendra, 2011). As an emerging megacity in the Global South, Bengaluru showcases key urbanization features such as rapid expansion, suburbanization, ecological and infrastructural overloads, uncontrolled development, vegetation clearing, and heterogeneous land use mosaics (Patil et al., 2018).

Bengaluru provides a particularly relevant case of blue infrastructure that is of anthropogenic (not: natural) origin and that has been developed over long time spans. Located in an area short of perennial rivers and prone to droughts, human settlements around Bengaluru have for centuries relied on an extensive network of freshwater reservoirs for water supply (Nagendra, 2016). The region was reported to have around 20,000 lakes in the 19th century, and some lakes are more than 1000 years old. Today, Greater Bengaluru has more than 200 lakes, while the recent number of lakes in its hinterlands is much greater, but unknown (Nagendra, 2016). The largest one, Bellandur lake, covers an area of 357 ha (Sen et al., 2020), while the smaller ones are around one or two ha in size. Overall, water bodies (including lakes, tanks, reservoirs etc.) covered less than 1% of the area in Bengaluru City Corporation with a 10 km buffer in 2012 (Aithal et al., 2013), whereas in the urban fringes extending to a 15 km radius from the Corporation boundaries they accounted for 3% of the land cover in 2018 (Nagendra & Hanjagi, 2019). The lakes are locally called "katte" (small lakes originally for water uses of humans and livestock) and "kere" (larger lakes used for irrigation) (Brinkmann et al., 2020). Lakes were created by damming streams to store the water from monsoon rains. They comprise sluices to regulate irrigation and weirs to control downstream flows (Enqvist et al., 2016). Local communities actively maintained the lakes; they regularly desilted lake beds and kept catchment areas free from encroachment. The lakes used to be so important to villages that many of them were named after their lakes (Brinkmann et al., 2020). Typical functions and uses of the lakes were groundwater recharge, provision of drinking water, irrigation of agricultural crops, fishing, fodder collection, livestock grazing, and cultural activities (Enqvist et al., 2016; Nagendra & Ostrom, 2014).

Most lakes in the rural and transitional areas are rainfed and turn dry during summer months. In the urban spaces of Bengaluru, lakes mostly remain perennial from continuous discharge of sewage and effluents. While water-filled lakes are used for fishing, bathing livestock, washing clothes etc., in dry state they support important functions such as foraging for wild greens from their beds and absorbing excess runoff during monsoons. Given these distinct uses, we categorised lakes as "dry" and "water-filled" in this study to understand societal perceptions on their ecosystem services.

In past years, development pressures increasingly caused lakes to be polluted with domestic and industrial waste, drained, partially or totally filled, and converted into commercial, industrial, and residential settlements (Nagendra & Ostrom, 2014). This has negatively affected water availability for local citizens and livelihoods of long-standing users (Mundoli et al., 2015). Demands for lake ecosystem services have also changed, shifting away from irrigation purposes toward recreational and sometimes commercialized leisure uses (D'Souza & Nagendra, 2011). At the same time, governance systems of the lakes underwent transformations from often century-old community-based management to state management. Long-standing and new as well as rural and urban lake users show increasingly divergent perceptions of the lakes (D'Souza & Nagendra, 2011). The impacts of urbanization on the lakes are rather heterogeneous. While in the majority of cases, transformations have dissociated local people from the benefits and uses of the lakes, these modernization processes have in some cases been emancipatory, liberating underprivileged castes from exploitative practices in the construction, use, and management of the lakes (Sen & Nagendra, 2020). In some of the more urbanized lakes of the area, citizen-driven environmental stewardship together with state initiatives have triggered successful restoration efforts (Nagendra & Ostrom, 2014; Sen & Nagendra, 2020).

In this study, we focus on two areas that form a common research space of a larger Indo-German research project titled "Social-ecological systems in the Indian rural–urban interface". These two areas reach out from urban Bengaluru into the rural hinterlands (Fig. 1, Appendix A). The Northern area forms a 50 km × 5 km rectangle in between the traffic axes to Doddabalapur and Devanahalli. The area in the Southwest covers a 300 km^2 area along Kanakapura Road, from the Vrishabhavarthi water reservoir in the West to Bannerghatta National Park in the East (Hoffmann et al., 2017). The two areas cover the complexity of urban, transitional, and rural spaces and include more intensive land uses (in the Northern area, which is influenced by Bengaluru's international airport) and more diversified land uses (in the Southwestern area). Waterbodies were estimated to cover 0.06%-1.42% of the area in the Northern side and 0.09%-2.28% in the Southwestern area in 2016 (Patil et al., 2021).

2.2. Photo questionnaire

At the centre of our study was a combination of two photos of a typical water-filled and a dry lake (Fig. 2, Fig. 3) with a paper-based questionnaire to elicit people's perceptions of lakes. Photo elicitation has been frequently used as a tool to trigger respondents' feedback, sharpen memories, reduce misunderstandings, and overcome research fatigue (Harper, 2002). The photos were taken by one of the authors in February 2020 in the study area. We tried to keep the light, weather condition, the angle, and the distance to the lakes consistent. The photos were colour-printed in A2 size and laminated.

