INTERLINKING LAKES
Decision support tool for sustainable lake ecosystem, Ahmedabad, India

MAHEK KOTECHA
July 2022

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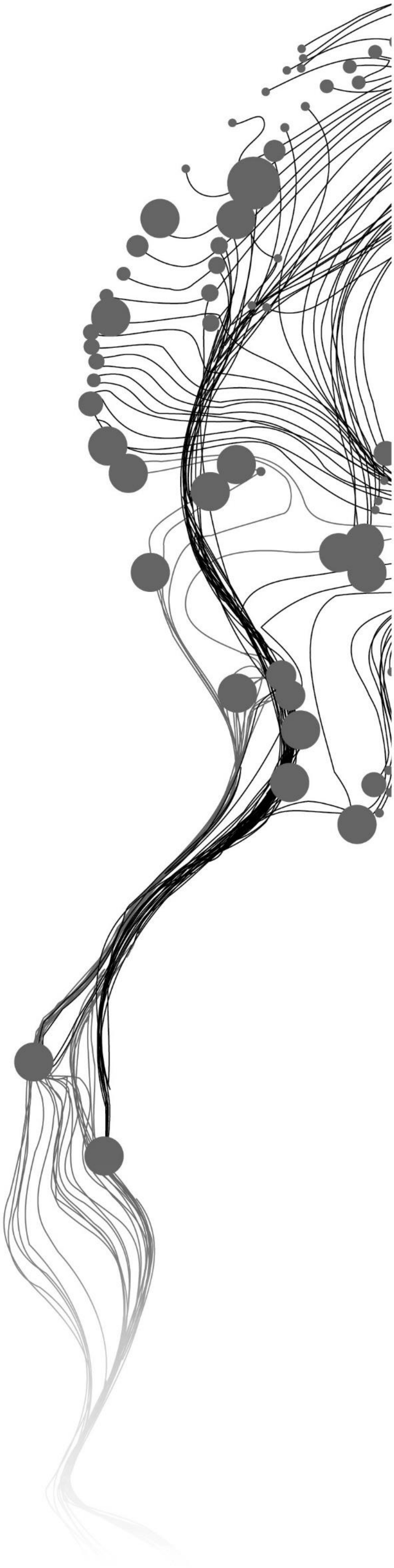

INTERLINKING LAKES
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MAHEK KOTECHA
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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.

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ABSTRACT

Lakes are an integral part of the urban ecosystem and mankind depends on lakes for several socio-economic services. However, due to anthropogenic pressures, the quality of urban lakes is deteriorating which is leading to the drying and/or vanishing of lakes in cities. Hence, the balance between the demand and supply of ecosystem services of such lakes is disturbed and the need for a more balanced and sustainable lake development approach is raised. To combat these issues related to the state of urban lakes, several attempts to revive the natural ecosystem are experimented with and practiced globally. One of the approaches to revive the lakes and deal with other urban issues like water clogging and stormwater management is the experimental approach of 'interlinking lakes.'

Interlinking of lakes in this research is considered to be a multidimensional approach dealing with social, environmental, and economic factors affecting the overall sustainability of the lake ecosystem. It deals with multiple levels of complexities and uncertainties as an intervention in one lake will affect the other interlinked lakes. Hence, it is important to evaluate the interlinking approach at different stages of planning and implementation. However, there were no studies found demonstrating a systematic, expert knowledge-based implementation of a multicriteria analysis based decision support tool to explore the degree of sustainability of interlinked lakes. Therefore, the research aimed to address the identified knowledge gap.

The main objective of the study was to develop and apply a multicriteria decision support tool for interlinked lakes to promote and support sustainable lake ecosystem planning and decision making. The decision support tool evaluates the sustainability of interlinked lakes. In addition, from this evaluation, the tool can give insights into decision making during the planning process. Hence, the tool can be used to assess the interlinking approach and can aid in different stages of planning. For this research, six interlinked lakes in western Ahmedabad (Gujarat, India) are studied.

The tool is based on a multicriteria evaluation methodology. To design the decision support tool, a multicriteria index was developed (from literature review and expert inputs), weights of the factors in the index were derived (using the Delphi method), the data related to the indicators in the index was collected (primary and secondary) and multicriteria evaluation was performed (using Definite tool). Local stakeholder and expert inputs at every stage of the research were considered very valuable. The sustainability index score was calculated for the six interlinked lakes in Ahmedabad. These scores give insights at a multidimensional level for decision making.

The results derived from the decision support tool indicate that not all the relevant social, environmental, and economic factors are currently considered in the planning process. In addition, no such monitoring and assessment tools are used to evaluate the existing planning approach of interlinking. With this research, it is demonstrated that the local authorities should re-evaluate the interlinking approach in Ahmedabad. They could do so by adopting a multicriteria decision support tool to make informed decisions to preserve and enhance the natural ecosystem of interlinked lakes.

Keywords: Multicriteria Evaluation, Sustainability, Lake Ecosystem, Decision Support Tool, Delphi method, Interlinking lakes, Ahmedabad

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LIST OF ABBREVIATIONS

AMC	Ahmedabad Municipal Corporation
AUDA	Ahmedabad Urban Development Authority
BOD	Biochemical Oxygen Demand
CCME WQI	Canadian Council of Ministers of the Environmental Water Quality Index
CEE	Centre for Environment Education
CEPT	Centre for Environmental Planning and Technology
CGWB	Central Ground Water Board
COD	Chemical Oxygen Demand
CTSI	Carlson Tropic State Index
DO	Dissolved Oxygen
EIA	Environmental Impact Assessment
GEMI	Gujarat Environmental Management Institute
GPCB	Gujarat Pollution Control Board
MBGL	Meters below ground level
MCA	Multicriteria Analysis
MCE	Multicriteria Evaluation
MI	Metal Index
NbS	Nature-based solutions
OSM	Open Street Map
PI	Pollution Index
PPP	Public Private Partnership
SI score	Sustainability Index score
SSNNL	Sardar Sarovar Narmada Nigam Limited
SSP	Sardar Sarovar Project
TDS	Total Dissolved Solids
WAWQI	Weighted Arithmetic Water Quality Index

1. INTRODUCTION

1.1. Background and justification

Human pressures on natural ecosystems around the world are one of the major causes of degrading natural biodiversity. With uncoordinated and rapid urbanization, natural green and blue ecosystems are being engulfed in the city limits. Such urbanization leads to the over exploitation of natural resources and conversion of the natural land cover into hard and impervious surfaces creating an imbalance in the natural ecosystem (Gupta et al., 2019). Natural ecosystems are disturbed by anthropogenic activities to the extent that their relations are distorted or in some cases completely destroyed. For example, regarding blue infrastructure, these activities result in drying up and/or flooding of water bodies, deteriorating water quality, and risk of natural flora and fauna (Shah, 2005).

Lakes are an important part of urban ecosystems[1] and mankind across the globe depend on urban lakes for several ecosystem services[2] (Van Ast & Bhargava, 2019). Irrespective of their size or location, urban lakes contribute to several social, cultural, environmental, and economic functions in cities. These functions of urban lakes range from being culturally/historically important, as a source of drinking water, food production, wastewater treatment, groundwater recharge, water storage, flood buffers, reducing urban heat island effect, biodiversity supporter, providing recreation/touristic services and others to enhance the quality of the urban landscape. Healthy urban lakes contribute to maintaining a balanced natural ecology and support the socio-economic needs of urban residents (Van Ast & Bhargava, 2019). Since the nineties, the importance of urban lakes and their role in maintaining ecological balance has been acknowledged in policy instruments, literature, and research frameworks to different extents globally (Van Ast et al., 2010). The European Commission acknowledged the value of lakes in its policy framework to protect and enhance its ecosystem (Carvalho et al., 2019).

India is known for its wide range of surface water bodies including lakes, which hold varied nature of cultural and historic importance across the country. However, in Indian cities, most of the urban lakes often fail to generate the expected valued functions. These failures are due to some social, economic, environmental, ecological, hydrological, and/or governance parameters (Van Ast & Bhargava, 2019). With the increasing urban population and rapid increase in impervious surfaces, the discharge of untreated stormwater and greywater in the urban lakes has disturbed the ecological balance in urban lakes. In addition, there is a lack of context-based understanding of the lake ecosystem and regional hydrology. It is observed that stakeholders, municipalities, development authorities, water boards, and research institutes are unable to put combined efforts together for the preservation of urban lakes (Van Ast et al., 2010). Moreover, there is little or no consensus about a sustainable development approach of urban lakes (Desai, 2020). This gap is due to various institutional and jurisdictional overlaps and stakeholder interests which contest the dialogue on urban lakes.

Hence, due to anthropogenic activities coupled with the pressure of development, the quality of urban lakes has been compromised. This results in altering its natural ecosystem and minimizes the ecosystem services provided by the lake area (Makarigakis & Jimenez-Cisneros, 2019). It also disrupts the balance between the supply of ecosystem services from the urban lakes and its demand. Moreover, its overexploitation leads to deteriorating conditions of the lakes which can cause greater threats to the

[1] Urban Ecosystem includes interactions between human, human built areas and nature (Shah & Garg, 2017).
[2] Ecosystem Services are indirect or direct contributions of a natural ecosystem to mankind supporting their survival and quality of life (Burkhard & Maes, 2017).

environment. Understanding this correspondence asks for a more balanced[3] and sustainable[4] approach to urban lake development.

In addition to having a sustainable approach for lake development, it is important to note that lakes are connected geologically, ecologically, and hydrologically. Also, lakes are an important node globally connected by flyways used by migratory birds due to their flora and fauna; they hold transnational importance (Higuchi, 2012). Water quality in one lake affects several lakes close to it as they are connected by aquifers. Hence, any intervention in one lake will affect its surrounding lakes and so on. However, uncoordinated urbanization makes the lakes independent units in the urban fabric, degrading their natural ecosystem (Anand, 2014).

In reference to this, in practice, several attempts are being made to physically connect the lakes (discussed in more detail in chapter 2). For example, in Ahmedabad, lakes are interlinked by laying underground network linked with stormwater channels to increase the water catchment and reduce urban water clogging (Anand, 2014). In addition to rejuvenating the natural ecosystem of lakes, the concept of 'interlinking of lakes' addresses issues like rainwater harvesting, floodwater management, and promote socio-economic activities along the waterfront. Interlinking of lakes deals with multiple social, environmental, and economic factors, which if ignored during the planning process can have negative impacts (Bal et al., 2011). It is thus imperative to evaluate the planning strategy of the 'interlinking of lakes' approach for sustainable lake development to anticipate future impacts of follow-up projects.

Interlinking of lakes is a multi-dimensional process and context-specific factors affecting the overall sustainability of lakes cannot be ignored (Bal et al., 2011). Multicriteria analysis (MCA) is a systematic analytical approach that can be used to assess sustainability based on the defined goals (Adams & Ghaly, 2007). This research focuses on using MCA to evaluate the sustainability of interlinked lakes based on the integration of social, economic, and environmental values. The analysis can contribute to identifying and analyzing the problem. It can further also be used to develop a planning support tool that can handle a wide range of factors, which can be evaluated based on different selected criteria for decision support (Tsoutsos et al., 2009). In order to use multicriteria analysis, the study aims to develop a decision support tool. The tool evaluates the sustainability of interlinked lakes and gives insights that can be incorporated into further decision making and planning processes.

1.2. Problem

Lakes are an important part of the urban ecosystem and provide several ecosystem services that humankind depends on. However, one-third of the lakes in the world are under pressure due to anthropogenic activities (Mammides, 2020). In global south countries like India, planning of lakes is more inclined towards lake development as a land parcel and not as a part of larger ecosystem conservation. India has a varied range of lakes as water bodies across the country, but their number and size have drastically reduced over years (Reddy & Char, 2006). Existing lakes are poorly treated or ignored and lack a sustainable spatial planning strategy (Van Ast & Bhargava, 2019).

To address the issues of the deteriorating condition of lakes, reducing number of lakes, dried-up lakes, and urban water clogging, lakes are interlinked to protect and enhance their natural ecosystem. Several attempts to interlink the lakes with different approaches that aim to achieve multiple objectives are being

[3] Balanced approach refers to the balance between the extent and nature of anthropogenic activities that has influence on urban lakes (demand) and benefits that can be taken from its ecosystem services (supply)

[4] UN Brundtland Commission (Cassen, 1987, p.16) defined sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs by integrating and acknowledging social environmental and economic concerns throughout decision making process."

experimented with in global north and global south cities. Interlinking of lakes is multi-dimensional and will affect the social, environmental, and economical values related to the lakes. However, such an experimental approach has several uncertainties and challenges. For example, degradation of water quality will not only affect the interlinked lake ecosystem but will also pollute the receiving waters (Anand, 2014). In order to better understand the multidimensionality, the interlinking of lakes can benefit from a systematic application of MCA for sustainable lake ecosystem planning.

1.3. Research Problem

There were no studies found demonstrating a systematic, expert knowledge-based implementation of a multicriteria analysis based decision support tool to assess the sustainability of interlinked lakes. However, there is a need to study the multidimensionality of interlinking lakes. Therefore, the research aims to address the identified knowledge gap. It is expected that the exploratory research can demonstrate the use and application of decision support tool based on multicriteria analysis for interlinked lakes.

1.4. Objective of the study

1.4.1. Research objective

The main objective of the study is to develop and apply a multicriteria decision support tool for interlinked lakes to promote and support sustainable lake ecosystem planning and decision making.

1.4.2. Research sub-objectives

1. To analyze existing planning approaches of interlinking lakes.
2. To design and apply a multicriteria decision support tool for interlinked lakes to promote and support sustainable lake ecosystem planning and decision making.
3. To discuss the potential of the tool for planning and decision making processes.

1.4.3. Analytical Questions

To operationalize these objectives, analytical questions formulated are as mentioned in Table 1.

Table 1: Analytical Questions

Sub-objective 1	Sub-objective 2	Sub-objective 3
1.1 What are the existing planning approaches employed for interlinking lakes?	2.1 Which factors are important to consider for interlinking lakes?	3.1 How can the insights be incorporated into the planning process to achieve multiple objectives?
1.2 What are the characteristics of different planning approaches for interlinking lakes?	2.2 How do the factors in the multicriteria index affect the overall sustainability of the lake ecosystem?	3.2 How can the developed tool be used in the planning and decision making of interlinking lakes?
1.3 What are the strengths, gaps, and challenges of the planning approaches for interlinking lakes?	2.3 What is the relative importance of the factors and how can the factors be measured?	
	2.4 What are the inferences and insights the multicriteria decision support tool output provides?	

1.5. Thesis Structure

The thesis is presented and structured in 7 chapters. Chapter 1 focuses on developing the background of the study, its scientific and societal relevance, the research problem, and identified objectives of the research. Chapter 2 is the review of literature on two main aspects of interlinking lakes (1) different existing interlinking lake planning approaches and (2) factors important to consider during the planning process of interlinking lakes. Chapter 3 discusses the selection of the study area and interlinked lakes in the study area, the need for the study, and identified issues/challenges/gaps in the existing interlinking lakes approach. Chapter 4 highlights the research approach and methodology adopted to achieve the main objective of the study followed by data collection, analysis, and management details. Chapter 5 is the interpretation and elaboration of results obtained under each of the three sub-objectives. The results are discussed and interpreted also linking it back to the learnings from the literature review in Chapter 6. Chapter 7 contains the conclusions that can be derived from the study and the recommendations based on these conclusions. The support materials and details are attached in the appendix. The summary of all the interviews conducted in the research is compiled in the appendix.

2. LITERATURE REVIEW

2.1. Interlinking of Lakes: Existing planning approaches

Lakes are connected by confined or unconfined aquifers. The cognizance of the interconnectedness of surface water bodies like lakes among water experts is increasing and being explored globally in projects like AQUACOSM[5]. Several attempts are being experimented with to unify and connect lakes to address water management issues of rainwater harvesting, stormwater collection, and reducing flooding in urban areas (Haghighatafshar et al.; 2014, Mirza, 2018; Shih & Qiu, 2021; Anand, 2014). While the city municipalities attempt to address these issues, uncoordinated urbanization with hard landscape and impervious surfaces acts as friction in natural groundwater recharging that affects the natural linkage of lakes with one another. This makes them individual units in the urban fabric eventually leading to the degradation of its natural ecosystem (Anand, 2014).

To understand different planning approaches, five cases of interlinking lakes are studied. The cases were selected based on the justification to study different interlinking approaches in varied geographical contexts.

2.1.1. Case 1: Malmo, Sweden

The city of Malmo is surrounded by several ponds and other surface water bodies. As a part of sustainable development initiatives since the 1990s, ponds in the city are interlinked through an open network system. To interlink the ponds, a *nature-based solutions planning approach* is adopted for stormwater management to reduce urban flooding (Barton, 2016). The open network is passing through the soft permeable landscape to a chain of green (parks, forests) and blue spaces (ponds, lakes, wetlands). This reduces urban run-off and reduces the amount of urban pollutants flowing into the receiving waters (Niemczynowicz, 1999).