The questionnaire was composed of three parts. The first part covered sociodemographic characteristics of respondents, including age, gender, caste, and education. The second part presented a list of

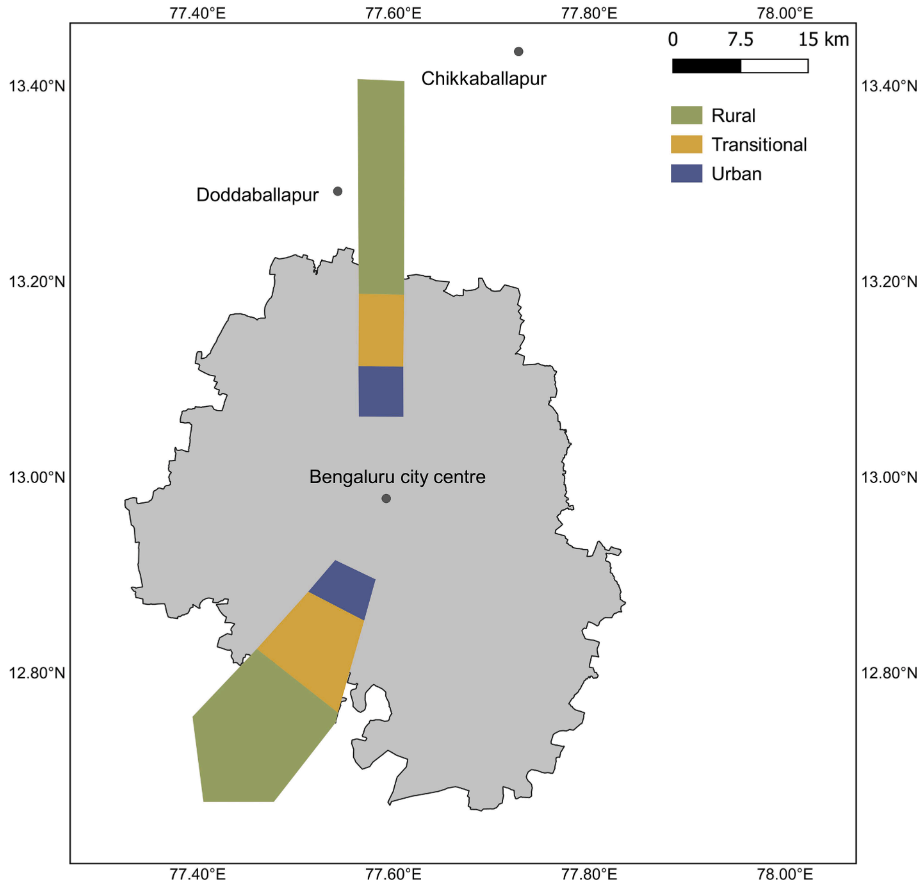

Fig. 1. Map of the two study areas in the North and Southwest of Bengaluru.

Fig. 2. Image of a water-filled lake around Bengaluru, used in the photo-elicitation survey.

potential ecosystem services and disservices from lakes. Respondents were asked to rate the importance of each lake for the provision of these services and disservices, based on their livelihood needs and experiences. Ecosystem services were selected on the basis of the categories of the Millennium Ecosystem Assessment (2003) and then adapted to local conditions after carrying out informal interviews with local experts and lake users in the area. They were grouped into categories of provisioning, regulating, and cultural ecosystem services (Table 1). Conceptually, we investigated interactions between ecosystem services and local people by enquiring about ecosystem services perceptions (Scholte et al.,

Fig. 3. Image of a dry lake around Bengaluru, used in the photo elicitation survey.

Table 1
Classification and description of ecosystem services and disservices used in the survey.

Ecosystem services category	Individual ecosystem services or disservices	Description
Provisioning services	Food/Feed	Possibility for fishing, collecting food for people and livestock, grazing
	Medicinal resources	Possibility of collecting medicinal plants/leaves
	Irrigation water/ Household water	Possibility to extract irrigation water or to perform household chores
	Silt/Sand	Possibility to extract silt for fertilizing crop fields or sand for construction
Regulating services	Habitat maintenance	Support of wild animals, birds, or a diversity of plants
	Air/Climate regulation	Provision of shade and coolness or air purification
	Water purification	Water regulation/purification
	Natural hazard protection	Protection against natural hazards such as floods
Cultural services	Social relations	Possibility to spend time with other people or to join social events
	Aesthetic values	Possibility to enjoy natural beauty or scenery
	Spiritual values	Possibility for practicing belief/ religion or meditation/spirituality
	Sense of place	Possibility to feel at home or to build a personal identity to this place
Ecosystem disservices	Unpleasant odours	Smells from rotting organic matter
	Dangerous or poisonous animals	Presence of dangerous or unpleasant animals e.g. snakes or rodents, breeding grounds for disease-spreading mosquitoes
	Waste dumping	Open defecation/dumping of garbage and/or discharge of sewage/effluents
	Space for antisocial activities	Consumption of alcohol/drugs etc. in groups, security threats for women

2015). We did not include supporting services (e.g., primary production, nutrient cycling) as this category of ecosystem services contributes only indirectly to human well-being (Abson & Termansen, 2011). For this reason, supporting services are poorly perceived by people and difficult to measure through socio-cultural valuation (Brown et al., 2012). As our exploration indicated that lakes do also exert nuisance on local people, our survey included an ecosystem disservices category. Here, we used the classification framework by Shackleton et al. (2016) as a starting point and selected four locally relevant disservices. Respondents assessed ecosystem services supply separately for water-filled and for dry lakes, indicating their answers on a Likert-type scale ranging from 1 ("not important") to 5 ("very important"). The third part of the questionnaire comprised open questions. One question asked about the challenges that limit or stop the use of lakes in the respondents' villages. Another question was about suggestions for better management of the lakes. The questionnaire was pretested among residents (not included in our sample) in the two study areas in January 2021 and modified according to these experiences. We tried to elicit respondents' perceptions of lakes in a comprehensive and complementary way: While the questions on pre-defined ecosystem services and disservices allowed for a generalizing perspective, the open questions facilitated a context-specific perspective that may reflect a more holistic conceptualization of the relationship between people and lakes.