Hence, before the water reaches the main collection point, it passes through a soft permeable landscape that recharges groundwater, prevents flooding in urban areas, and filters water before flowing into the receiving reservoir (Haghighatafshar et al., 2014). Any new urban development is planned to take into consideration the interconnected open stormwater channels laid in the city. Different technical departments of local authorities with the involvement of the public in coordination and equal engagement have been successful in the implementation and management of interlinked open networks through sustainable practices (Stahre, 2002).

Despite following sustainable practices for stormwater management, it was proved during 2013 and 2014 storms and cloudbursts that Malmo is at risk of urban flooding in case of extreme rainfall. Water in the open channels raised up to 1.5m from 15cm during the storm. Raising sea water levels and changing climate is a major concern for Malmo city. The city planning authorities are taking into consideration these aspects and taking flood mitigation measures in the new development while also continuing to implement the sustainable practices of interlinking ponds (Haghighatafshar et al., 2014).

2.1.2. Case 2: Copenhagen, Denmark

Water quality in Copenhagen harbour has always been an issue. One of the major causes of degrading water quality is reportedly the release of household and industrial waste into the water without the filtering process. Due to this, the harbour could not be used for socio-economic activities. Local representatives reacted to this by laying the responsibility on the municipality. Amidst this, an intense storm in 2011

[5] Scientists from across Europe are collaborating on a project AQUACOSM to support the systematic experiments on linking lakes, rivers, and oceans across Europe (AQUACOSM, 2017).

caused great damage to city infrastructure and other services. Since the 1990s, the municipality has been making efforts to improve the water quality along with controlling flooding in the city (Lindegaard, 2001).

Vulnerable neighbourhoods prone to flooding were studied and identified by the local municipality. Based on this knowledge, quick discharge of storm water from these identified areas to the sea has been planned. To do this, there have been interventions to interlink the canals which receive water from surrounding catchment areas released into the sea (Haghighatafshar et al., 2014). Interlinking in Copenhagen follows a *flood resilient planning approach* for storm water management to reduce urban flooding. Unlike as discussed in the previous case, Copenhagen is following a closed piped connected network that has proved to be not a sustainable solution in terms of maintenance (Barton, 2016).

However, the city is shifting to adopt more sustainable practices of stormwater management with an open network system. There have been small-scale interventions where the canals receive stormwater from surrounding buildings and shared open spaces (Haghighatafshar et al., 2014). Hence, water management initiatives started with the reason of improving water quality, and the event of a storm changed the stormwater management fundamentally leading to adopting the solution of interlinking canals.

2.1.3. Case 3: Udaipur, India

Udaipur, known as the 'city of lakes' had successfully developed a water management system in the mid-16th century. Interconnected descending lakes were constructed which has been one of the most famous examples of manmade interconnected lakes for water management. The *planning approach* of interlinking lakes in Udaipur focused on *rainwater conservation and management*. These lakes are interconnected by considering the catchment areas with the aim of keeping the water falling in the Udaipur basin within itself with minimum loss of water. Traditionally, this was considered the most unique solution for rainwater storage and its management. (Mirza, 2018).

This environmental and ecological sustenance of lakes by making a web of interconnected lakes was accompanied by other social and economic dependency on lakes. These lakes were used for recreational purposes, and the livelihood of several stakeholders was dependent on these lakes (Razdan, 2005). Moreover, it was found that the overall water quality of the interlinked lakes has improved over years (Choudhary & Sharma, 2021). Hence, interlinking lakes of Udaipur are considered a sustainable solution to maintain and enhance the lake ecosystem.

However, recent studies have found that increasing human pressures are causing deteriorating conditions of the lakes. The number of migratory birds visiting the lakes is decreasing. Besides, deforestation, increasing infrastructure development, and encroachment around the lakes are contributing to the degrading lake ecosystem in Udaipur. Increasing tourism activities and services are magnifying the mentioned problems. There is a need to maintain the natural ecosystem of interlinked lakes that was developed with a sustainable planning approach (Nair et al., 2016).

2.1.4. Case 4: Taoyuan, Taiwan

Another example of manmade interlinking is Taoyuan metropolitan area in Taiwan known as the 'pond city'. The pond city is known for its interconnected ponds through canals that act as open networks placed within the urban fabric. The canals which act as waterfront in the urban fabric are used for the purposes of transportation, irrigation, and water storage (Shih & Qiu, 2021). This contributed to creating a prominent feature of the city landscape. However, due to rapid and uncoordinated urbanization, the natural ecosystem of the ponds was degrading. The city had over 3290 ponds in the 1970s which reduced to 1800 in 2011 (Huang et al., 2011).

To address this issue, the re-development adopted a *sustainable planning approach* that aimed to achieve the maximum potential of these waterfronts socially, economically, and environmentally. Ponds were used as a spatial tool to connect urban fabrics in the city to revive the lakes and the lost interlinked network. The ponds were interconnected through open canals in a sustainable manner which is also used for transport. As a result of this, ponds were used for recreational purposes and economic activities like fishing (Shih & Qiu, 2021).

Hence, the city landscape was revived by restoring the use of the canal as waterways and maximining the use of the waterfront as a public space with minimum intervention in the hydrological system of the ponds. As a result of adopting such an approach to interlink, the overall sustainability of the interlinked ponds improved over time. Hence, it is considered important to take into consideration social, environmental, and economic factors for sustainable development of lakes/ponds to enhance and protect their natural ecosystem.

2.1.5. Case 5: Ahmedabad, India

Due to rapid and uncoordinated urbanization, lakes are being engulfed by cities in Ahmedabad and the number of lakes has reduced from 630 to 122 over years the period of 20 years (Desai, 2020). On the other hand, the city faces the issues of climate change, increasing temperatures, urban water clogging, wastewater management, water pollution, etc. To address these issues, the local government authority has come up with an initiative of interlinking lakes in the city in 2004 (Anand, 2014).

Under this initiative, 44 lakes in western Ahmedabad were identified for development with the provision of interlinking. The *planning approach* of interlinking lakes is a *techno-planning solution* to the urban water-clogging issue (Anand, 2014). The lakes were connected through an underground laid piped network to increase the catchment of stormwater and decrease water logging in urban areas. Neighbourhoods that were vulnerable to urban flooding before 2004 have reportedly reduced after increasing the catchment area of stormwater flowing into the interlinked lakes (AMC, 2021).

However, water experts have criticized the approach as it involves unsustainable practices like altering the natural lake edge, using materials like concrete, land grabbing around the lake for recreational activities, etc. (Desai, 2020). In addition, after interlinking lakes, the development authorities are facing several challenges and complexities like the survival of aquatic life, lake maintenance, and retention of water in the lakes. Nevertheless, this initiative is considered an innovative project and is perceived as a success by the local authorities. In addition, this is seen as a reference project for lake development across several cities in Gujarat state (Bal et al., 2011).

2.1.6. Summary and Conclusion

The common factor that remained similar across all the cases of interlinking lakes/ponds was the overarching aim to revive/enhance and maintain ecological and environmental health. Malmo interlinks the ponds through an open network and focuses on environmental factors by adopting a nature-based solution planning approach to reduce urban flooding. Udaipur and Copenhagen use an underground piped network for the connection. Copenhagen has been experimenting with other sustainable solutions by studying the environmental impacts of the solutions. However, with the interlinking of lakes/ponds, Udaipur aims to conserve and manage rainwater with minimum water loss and Copenhagen aims to address the issue of urban flooding in the city. In the case of Taoyuan, socio-economic activities linked to the lakes are given more importance and it is discussed that these activities depend on the environmental and ecological state of the water body that affects its overall sustainability. As Taoyuan considers relevant the social, environmental, and economic factors linked with the ponds, overall sustainability has been observed to be improved over years. In the case of Ahmedabad, the interlinking of lakes is focusing on social and environmental factors. However, solutions adopted as a part of the planning approach are not considered sustainable by several experts.

The five cases from different geographical context and aiming to achieve multiple goals of water conservation and management through interlinking lakes/ponds was studied. It was concluded that the interlinking of lakes is a complex and multi-dimensional process that depends on several context-specific factors. These factors can have a positive and negative impact on each other and cannot be ignored (Anand, 2014). Hence, it is very important to consider all three dimensions of sustainability (social, environmental, and economic) during the planning process. The next section discusses these dimensions that affect the sustainable development of interlinked lakes.

2.2. Interlinking of Lakes for sustainable lake ecosystem

UN Brundtland Commission (Cassen, 1987, p.16) defined sustainable development as *"meeting the needs of the present without compromising the ability of future generations to meet their own needs."* Sustainable development requires a balanced and integrated analysis from three main perspectives, commonly known as the three pillars of sustainability: social, environmental, and economic. The 2030 Sustainable Development Agenda has 17 goals that ask for global attention (United Nations, 2015). Sustainable development of lakes and reservoirs is important and directly linked to nine[6] Sustainable Development Goals (SDGs) (Ho & Goethals, 2019). For urban lakes, this supports the idea of long-term ecological stability by considering context-specific social, environmental, economic, and ecological dimensions during the planning process. The factors contributing to these dimensions are shown in Figure 1.

2.2.1. Social Dimension

The social dimension in urban areas supports social issues of cultural development and human interaction. This has a good mix of qualitative and quantitative measurements that depend on both objective and subjective factors. Larimian & Sadeghi (2021), and Murphy (2012) discuss overarching concepts for analysis and measurement of the social dimension. These have been grouped into two domains: 'social sustainability' and 'public acceptance'.

The *social sustainability* domain investigates the factors contributing to the overall social sustainability of lakes from a planning perspective. The factors discussed under this are:

Cultural Importance: Traditionally, socio-cultural/historic aspects linked to water bodies are considered sacred. Cultural values are one of the important driving forces to achieving sustainability of lakes and hence cannot be ignored amidst rapid urbanization (Bal et al., 2011).

Social Inclusion: Social inclusion focuses on enhancing the opportunity for using the lake and surrounding spaces by all age groups and gender. This can be achieved by considering the needs of all the users in the design (Dempsey et al., 2011).

Public Participation: This factor promotes the inclusion of stakeholder participation during the planning process thereby contributing to increasing overall social sustainability. Including stakeholder perspective during the planning process is a benefit to both the users of the lakes and also the planning authorities (Murphy, 2012).

[6] The sustainable developments in relation to lakes and reservoirs: Goals 6 (clean water and sanitation), 13 (climate action), 14 (life below water), and 15 (life on land) are related to environmental dimension and Goals 1 (no poverty), 2 (zero hunger), 3 (good health and wellbeing), and 8 (decent work and economic work) are related to social and economic dimensions (Ho & Goethals, 2019).

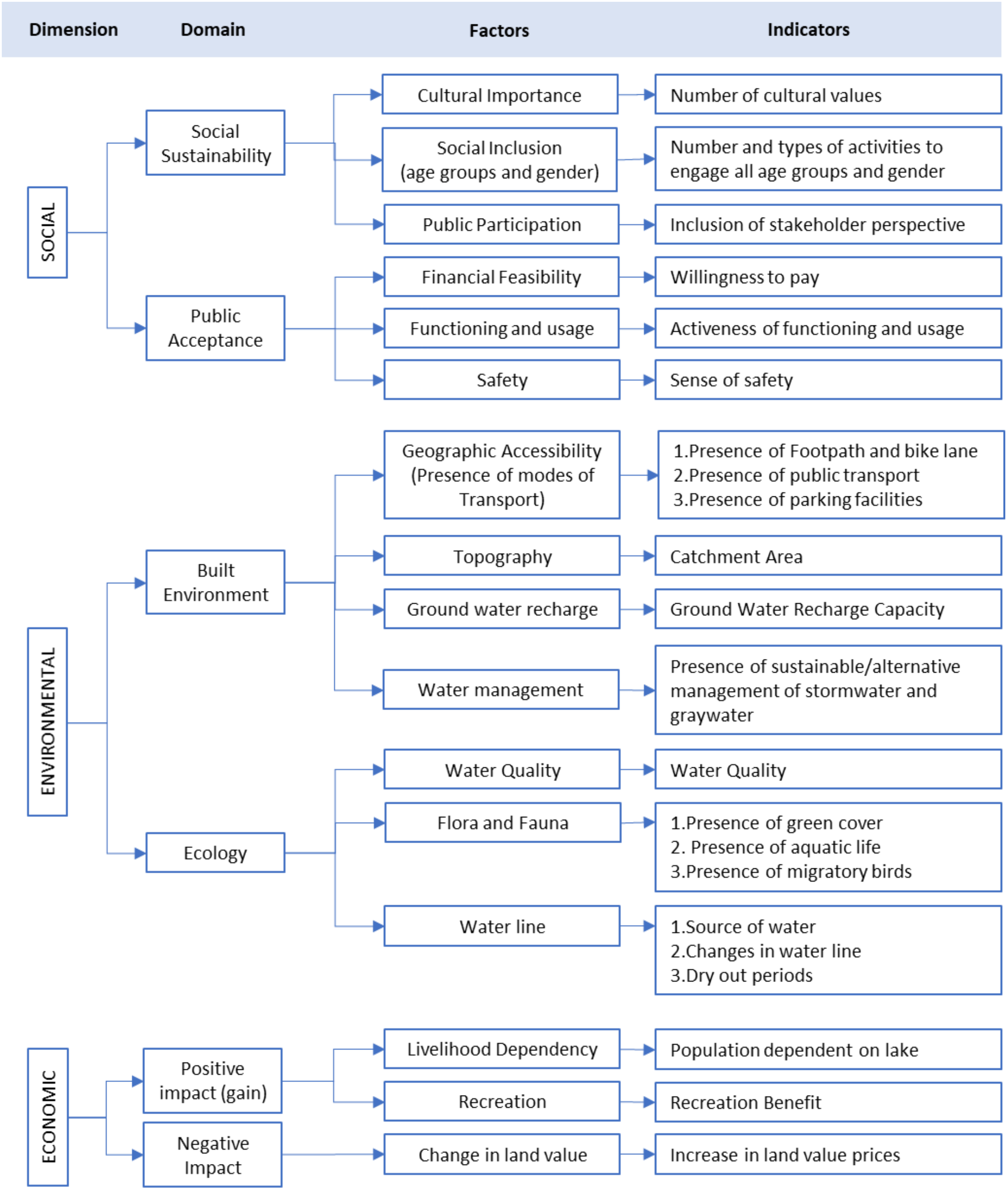

Figure 1: Multicriteria Index (Developed by the author based on the literature review)

The *public acceptance* domain investigates the satisfaction/success and actual use of lakes. The factors that can evaluate public acceptance are:

Financial Feasibility: The ability and willingness to pay for using environmental resources like lakes are under constant debate. Some stakeholders see this as an added value and are willing to contribute while some cannot afford it or are not willing to pay. Ability and willingness to pay can contribute to partly knowing the financial feasibility of the development (Bal et al., 2011).

Functioning and usage: The functioning and usage of the public space are dependent on its attractiveness and function for its stakeholders and users (Dempsey et al., 2011). It is important to monitor the activities in the lakes for their long-term functioning and usage by the residents.

Safety: The feeling of safety by all age groups and gender across all times of the day is an important factor to ensure positive social activities (Larimian & Sadeghi, 2021).

2.2.2. Environmental Dimension

The environmental dimension refers to the lake ecology, built-up environment around the lake, and its management. The environmental sustainability of lakes affects the life of the lake. Moreover, social, and economic activities depend on the state of the lake. Hence, in the case of urban lakes, it is crucial to evaluate and achieve the environmental sustainability of urban lakes to maintain overall sustainability (Ho & Goethals, 2019).

The *built-up environment* domain investigates the physical factors, its planning, functioning, and management. These physical factors are:

Geographic Accessibility: Geographic accessibility to the urban lakes is an important factor to consider while planning the built-up environment around the public space (Dempsey et al., 2011). The provision of public transportation facilities, pedestrian walking, biking lakes, and parking facilities under the built environment are important aspects to ensure access and usage of the lake.

Topography: It is important to understand the urban topography and catchment area of the lake to ensure the flow of stormwater in the lake and avoid urban flooding (Bal et al., 2011).

Groundwater Recharge: Uncoordinated and rapid urbanization has led to impervious surfaces that reduce the soft permeable surfaces and hence reduce the capacity of lakes in an urban fabric to recharge groundwater. It is thus essential to measure and ensure the capacity and quality of groundwater recharge (Bal et al., 2011).

Water management: It is important to ensure a sustainable filtration process of stormwater and greywater before it enters the lake to ensure its water quality (Reddy & Char, 2006).

Other factors under the *ecological domain* affecting the life of lakes are:

Water quality: It is important to check the water quality of lakes as it affects the life of lakes and other activities linked with the lake ecosystem. Deteriorating water quality will lead to degradation of the natural lake ecosystem affecting the overall sustainability of the lake and other green and blue spaces around the lake (Reddy & Char, 2006).