2.3. Data collection

Data collection was performed by locally recruited enumerators in January and February 2021. The survey population of this study comprised residents in the two study areas. These were selected in a two-step sampling procedure. First, each of the two areas was grouped into three strata (urban, transitional, and rural – as defined by the proportion of built-up area and the distance to the city centre) (Hoffmann et al., 2017). Approximately ten villages were randomly chosen in each of the 2 × 3 strata (total: 61 villages). These villages correspond to approximately 30% of villages in the two study areas. Second, approximately 10 households per village were targeted (Steinhübel & von Cramon-Taubadel, 2021). We had obtained lists of all households in the villages from the local health care centres (Anganwadi centres) and aimed to keep the number of households per village proportional to population numbers in each village. In each village, we selected households by a random sampling approach, based on caste, gender, and age. We strove to interview an equal number of women and men representing each household. We also aimed to keep distributions of age and caste in our sample close to those indicated in the 2011 Census of Karnataka. When a household was not available to respond to our survey, we randomly selected another household fulfilling the criteria of survey stratification. Our final sample comprised 536 households. Of this sample, 48% were men and 52% were women. Twenty-three percent of respondents were 18–29 years, 57% were 30–60 years, and 20% were >60 years old. Twenty-five percent of the respondents belonged to socially marginalized castes, either a scheduled caste (21%, also called "dalits") or a scheduled tribe (4%). Survey participants were visited and interviewed outside their homes. The interviews were carried out orally in Kannada language, which were then translated and noted down in English in the paper-based questionnaire-sheet. The enumerators informed respondents on the background and purpose of the survey and on rules regarding data use. They also presented the lake photographs and explained the meaning of the Likert scales. Respondents did not receive a financial compensation. A systematic self-assessment provided by the University of Kassel indicated that our survey should be performed in an ethically sensitive procedure, but the university's ethics board did not require formal ethical approval. We used ethical guidelines developed for the European Commission's Horizon 2020 Programme (European Commission, 2019) as guidance. A covid19 protocol was developed and strictly applied, prescribing for instance that all interviews were carried out in outdoor settings and in absence of direct physical contacts and that medical masks were worn throughout the interview process. We obtained informed consent verbally before performing the interviews. The dataset is available on the Zenodo open-access repository (Plieninger et al., 2021).

2.4. Data analysis

We used descriptive statistics (mean values and standard deviations) to display the respondents' perceptions of ecosystem services. We performed a Wilcoxon signed rank test to compare the perceived ecosystem services and disservices between water-filled and dry lakes, as well as a Kruskal Wallis test and Dunn's post hoc test (with Bonferroni correction) to compare the perceived capacity of each lake type to supply ecosystem services and disservices between rural, transitional, and urban areas. These statistics are reported in Appendices B, C, and D.

To test for factors influencing respondents' perception of ecosystem services and disservices, cumulative link mixed models (CLMM) were employed at the level of ecosystem service categories. Following the approach of Zoderer et al. (2016), we first used the classification of the Millennium Ecosystem Assessment (2003) to group all ecosystem services belonging to the same ecosystem (dis)service category together (see Table 1). In a second step, a separate CLMM was built for each ecosystem service category, while retaining perceptions of individual ES as units of analysis (i.e. for each model 4288 responses were considered as 536 respondents assessed four ecosystem services per category for two lake types). Respondents' sociodemographic background variables as well as the lake type, ecosystem service type, and the interaction between the two were included in the models as independent variables. To additionally test for the influence of rural, transitional, and urban environments on respondents' perception of each ecosystem services category and how this relationship changes depending on the lake type, we included urbanization level and its interaction with lake type as independent variables. Since each respondent assessed the supply of ecosystem services and disservices for both lake types, we included the respondents' ID as random effect (i.e. random intercept) in addition to the other independent variables considered as fixed effects in a hierarchical two-level model. To account for the ordinal measurement scale of the dependent variables (i.e. ecosystem services categories, ranging from 1 to 5), we employed CLMM with logit function and calculated the odds ratio (OR) of each variable. Positive effects (OR > 1) indicate that an increase in the independent variable relative to its reference category leads to an increase in the likelihood to perceive higher supply levels of the ecosystem services category, and negative effects (OR > 1) the opposite. Overall, the CLMMs were fit based on answers from 520 valid questionnaires. Model fit measures such as McFadden's and Cox & Snell's R^2 were further calculated for all four models. In addition, likelihood ratio tests were performed to test for the significance of the main effects of all independent variables considered in the CLMMs.

Responses to the two open questions were coded through inductive content analysis, using MAXQDA to elicit challenges and management options for the lakes. Challenges were grouped into three categories, separating between predominantly natural nuisances, predominantly social nuisances, and low usability of lake resources. Management options were coded by listing all suggestions made by the respondents and categorized into options related to lake surroundings and safety, to water storage and quality, and to accessibility and usability. We classified each response into one or more categories and reported frequencies of each theme (for those mentioned by ten or more respondents). To test for significant differences in people's perception of challenges among urban, transitional, and rural areas, Chi^2-tests were employed.

3. Results

3.1. Which ecosystem services do local people associate with lakes?

On average, lakes were appreciated more for their capacity to supply regulating ecosystem services ($\bar{x}$=3.52, SD = 1.72, water-filled lakes; $\bar{x}$=2.78, SD = 1.55, dry lakes) than for cultural ($\bar{x}$=3.33, SD = 1.82, water-filled lakes; $\bar{x}$=2.11, SD = 1.35, dry lakes) and provisioning services ($\bar{x}$=1.92, SD = 1.55, water-filled lakes; $\bar{x}$=2.05, SD = 1.59, dry lakes). In addition, both lake types were perceived less as a source of ecosystem disservices ($\bar{x}$=2.30, SD = 1.65, water-filled lakes; $\bar{x}$=2.27, SD = 1.63, dry lakes). The strongest significant differences in the perception of ecosystem services categories were found between the two lake types (Table 2): According to the CLMM models (Appendix E), regulating and cultural services as well as disservices were more likely to be associated with water-filled lakes than with dry lakes.