Flora and fauna: Aquatic life depends on the natural ecosystem of lakes. Lakes are an important stop for migratory birds. To maintain the natural ecosystem of lakes, it is important to maintain the quality of flora and fauna (Higuchi, 2012).

Waterline (source, amount): To maintain the natural ecosystem of the lake, it is important to monitor the source of water, changes in the water line in the lake over years, their dry-out periods (if any), and the reasons behind these phenomena (Reddy & Char, 2006).

2.2.3. Economic Dimension

Economic sustainability is examined in terms of the positive and negative impacts of ecosystem services provided within and around the lake. The *positive impacts* consider the factors:

Livelihood dependency: Several social and economic activities are linked to the lake which is an economic gain for some stakeholders (Bal et al., 2011). Socio-economic activities linked to the lake in a sustainable manner enhances its usage and importance.

Recreation of the lake: Recreational activities linked with the lake in a sustainable manner also contribute to its usage and functioning. This also is a potential economic gain for urban authorities which can be used to maintain and manage the lake (Ho & Goethals, 2019).

The *negative impacts* of lake development consider the factor:

Change in land value: High ecosystem services provided by the lake improve the quality of the surrounding neighbourhoods but affects the land prices in the area (Bal et al., 2011).

2.2.4. Summary and Conclusion

Consideration of social, environmental, and economic dimensions during the planning process with the aim of achieving overall sustainability has been advancing as compared to a more engineered techno-solution approach and are referred to as '*adaptive management*,' '*integrated water management'* or '*sustainable water management*.' Such an approach focuses more on maintaining a balance between costs and benefits for different stakeholders (Van Ast et al., 2010). However, the meaning, importance, and interpretation of these multi-dimensional criteria to ensure sustainable development are different for different stakeholders. Valuation by relevant stakeholders can aid the decision making process. This can be done by multicriteria analysis that gives information on synergies and trade-offs between the social, environmental, and economic values (Adams & Ghaly, 2007).

3. STUDY AREA

3.1. Selection Criteria

Cases discussed in the literature review (section 2.1) were considered as choices for study area selection. The study area should cater to the four selection criteria (Table 2) which are: lakes in the study area are under pressure/ignored and requires attention; interlinking of lakes is experimented in the study area; interlinking of lakes is facing several challenges/uncertainties which raises conflicts on the development approach; feasibility of the study in terms of the familiarity of the study area and ability to communicate for conducting interviews.

Table 2: Study area selection

Selection Criteria	Malmo	Copenhagen	Udaipur	Taoyuan	Ahmedabad
City where urban lakes are under pressure/ignored and need attention	✓	✓	✓	✓	✓
Interlinking of lakes is experimented	✓	✓	✓	✓	✓
Interlinking of lakes is facing challenges/uncertainties AND which raises conflicts in the development approach among authorities and other stakeholders	✗	✓	✗	✗	✓
Feasibility of study to achieve the identified objective (Familiarity with the area and ability to communicate to conduct interviews)	✗	✗	✓	✗	✓

Amongst the considered cases, all the four selection criteria are fulfilled by the case of interlinking lakes in Ahmedabad. Lakes in Ahmedabad are being engulfed into the city limits due to the pressures of development. Contradicting to this, the number of lakes in the city is reducing over years and the existing lakes require attention to revive and enhance their natural ecosystem (Desai, 2020). In addition, the interlinking of lakes is experimented with in Ahmedabad in 2004 which is facing certain challenges and uncertainties (discussed further in the chapter). As a result, over years, there is a constant and growing debate on the adopted planning approach of interlinking in Ahmedabad (Desai, 2020). Based on these selection criteria and also considering the feasibility of the study in terms of familiarity with the study area, the case of interlinking lakes in Ahmedabad is studied for the research.

3.2. Background

Ahmedabad (location indicated in Figure 2) is India's first UNESCO world heritage city (Gujarat Tourism, 2017) and one of the fastest-growing cities in the state of Gujarat having a population of over five million with a growth trend of 22% (Census of India, 2011). As the city is rapidly expanding, it engulfs rural areas into the city limits and hence the green and blue spaces are subject to redevelopment in the urban fabric (Desai, 2020). The Ahmedabad Urban Development Authority (AUDA) is responsible for urban development in the city. Ahmedabad Municipal Corporation (AMC) is responsible for providing, managing, and regulating all socio-economic services for domestic, industrial, and commercial purposes.

Figure 2: Location of Ahmedabad (Source of the map: Adhvaryu, 2011)

In 1999, AUDA identified 630 lakes in its jurisdiction of which 79 lakes were notified as urban lakes (Bal et al., 2011). The total number has reduced and has come down to 122 over the years in 2020 (Desai, 2020). One of the reasons behind this is that there is no firm definition of a lake. Chapman, 1996, p. 325 defines a lake as *"… an enclosed body of water (usually freshwater) totally surrounded by land and with no direct access to the sea. A lake may also be isolated, with no observable direct water input and, on occasions, no direct output"*. Reddy & Char, 2006, p. 3 define an urban lake as *"… a subset of all freshwater bodies such as reservoirs, lakes, ponds, tanks, etc. those are surrounded by land on all sides and located in urban situations"*. There is no single accepted definition of lakes in India and its classification is commonly perceived based on geographical context (e.g., peninsular, coastal), functional value (e.g., irrigation, drinking water supply), water quality (e.g., based on water quality standards), management (e.g., conserved, protected, Ramsar sites), etc. (Reddy & Char, 2006).

In Ahmedabad, since several water bodies are shallow and did not retain natural water for 10 years, they got excluded from being called a lake. And as they were not designated as lakes, the area was open for development and construction (Reddy & Char, 2006). However, lakes are an integral part of an urban ecosystem which requires a sustainable development approach to address several issues of an urban heat island effect, water scarcity, water storage, groundwater recharge and to provide ecosystem services. AUDA has put several efforts into urban lake development. Nevertheless, the interlinking and lake development approach has been under constant debate and hence gives a good inducement to analyze its planning approach.

3.3. Interlinking of lakes in Ahmedabad

The experimental approach of 'interlinking lakes' was initiated by Ahmedabad Urban Development Authority (AUDA) in 2004. 44 lakes in western Ahmedabad were identified for development with the provision of interlinking, out of which, 8 lakes were interconnected in the first phase (Anand, 2014). The concept diagram of interlinking lakes is shown in Figure 3. The lakes were connected through a piped network to increase the catchment of stormwater and decrease water logging in urban areas. The linked network has an outflow in the Sabarmati river (Anand, 2014).

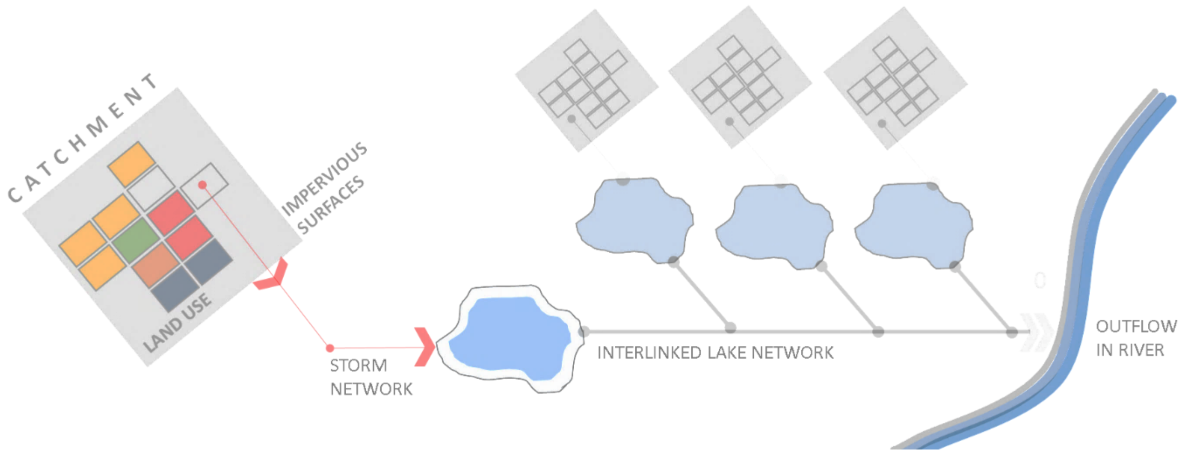

Figure 3: Interlinking of lakes, Ahmedabad | Conceptual diagram (Anand, 2014)

As shown in Figure 4, the overarching strategy of the interlinking lakes project was formulated in two development components which were inside and outside the lake area (Bal et al., 2011). These development components have some social, environmental, and economic concerns. Interlinking pipes were laid under environmental concerns for stormwater flow to increase the catchment area and reduce waterlogging in urban areas. Functional usage of the lake was planned as a recreational public open space for socio-economic concerns.

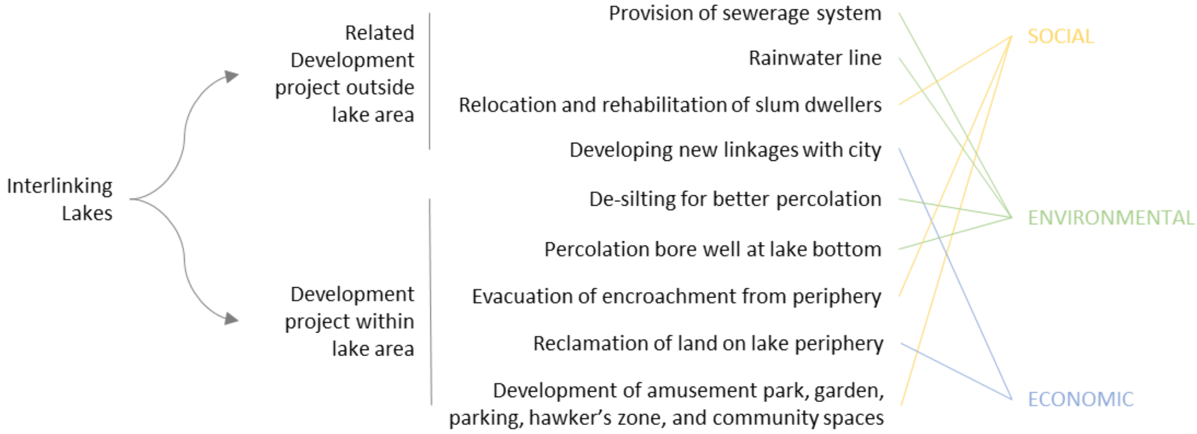

Figure 4: Ahmedabad Interlinking of lakes development components (Developed by the author, based on Bal et al., 2011)

Vastrapur Lake Development Project (VLDP) in western Ahmedabad was a pilot project used to conceptualize the 'Interlinking of lakes' initiative. Nonetheless, Desai, 2020 mentions that according to the local experts, the development approach in this pilot project has not been entirely successful. Vastrapur lake was developed as 'a concrete pool' with water unable to percolate in the ground. This disturbed the ecological balance making it difficult for aquatic life to sustain and rainwater does not recharge the water capacity of the lake naturally (Desai, 2020). Moreover, land reclamation around the lake is not implemented naturally which disturbs the natural landscape. Urban lakes are marked by cadaster boundary which is acknowledged by development authorities. However, in this case, the lake ecosystem boundary should be taken into consideration for the sustainable development of the lake.

The experimental approach of interlinking lakes is likely to have uncertain impacts and effects on dealing with different levels of complexities. In addition to these flaws, lake management and development are facing several challenges and complexities in Ahmedabad. Depending on the location, scale, and context some of these challenges are becoming prominent due to an increase in urban density, haphazard development, illegal sand mining activities, an unhygienic environment, rainwater outlets do not reach the lake, and the release of wastewater without filtering (Desai, 2020). The 'techno-planning' solution of linking lakes does not consider how it will affect the water quality of linked lakes (Anand, 2014).

Lakes in Ahmedabad have been drying out over the past few years. The water is brought in manually at a cost that is a part of a water supply network at the state level under the Sardar Sarovar Project (SSP). In addition, the development of lakes with recreational activities and waterfront will contribute to increasing trends in land prices around the lake. Social inclusion, accessibility, and other social aspects considering all relevant stakeholders should be considered (Bal et al., 2011). The absence of the aforementioned components in the planning process raises several social, environmental, and economic concerns as a result of impacts, exposure, response, and effects of interlinked lakes (Figure 5).

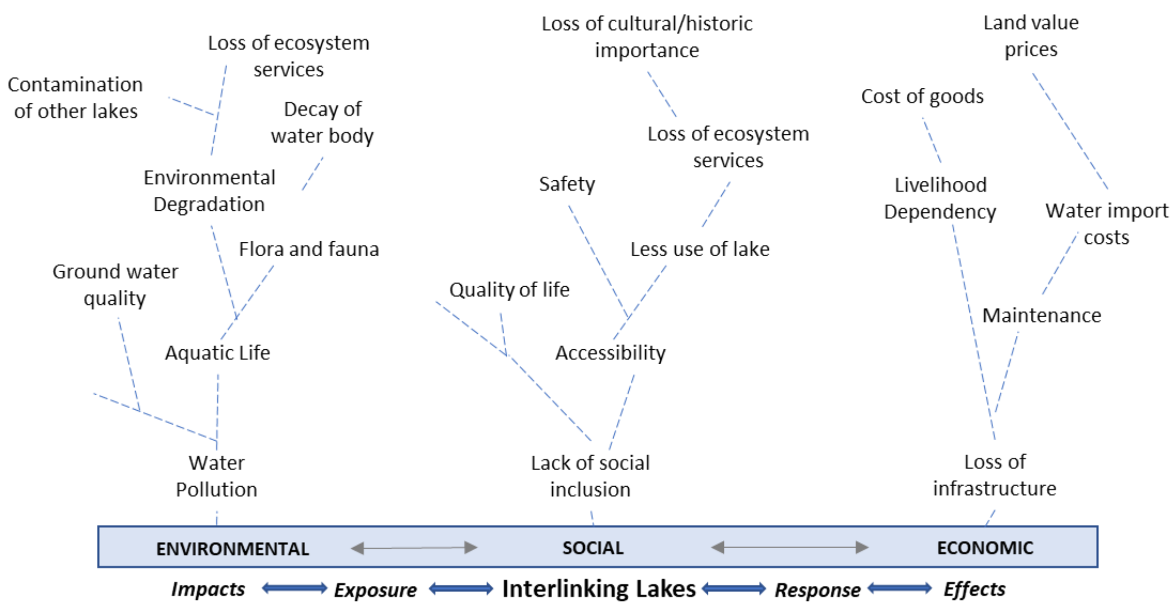

Figure 5: Social, environmental, economic concerns of interlinking lakes (Developed by the author)

The study departs from the assumption that interlinking lakes in Ahmedabad require a sustainable planning approach that considers multiple dimensions and not just a technical-hydrological intervention as it does not consider all social, environmental, and economic concerns for sustainable interlinking of lakes. Hence, the study aims to develop a multicriteria decision support tool to evaluate the relative degree of sustainability of interlinked lakes in Ahmedabad based on their existing condition which can provide insights into decision making in the further planning process.

3.4. Selection of lakes in the study area

The selection of lakes in this study is based on the criteria mentioned in Table 3. The selection criteria aim to capture the diversity in selected interlinked lakes based on their spatial location in reference to the city limits (urban, peri-urban, rural), varied land use around the lake, different cultural/historic importance, and different level of active usage. The six lakes mentioned in the table were interlinked in the first phase of the interlinking project by AUDA in 2004. Based on the selection criteria, the six interlinked lakes provided a good diversity of location, surrounding land use, associated importance, and varied usage. The location map of the selected lakes in as shown in Figure 6.

Table 3: Selection of the lakes in the study area

Selection Criteria	Memnagar	Vastrapur	Thaltej	Bodakdev	Prahaladnagar	Sarkhej
Lakes are part of the interlinking network in the study area	Yes	Yes	Yes	Yes	Yes	Yes
Lakes in urban and peri-urban areas (currently or before development)	Urban	Urban	Peri-Urban	Urban	Urban	Peri-Urban
Diversity in land use around the lakes	Residential	Residential	Mixed-use	Mixed-use	High density residential	Mixed-use
At least one lake with cultural/historic importance	No	No	Yes	No	No	Yes
Presence of informal/illegal settlements or temporary hawkers around the lakes	Yes	Yes	Yes	No	No	Yes
Varied status of usage (low, moderate, high)	Low	High	Low	Moderate	High	High