The perception of individual ecosystem services also varied strongly between water-filled and dry lakes (as indicated by the significant interaction term between ecosystem services and lake type), most notably for individual provisioning and regulating services, but also for cultural services (see high likelihood ratio statistics in Table 2 for ES × lake type). For instance, while habitat maintenance and aesthetic values were more likely to be associated with water-filled lakes, silt/sand extraction and natural hazards protection were more likely to be perceived in dry lakes (Fig. 4, Appendix B).

3.2. How do ecosystem services perceptions differ between rural, transitional, and urban areas?

The importance of water-filled and dry lakes as a source of ecosystem services and disservices significantly changed across the rural–urban gradient (Table 2, Appendix E). Water-filled lakes were appreciated more for their overall supply of ecosystem services (for all provisioning, regulating, and cultural services combined) in transitional areas ($\bar{x}$=3,16, SD = 1.82) than in rural ($\bar{x}$=2.77, SD = 1.85) and urban ($\bar{x}$=2.79, SD = 1.84) areas. Dry lakes, by contrast, were appreciated mostly in rural areas for their overall supply of ecosystem services ($\bar{x}$=2.46, SD = 1.55), followed by transitional ($\bar{x}$=2.28, SD = 1.41) and urban areas ($\bar{x}$=1.91, SD = 1.41). In addition, both water-filled and dry lakes were more strongly associated with disservices and less with provisioning services when located in urban areas (Table 3). Besides differences in the perception of ecosystem service categories, respondents perceived individual services and disservices from lakes with

Table 2
Results from likelihood ratio (LR) tests to test for the main effect of lake type, ecosystem services (ES), urbanization level, and respondents' background on the perception of each ecosystem service category. Significant effects are shown in bold.

	Provisioning services			Regulating services			Cultural services			Disservices		
	LR statistics	df	p value	LR statistics	df	p value	LR statistics	df	p value	LR statistics	df	p value
ES	**277.98**	**3**	**<0.001**	**66.83**	**3**	**<0.001**	**511.85**	**3**	**<0.001**	**123.57**	**3**	**<0.001**
Lake type	**12.32**	**1**	**<0.001**	**268.58**	**1**	**<0.001**	**719.21**	**1**	**<0.001**	1.55	1	0.214
Lake type × ES	**252.54**	**3**	**<0.001**	**343.53**	**3**	**<0.001**	**122.98**	**3**	**<0.001**	**18.47**	**3**	**<0.001**
Urbanization level	**41.67**	**2**	**<0.001**	**11.89**	**2**	**0.003**	**6.94**	**2**	**0.031**	2.81	2	0.246
Lake type × urbanization level	**32.62**	**2**	**<0.001**	**88.31**	**2**	**<0.001**	**38.97**	**2**	**<0.001**	**10.03**	**2**	**0.007**
Respondents' background												
Gender	**10.77**	**1**	**0.001**	0.00	1	0.953	**9.73**	**1**	**0.002**	0.09	1	0.760
Age	0.32	1	0.571	1.29	1	0.257	1.56	1	0.212	2.50	1	0.114
Education	1.96	3	0.580	6.46	3	0.091	0.66	3	0.882	5.69	3	0.128
Religion	**31.46**	**2**	**<0.001**	3.46	2	0.177	1.58	2	0.454	0.50	2	0.779
Caste	**15.31**	**3**	**0.002**	2.67	3	0.445	6.88	3	0.076	3.08	3	0.380
Occupation												
Agriculture	0.022	1	0.883	0.15	1	0.698	0.23	1	0.629	**6.77**	**1**	**0.009**
Daily wage labour	0.074	1	0.785	0.11	1	0.744	0.07	1	0.790	1.77	1	0.183
Services	1.83	1	0.176	3.43	1	0.064	0.01	1	0.924	0.67	1	0.414
Manufacturing	0.59	1	0.444	0.15	1	0.703	0.04	1	0.844	0.31	1	0.579
Retired	1.68	1	0.195	1.74	1	0.187	0.62	1	0.432	0.64	1	0.425
Length of residence	1.32	1	0.250	0.24	1	0.621	1.05	1	0.305	0.47	1	0.492