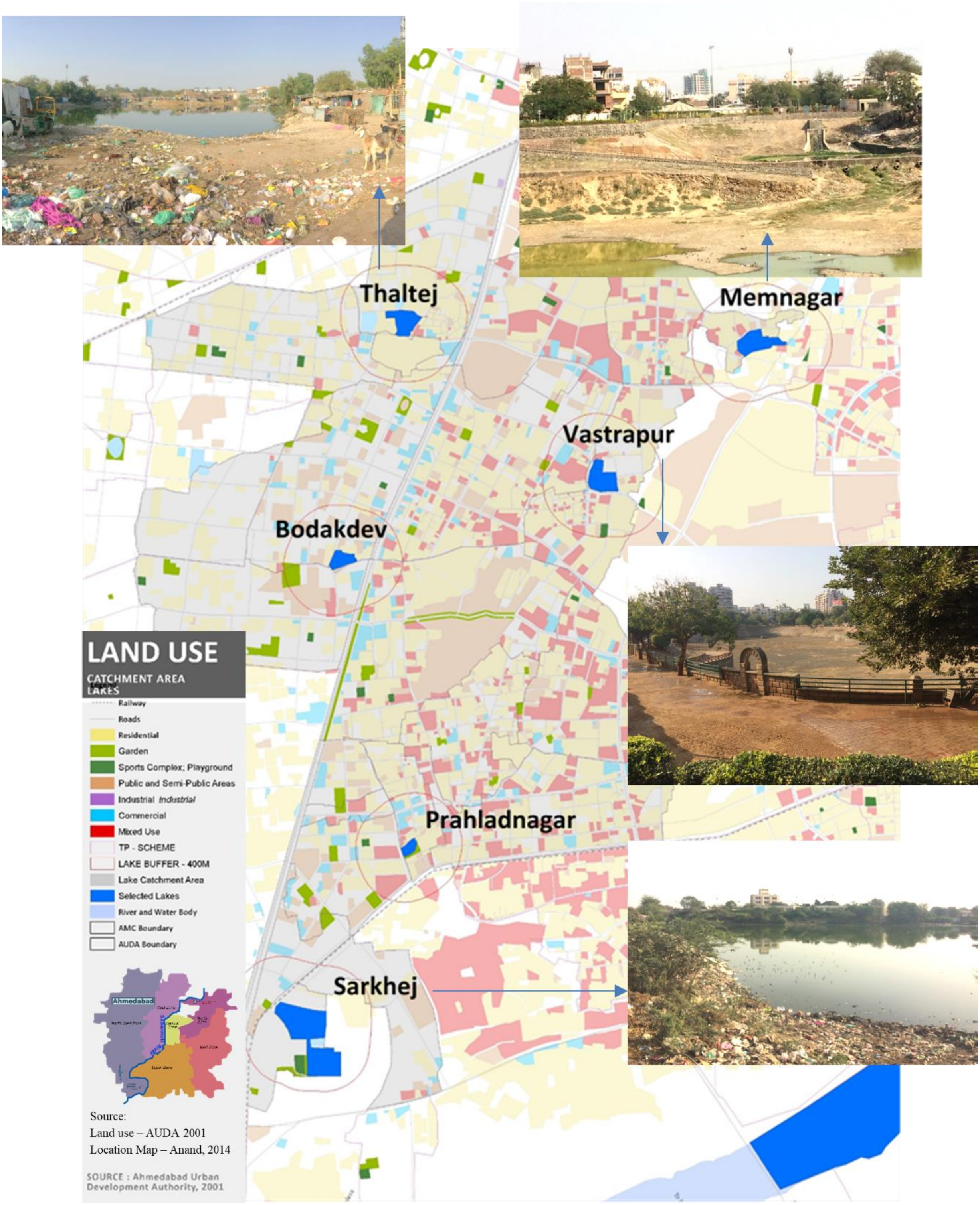

Figure 6: Location map of selected interlinked lakes in Ahmedabad (Source: Land use: AUDA; Location map: Anand, 2014; Photographs: Author)

4. RESEARCH APPROACH AND METHODS

4.1. Methodology: Justification

The study aimed at developing a decision support tool considering multiple dimensions of sustainability for 6 selected interlinked lakes in Ahmedabad. The tool can aid in the evaluation of the relative degree of sustainability of the interlinked lakes. Employing a broad understanding of sustainability consisting of the social, environmental, and economic dimensions, the decision support tool needed to be based on a method that can combine multiple factors. Therefore, the tool was based on multicriteria analysis (MCA) since it is a systematic and analytical method that allows considering multiple context-specific factors under the three dimensions of sustainability. MCA helped to create a multi-dimensional index that considers several factors to achieve multiple objectives. The purpose of the index was to assess the relative degree of sustainability of interlinked lakes. This means that the index tells how sustainable the interlinked lakes are and it may also help in identifying areas of improvement for the future to have a higher degree of sustainability.

The index incorporated multiple relevant qualitative and quantitative factors having different measuring units. These factors can be integrated by standardizing them and assigning weights according to their relative importance in the index. Based on this and the role of the factor in the index (cost/benefit), MCA allows to generate results that are easy to understand, communicate, and analyze (Adams & Ghaly, 2007). In addition, MCA can also incorporate stakeholder perspectives (Tsoutsos et al., 2009) and offer a platform to analyze the existing condition of interlinked lakes. The assessment of the index provided insight into the nature of the problem, synergies, and trade-offs between considered dimensions. This contributed to supporting complex decisions involving multiple factors and objectives.

4.2. Research Design | Operationalization of sub-objectives

The operationalization of the 3 sub-objectives (Table 4) is discussed in this section. Under each of the three sub-objectives, along with the literature review, context-embedded knowledge of relevant stakeholders and experts was considered important and valuable in the research (Van Ast et al., 2010). To incorporate this, semi-structured interviews, surveys, and a panel discussion were conducted after identifying relevant stakeholders and experts. Methodology, data description, data source, and expected outputs are discussed in Table 4. The operationalization of the three sub-objectives to develop and apply multicriteria decision support tool for the 6 selected interlinked lakes in Ahmedabad to promote and support sustainable lake ecosystem planning and decision making was achieved by 4 main steps indicated in Figure 7. These 4 steps are discussed in detail in the next sections.

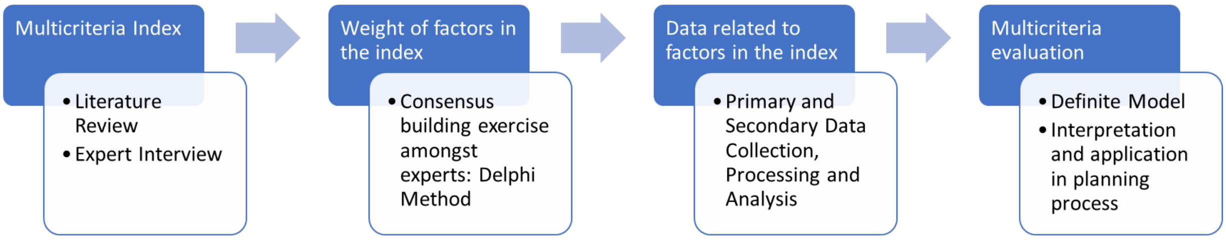

Figure 7: Four steps to achieve the main objective

Table 4: Operationalization of sub-objectives

Sub-objective 1: To analyze existing planning approaches of interlinking lakes.				
Analytical Questions	Methodology	Data Description	Source	Expected Output
1.1) What are the existing planning approaches employed for interlinking lakes?	1. Literature Review	1. Overarching aim and purpose 2. Existing Interlinking lakes planning approach	Scientific Literature, papers, articles, conference papers, reports, etc. Total referred: 14	Summary of different approaches for interlinking
1.2) What are the characteristics of different planning approaches for interlinking lakes?				Characteristics of different planning approaches
1.3) What are the strengths, gaps, and challenges of the planning approaches for interlinking lakes?		Assessment/evaluation summary, infrastructure costs, potential/actual benefits, etc.		Strengths/Gaps/ Challenges of different planning approaches
Sub-objective 2: To design and apply a multicriteria decision support tool for interlinked lakes to promote and support sustainable lake ecosystem planning and decision making.				
Analytical Questions	Methodology	Data Description	Source	Expected Output
2.1) Which factors are important to consider for interlinking lakes?	1. Literature Review 2. Multicriteria Analysis	Literature	Scientific Literature-papers/articles/conferences	1. Multicriteria Index 2. Meaning and importance of each factor
	Expert Interviews	1. Experts from different backgrounds 2. Questionnaire for interview	Citizen's collective (Group of water experts)	1. Multicriteria Index contextualized to the study area
2.2) How do the factors in the multicriteria index affect the overall sustainability of the lake ecosystem?	Literature Review Expert Interview Analysis	Literature and expert inputs	1.Scientific Literature-papers/articles/conferences 2. Expert Interviews	1. Meaning, Importance, and Assumption of each factor
	Literature Review	Contribution of each indicator in terms of cost/benefit	Scientific Literature-papers/articles/conferences, reports	1. Role of indicators (cost/benefit)
2.3) What is the relative importance of the factors and how can the factors be measured?	Delphi Method	1. Literature 2.6-8 experts from different backgrounds 2. Structured survey form	Citizen's collective (Group of water experts)	1. Weight of each factor
	Literature Review Expert Interview Analysis	Computation/ Measuring Method/Proxy indicators etc.	1.Scientific Literature-papers/articles/conferences, reports 2. Expert Interviews	1. Computation Method
2.4) What are the inferences and insights the multicriteria decision support tool output provides?	MCE	Tool inputs and settings	from 2.1, 2.2, 2.3	SI scores, score of dimensions
	Interpretation of outputs	SI scores, score of dimensions	Results from the tool	Decision-making insights
Sub-objective 3: To discuss the potential of the tool for planning and decision making processes.				
Analytical Questions	Methodology	Data Description	Source	Expected Output
3.1) How can the insights be incorporated into the planning process to achieve multiple objectives?	Panel discussion with experts	1. 2 experts 2. Semi-structured interview questions	1. Citizen's collective (Group of water experts) 2. Output from the tool	Potential use of the tool in practice
3.2) How can the developed tool be used in the planning and decision making of interlinking lakes?				Strengths, Limitations, and applicability of the tool in practice