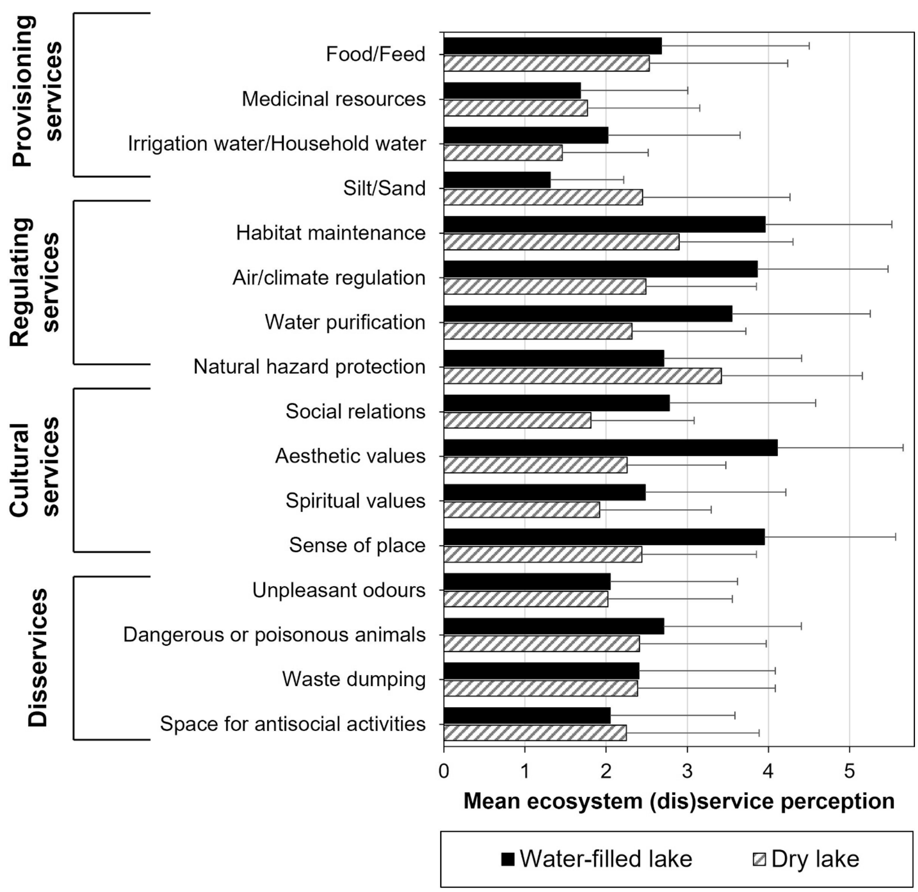

Fig. 4. Respondents' perception of individual ecosystem services and disservices from water-filled and dry lakes. Error bars indicate standard deviation (SD).

significant differences between rural, transitional, and urban areas (Fig. 5, Appendices C and D). Rural lakes were valued significantly more for the provision of food/feed, silt/sand extraction, habitat maintenance, and natural hazards protection (dry lakes) as compared to lakes located in transitional and/or urban areas. Lakes in transitional areas, by contrast, were appreciated significantly more for their supply of irrigation water/workspace (water-filled lakes) than those in the two other areas. Urban lakes were significantly more associated with unpleasant odours and waste dumping (water-filled lakes), and lower capacities to provide food/feed (water-filled lakes) as well as air/climate regulation and aesthetic values (dry lakes).

3.3. *Which factors do influence the perceptions of ecosystem services among local people?*

Sociodemographic differences in the perception of ecosystem

Table 3
Respondents' perception of ecosystem services and disservices categories from water-filled and dry lakes across rural, transitional, and urban areas. Mean values and standard deviations (SD, in brackets) are shown.

	Water-filled lakes			Dry lakes		
	Rural	Transitional	Urban	Rural	Transitional	Urban
Provisioning services	1.90 (1.53)	2.10 (1.63)	1.51 (1.26)	2.23 (1.64)	2.02 (1.59)	1.51 (1.21)
Regulating services	3.27 (1.81)	3.81 (1.58)	3.60 (1.65)	2.95 (1.51)	2.73 (1.54)	2.35 (1.58)
Cultural services	3.15 (1.87)	3.57 (1.74)	3.27 (1.83)	2.19 (1.36)	2.10 (1.34)	1.85 (1.29)
Disservices	2.20 (1.66)	2.24 (1.57)	2.85 (1.69)	2.24 (1.62)	2.21 (1.58)	2.53 (1.68)
All ecosystem services	2.77 (1.85)	3.16 (1.82)	2.79 (1.84)	2.46 (1.55)	2.28 (1.41)	1.91 (1.41)

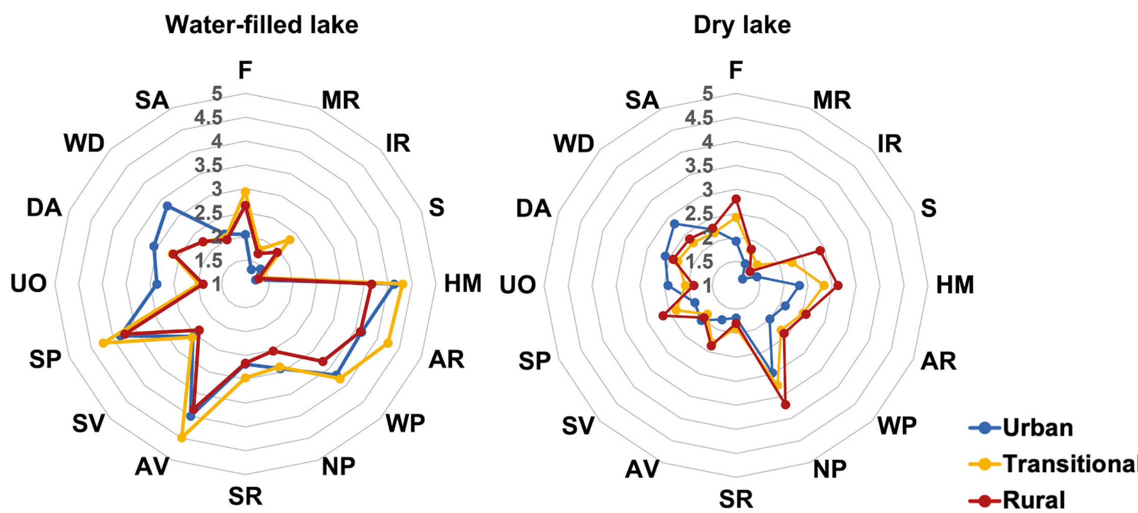

Fig. 5. Radar charts depicting respondents' perception of ecosystem (dis-)services from water-filled (left) and dry (right) lakes in urban, transitional, and rural areas. Provisioning services: F: Food/Feed, MR: Medicinal resources, IR: Irrigation water/Household water, and S: Silt/Sand; Regulating services: HM: Habitat maintenance, AR: Air/climate regulation, WP: Water purification, and NP: Natural hazard protection; Cultural services: SR: Social relations, AV: Aesthetic values, SV: Spiritual values, and SP: Sense of place; Disservices: UO: Unpleasant odours, DA: Dangerous or poisonous animals, WD: Waste dumping, and SA: Space for antisocial activities.

services categories from lakes were moderately expressed. However, the CLMM and associated likelihood ratio tests identified some significant differences (Table 2, Appendix E). Male respondents, Muslim and Christian respondents, as well as those belonging to a scheduled caste were more likely to value lakes for their capacity to provide provisioning services. Male respondents also showed a higher likelihood to associate cultural services with the two lake types than women. Respondents with high school education were more likely to perceive lakes as a source of regulating services, whereas respondents working in agriculture were less likely to associate disservices with the two lake types (Appendix E).

Overall, the CLMM models of the three ecosystem services categories showed a moderate fit, as expressed by McFadden R^2 values of 0.07, 0.09, and 0.11. For the disservices category ($R^2 = 0.02$), the variables considered in this study only poorly described the variation.

Table 4
Challenges to respondents' use of lakes across the urbanization gradient (only themes mentioned by ≥10 respondents). Significant differences were tested using Chi^2-Test (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$). Values marked with the same letter are not significantly different.

Challenges	Themes	Rural (n)	Transitional (n)	Urban (n)	Chi^2-test
Predominantly natural nuisances		161^a	147^{a,b}	59^b	8.54**
	Unpleasant odours	72^a	90^b	39^b	19.74***
	Disturbance by/risk of mosquitos	82	66	30	2.40
	Risk of wild and feral animals (snakes, rodents, elephants, crocodiles, feral dogs, tigers)	65	51	12	2.66
	Low water quality	12	13	9	5.53
	Low water level*	12	4	2	–
	Risk of falling into the lake and risk of drowning*	3	7	1	–
Predominantly social nuisances		148^a	123^a	55^b	7.50*
	Waste dumping	73	58	29	4.00
	Antisocial activities	78	71	19	1.68
	Discharge of wastewater	49^a	42^a	37^b	33.44***
	Open defecation*	22	13	2	–
Low usability of lake resources		23	12	5	1.87
	Poor roads*	11	5	1	–
	Bush, weed, and tree encroachment*	10	5	2	–
	Lack of recreation areas	7	4	2	–

* Due to low frequencies of answers Chi^2-test could not be run.

3.4. Which challenges and management options do local people express around lakes?

A total of 1196 items were received from the open question on perceived challenges associated with the use of lakes. Unpleasant odours from lakes, caused by the dumping of wastes (including animal carcasses), discharge of sewage, open defecation, and generally low water quality, were the most frequently mentioned themes. Hazards from animals (mosquitoes, but also mammals and reptiles) were also named prominently. Among the nuisances directly caused by humans were themes like waste dumping, antisocial activities, and discharge of wastewater. These themes were frequently mentioned as being interconnected among each other. Themes of lacking accessibility or impediments to the use of lake resources were also mentioned, but with lower frequency (Table 4). Respondents' perception of challenges also significantly differed between urban, transitional, and rural areas. Respondents in urban and transitional areas mentioned unpleasant odours from lakes significantly more often than those in rural areas. Similarly, nuisances directly caused by humans – in particular the discharge of wastewater – were significantly more often perceived as a challenge in urban areas.

Respondents named 573 management options in total. A wide variety of measures to improve lake surroundings and safety was proposed, some addressing a particular ecosystem service or disservice and others being of more general nature. The options proposed most notably referred to stronger management and control of the lakes and their surroundings, including enclosure and guarding lakes, but also increase of green cover (in particular, of tree cover) and environmental education and other awareness-raising measures. Technical measures to improve storage and quality of water, for instance through better sewage treatment, were also frequently suggested. Better maintenance and development of lakes and their surroundings for recreation and other uses was the third frequently mentioned category (Table 5).

4. Discussion

Blue infrastructures – lakes, ponds, rivers, channels, wetlands, and other landscape elements – have been shown to provide resilience against global environmental changes and underpin human well-being in cities (Haase, 2015). Here, we deployed the ecosystem services framework for linking GBI to societal needs (McPhearson et al., 2014) and as a tool to support planning of urban sustainability (Tan et al., 2020) in and around a Global South city. We set out to identify how local people perceive ecosystem services from a widespread, historically grown type of blue infrastructure, considering multiple interactions between ecosystem services categories, lake types, rural–urban environments, and sociodemographic characteristics. Our survey revealed that local people appreciate lakes for the supply of a range of ecosystem services. We additionally found significant differences between the perceptions on supply of ecosystem services from these lakes depending on the type of lake and the characteristics of the respondents. Here, we discuss the importance of different ecosystem services categories, the differences between water-filled and dry lakes, the influence of rural, transitional, and urban environments, the role of respondents' sociodemographic characteristics, and the challenges and management options identified.

Table 5
Options suggested for better management of lakes (only themes mentioned by ≥ 10 respondents).

Management options	Theme	Responses (n)
Lake surroundings and safety	Establish fencing, guarding, compound construction	103
	Improve/increase green cover	54
	Improve maintenance and cleanliness, control garbage dumping	45
	Create public awareness	36
	Take measures against pests and wild animals	14
	Take measures to increase security and control antisocial activities	11
Water storage and quality	Reduce sewage/drainage discharge	65
	Desilt lake	26
	Install sewage treatment plant	24
	Improve lakebed and embankment	22
	Improve water channel system and construct check dams	18
	Establish water purification and quality maintenance	15
Accessibility and usability	Improve/increase recreational possibilities	46
	Manage growth of wild vegetation	30
	Construct and improve roads and parking areas	17

In agreement with trends reported elsewhere (Elmqvist et al., 2015; Vierikko & Niemelä, 2016), lakes were perceived to be rich in regulating and cultural services (notably for aesthetic values, habitat maintenance, and air/climate regulation), and relatively low in provisioning services. By that, lakes appear to have lost in much of the study area some of their formerly most relevant functions – the provision of food and fodder, with reduced multifunctionality being a consequence of urbanisation. Similar shifts from provisioning to cultural and regulating services have been described for the perceptions and uses of green infrastructure (Nagendra, 2016) and intra-urban lakes (Derkzen et al., 2017) in Bengaluru. Negative contributions from lakes (ecosystem disservices) did matter to respondents as well (most notably, those originating from dangerous or poisonous animals), but to a much lower degree than positive contributions (ecosystem services).

Both water-filled and dry lakes are important for local people, but they have different potentials to provide ecosystem services. While water-filled lakes are perceived to be particularly relevant for both cultural and regulating ecosystem services, dry lakes offer key regulating ecosystem services, like protection against natural hazards, and some provisioning services, such as extraction of silt and sand. But perceptions of ecosystem services capacity were much higher for water-filled lakes regarding all other ecosystem services. There is a general trend of vegetation encroachment and drying up of lakes in the study area. For instance, Brinkmann et al. (2020) revealed substantial surface losses of water-filled lakes, while the surface of dry lakes (described as "hydrophytic vegetation") increased in the more rural parts of Bengaluru from 1965 to 2018. Thus, restoring some dry lakes to their former water-filled state may be useful for a stronger capitalization on ecosystem services. However, lakes often change over the year between water-filled and dry states in rural and transitional zones, while they are typically water-filled throughout the year in urban areas. Therefore, our results may also be expression of a seasonality in the appreciation of particular ecosystem services (c.f. Oteros-Rozas et al., 2014, a study that identified seasonality in ecosystem services perceptions of rangelands).

Ecosystem services changes along rural–urban gradients have been studied for mountain (Aguado et al., 2018), forest (Constant & Taylor, 2020), coastal and island (Lapointe et al., 2021), and post-industrial (Kroll et al., 2012) settings, through biophysical, economic, and sociocultural assessments, and both in terms of ecosystem services supply and demand – but not specifically for blue infrastructure. While there is no universally valid pattern of ecosystem services supply or demand along rural–urban gradients, many studies agree that urban areas provide similarly high ecosystem services levels than rural areas (Larondelle & Haase, 2013). However, there are differences between ecosystem services categories, with provisioning services (especially for meeting basic material needs) frequently being important in rural areas and regulating and cultural services (especially recreational services) appearing prominently in urban areas (Elmqvist et al., 2015; McPhearson et al., 2015). Confirming this tendency, our analysis showed that lakes are considered important for ecosystem services supply in all areas but also that urbanization level has a significant influence on how people perceive different ecosystem services from lakes. Our multivariate analysis further showed how the relationship between urbanization level and the perception of the four ecosystem (dis)services categories changed depending on the lake type (see significant interaction term between lake type and urbanization level in Table 2). Accordingly, the role of lake types in terms of ecosystem services perceptions varies as a function of where they are located. We distil three potentially important insights from these complex interrelationships. Firstly, people in rural areas appreciate especially the ecosystem services from dry lakes, such as use of silt for agriculture or flood control, much more than those in urban areas. Secondly, in transitional areas the ecosystem services offered from water-filled lakes are most relevant. Thirdly, in urban areas perceptions of ecosystem disservices are most pronounced. Lakes are much less important for the supply of provisioning services in urban areas. Here, the perception of regulating and cultural services remains high in regard to water-filled lakes but is generally low for dry lakes. We conclude that urbanization plays a strong role in changing local people's relationship with the lakes.

Lakes in and around Bengaluru have – in their original expression – been described to support multiple actors and their specific perceptions and uses of lakes (Baindur, 2014). In our survey, it seems that different social groups in and around Bengaluru share similar views of ecosystem services from lakes. Our models indeed showed that lake type has much stronger influence on people's rating than their sociodemographic background. This relative homogeneity of perceptions should be scrutinized in future studies, as it may point to subtle forms of displacement of certain values or uses of the lakes (Baindur, 2014). But despite these commonalities, our models also identified some differences that may be worth to be explored more profoundly: Women perceive less benefits from lakes than men, particularly regarding cultural and provisioning services. It appears intuitive that the importance of the more abstract and "biological" regulating services is more intensively perceived by those who have a higher education level. Agricultural workers may be more used to the nuisances of lakes, such as mosquitoes or odours, and thus perceive lower levels of such disservices. In fact, urban sewage discharged into peri-urban lakes is widely used for irrigating commercial crops such as baby corn and mulberry in parts of our study area, prompting agricultural workers to express more tolerant views towards such disservices (Patil et al., 2018). Most interestingly, people belonging to marginalized groups (in terms of caste membership or religion) appear more reliant on provisioning ecosystem services. These groups may be less affluent and thus more dependent on lakes for basic subsistence, for instance in terms of food, feed, medicine, and household water. Our study shows that dry lakes provide important ecosystem services to poorer and marginalized groups, and these groups may therefore particularly suffer from the general trend of encroachment and conversion of dried-up lakes. In our study area, fishers, fodder collectors, and agricultural users who used and maintained lakes traditionally have often been side-lined when community-based management of lakes was replaced by state management in the process of urbanization (D'Souza & Nagendra, 2011; Nagendra & Ostrom, 2014).

The challenges to the use of lakes mentioned were broadly classified into predominantly natural and predominantly social factors (c.f. Wihlborg et al., 2019). Both types of challenges were expressed more frequently in urban areas. Some of these challenges take up themes from the disservices categories, but they are more nuanced. Comprising factors such as physical alterations, deposition of pollutants, or spread of invasive plant and animal species, they largely agree with scientific assessments of threats to lakes in Bengaluru (Mundoli et al., 2015). It appears that respondents are broadly aware of multiple disservices, but do not perceive them as very serious (according to the relatively low importance assigned to individual disservices). Interestingly, lacking access to the lakes and their ecosystem services was only mentioned by few respondents, and conflicts created by replacing traditional commons management of lakes by modern state management (described for instance by Sundaresan, 2011) were not mentioned by our respondents. This apparent lack of concerns about access to lakes may be consequence of the general decrease in importance of provisioning services, as physical access is not necessary for many of the widely appreciated regulating (e.g., flood regulation) and cultural (e.g. aesthetic values) services.

People also identified several potential solutions to improve the quality and increase the use of blue infrastructure, tackling most of these nuisances directly. Interestingly, although civic engagement, partnerships, community management, and co-management have been advocated as solutions for urban lake protection in the literature (Nagendra & Ostrom, 2014; Nath & van Laerhoven, 2021), none of these appear as challenges or suggestions for better management in the responses we received. Also, some of the key social-ecological mechanisms proposed for lake conservation – for example, restoring ecological functions, reducing stress on water supply, and breaking gridlocks of inaction (Enqvist et al., 2016) – were not addressed. Rather than promoting local agency for improving lake conditions, many respondents expressed support for conventional environmental engineering measures (such as construction of sewage treatments plants). It is surprising that fencing, which has been widely criticized by environmental justice scholars (Amaral et al., 2021; Baindur, 2014), is the most frequently recommended management option. It appears that the viewpoints of our respondents depart considerably from those engaging in neighbourhood lake groups in urban Bengaluru who often advocate for more comprehensive approaches to lake management, integrating social justice and nature conservation (Murphy et al., 2019). The changing relations of people to lakes must be seen in the context of larger socio-economic and cultural transformations brought about by urbanization, for instance in terms of occupational changes and decreasing dependence on local ecosystems, which present challenges to fostering stewardship of blue infrastructure. A better understanding of the requirements and behaviours of actors around lakes, as well as their potential for developing stewardship behaviours, appears as a crucial prerequisite for lake conservation (Lamond & Everett, 2019).

Lastly, the process of individual perception of ecosystem services and its association to urban lakes is not equally intuitive for all ecosystem services (Agbenyega et al., 2009). Ecosystem services that are not directly perceived (e.g. air/climate regulation) require a developed reflection about the attributes of the blue infrastructure and its effect on ecosystem service supply. As a result, for some respondents this could lead to underestimation of the supply of some ecosystem services. The exploration of these potential mismatches could be an interesting research avenue for the design of nuanced blue infrastructure strategies.

Some uncertainties in our study need to be discussed. A first question refers to the representativeness of the sample. The covid19 pandemic imposed challenges to performing interviews in an international research project. Fortunately, a stratified random selection of households in the two transects around Bengaluru had been performed before the pandemic broke out, on which we could base our survey. By that we consider our sample representative of residents in the rural-urban interface around Bengaluru. However, our sampling scheme excluded population groups without formal and permanent residency in the area, such as those living in slums or migrant workers. As our results indicated, marginalized groups have different perceptions of the lakes, and a stronger integration of this group in the sample might have yielded stronger contrasts in the perceived importance of lakes for different ecosystem services. Another limitation to consider is that our study did not include photos of lakes filled with waste or sewage – using such photo may have increased the perceptions of ecosystem disservices. Our impression from the field is that many lakes are indeed viewed negatively by local people when they are polluted. Moreover, we studied respondents' perception of ecosystem services through photos, which may yield different results than measuring respondents' actual use of ecosystem services. We asked respondents to base their assessment of the importance of lakes for ecosystem services provision on their experiences and use of these lakes. However, this approach might not directly elicit people's needs, nor directly show whether and how people's well-being is affected by the lakes. Finally, our study did not compare perceived ecosystem services from lakes to those of other landscape elements, for instance of contemporary elements of green and blue infrastructure. These limitations may be worth to be taken up in future studies.

5. Conclusions

Blue infrastructure, a new planning measure to mitigate negative urbanization outcomes, has been limited by insufficient consideration of the societal values of waterbodies that have developed historically. Also, current discourses about blue infrastructure development for cities are predominantly focused on rivers. However, not all cities are built on or near perennial sources of water. Rather, there are many cities in semi-arid environments, where blue infrastructure needs to be developed around seasonal and smaller water sources, such as springs, ponds, and lakes. We therefore offer the following key lessons from smaller, historically evolved urban lakes in Bengaluru that may be taken up more broadly in blue infrastructure development in semi-arid urban environments:.

- Existing lakes are of high societal importance compared to their small surfaces as they are perceived as a source of multiple ecosystem services. Many of them might become keystone structures of blue infrastructure development. We recommend that planners systematically evaluate the potential of improved ecosystem services delivery through maintenance and restoration of such existing blue infrastructure when considering the establishment of new waterbodies.
- The potential for ecosystem services supply can be more visible and perceived more easily (water-filled lakes) or less visible and thus perceived less easily (dry lakes). Spatial planning should also recognise the contributions of the less conspicuous dry lakes to blue infrastructure networks, as these supply crucial provisioning services, but are at risk of being encroached and converted to other land uses.
- The role of lakes changes in the process of urbanization, with rural lakes being perceived as more important for provisioning ecosystem services and urban lakes for regulating and cultural services provision. Blue infrastructure strategies should support supply of those services that are in largest need in the respective rural, transitional, or urban environment.
- Poor and marginalized people express a strong perception of the importance of lakes for their livelihoods. Fostering provisioning services from urban lakes and facilitating access to these services may increase the multifunctionality of lakes and make them useful for a broader range of people.
- Lakes in and around Global South cities are often perceived to be polluted with waste and sewage, leading to reduced capacities of ecosystem services supply. Clean-up and awareness-raising strategies are required to include polluted lakes into blue infrastructure strategies.
- People living near lakes have local knowledge and clear ideas for lake improvement but are less vocal on how these can be implemented institutionally. Complex social-ecological strategies for improving ecosystem services supply from lakes (that go beyond "easy" solutions such as fencing) require better communication strategies. Promoting cultural attachment of people to lakes (e.g., through lake festivals) may facilitate greater sense of local ownership over blue infrastructure.

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.

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Appendix A. Supplementary data

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