4.2.1. Developing the multicriteria index

Learnings from studying the cases of interlinking lakes were used to construct a multicriteria index (Figure 1) based on the literature review (Chapter 2). The index was categorized under three pillars of sustainability: social, environmental, and economic. The index was contextualized and validated to the study area by experts' inputs. The study aimed at incorporating inputs from 6-7 experts to incorporate a varied range of inputs. Since the research expected interaction with experts multiple times and considering the uncertainty of their availability, more than the aimed number of experts were contacted so that in the end this number is maintained. A total of 19 experts from relevant and different backgrounds were contacted on (and through) a citizen's collective platform. This platform is a group called 'Ahmedabad Water People' where experts lead several water awareness related activities, publications, and projects both academically and professionally.

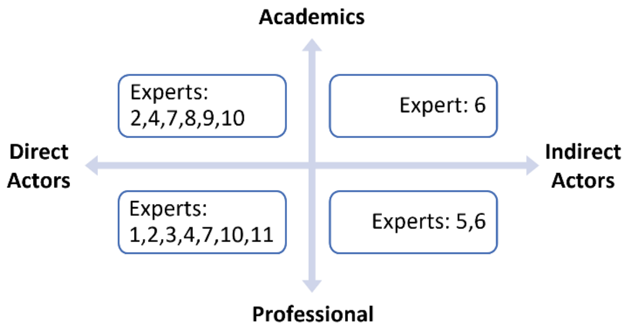

Figure 8: Experts

Out of 19, 11 experts agreed to contribute to the study, and one on one interviews with these experts was conducted online by the author. The purpose of the interviews was to use the knowledge of local experts to validate the factors in the developed multicriteria index (from literature) in the context of interlinked lakes in Ahmedabad and add the missing factors. These experts are linked with lakes directly or indirectly with the case study area (Figure 8). The number of experts directly linked with the interlinking of lakes in the case study area was more than the indirect experts. The number of experts in the field of academics and processionals was the same. The experts received the multicriteria index developed from the literature review and objective of the study prior to the interview. Based on the purpose of the index and the objective of the study, the inputs from the experts (Annex 1) were incorporated and the index was updated (Figure 11). The importance of each factor, it's meaning and assumption in the index, its effect on the index, and its role (cost/benefit) (Annex 3, Table 14) were derived from literature and supported by expert inputs. The computation method (Annex 3, Table 14) to measure the index and evaluate the sustainability of interlinked lakes was designed by the author.

4.2.2. Weights of the factors in the index

The weights of the factors in the index were derived using the Delphi method[7]. Planning is a collaborative process and experts from different backgrounds having varied experiences are involved in the decision making process. Delphi method was adopted because the consensus building amongst the experts can contribute to making informed and validated decisions.

For this, a survey was shared with 11 experts (Figure 8). The survey aimed to weigh the formulated factors according to their importance and reach a consensus among the experts. The survey included 19 factors along with their meaning in the index. The experts were asked to rank each factor between 1 to 5 based on its importance (where 1 is least important and 5 is most important). Taking into consideration the time constraint of the research, 3 rounds were conducted. Responses were compiled at the end of each round (Annex 2, Figure 19). From round 2, the experts were shared the answers of other experts anonymously, and based on that, they could decide whether they wanted to change their answers or not.

[7] Delphi method is a consensus building exercise amongst a group of experts on a particular topic (Dalkey, 1969).

To identify the weights of the elements in the index (dimension, domain, factors, indicators), first, the weights of the factors were identified based on the Delphi method results. To do this, the overall weight of the score category indicated in Table 5 was divided equally between factors that fall in the category. The weight of the factors derived was divided equally between the indicators. Similarly, the scores of groups of factors under each domain were added up to identify their weights and further added up to identify the weights of the three dimensions in the index. To use the weights in the tool, the weights were normalized to have the total of each group equal to 1 (Annex 2, Table 13).

Table 5: Derivation of factor weights

Score	Meaning of the score	Overall weight (%)
1	Very low importance	0
2	Low importance	0
3	Medium importance	5
4	High importance	40
5	Very high importance	55

4.2.3. Data collection, analysis, and management

To measure the sustainability of interlinked lakes, a computation method for the indicators in the index was designed. The computation method and data source for the indicators are mentioned in Annex 3, Table 14. Data was collected from five sources which are listed below. Details and questionnaires related to on-field data collection are mentioned in Annex 4.

1. **On-field observations**: This included 10 aspects of lakes to be observed on-site which are listed in Annex 4. Each of the 10 aspects relates to an indicator in the index. In order to document different activities during different times of the day, field observations related to documenting activities in and around the lake (observations: 1, 2, 8, and 10) were observed during both morning and evening times.
2. **On-field interviews with users of the lakes**: On-field interviews with 30 users of the lake were carried out in both morning and evening times. The sample size of 30 interviews was selected to allow incorporating a varied range of opinions from different age groups (young, adult, old) and gender (male, female). The distribution of interviewee sample size was equal between the identified classification of age group and gender. This means that 5 interviews were conducted for each gender for each age group. The questionnaire included 5 questions to know the opinion and perceptions of users of the lakes which are listed in Annex 4.
3. **On-field interviews with other stakeholders** (Corporator and Schools in neigbourhood): There are 48 wards in Ahmedabad and each ward has 4 corporators that are elected representatives of the ward. The corporators represent the residents and their needs. The selected lakes are under a total of three wards in Ahmedabad. An interview with one corporator of these three wards was conducted to ask 8 questions (Annex 4) on residents' involvement, engagement, and issues with the selected lake. During expert interviews, it was discussed that awareness and basic water education is very important. Schools play a vital role in creating this awareness and contributing to a larger extent by educating students about the importance of wetlands in their neigbourhood. This can be done by either engaging in activities at lakes or including knowledge in the course curriculum. To physically engage in activities at the lake, it is convenient if the lake is accessible within 20-30 minutes of walking. Hence, two schools within a radius of 3 km around the lake were selected. The selection of schools had diversity in terms of government, private schools, and pre-primary, primary, high school, and higher secondary schools. An interview was conducted

with social science teachers and 3 questions (Annex 4) were asked regarding the contribution of the school to increasing and creating awareness about water and local water bodies.

4. **Contacting government organizations for existing data**: Government organizations in Ahmedabad and Gandhinagar were contacted for current and temporal data. The organizations contacted and data received from them are listed in Annex 4.
5. **Other secondary open data sources**: Data for indicators available from open sources were used. This is mentioned in Annex 3, Table 14.

Sources 1 to 4 were collected from the fieldwork planned in the study area with the help of a local research assistant (Figure 9). The fieldwork was planned for 17 days. The research assistant spent 2 days at each lake for about 3 hours each in the mornings and the same in the evenings to document the field observations and interview the users of the lake. During the rest of the day, tasks related to interviewing other stakeholders and contacting government organizations were completed. The work plan and progress of the field work (Annex 5, Table 15) was regularly coordinated during the day with the research assistant supported with daily meetings at the end of the day.

Figure 9: Field work pictures (from left): women gathering in evening at Vastrapur lake, stakeholders engaging in activities to create and spread awareness about lake cleanliness at Vastrapur lake, research assistant at Sarkhej lake

All interviews were recorded (with the consent of the participant) and field observations were supported by photographs. Based on the notes taken by the research assistant in the field, supported by recordings of the interviews, photographs, and raw data from the institutions were compiled by the author. Microsoft Excel was used to understand, interpret, and analyze the data collected. Based on this, the indicators were evaluated (Annex 6) based on their computation method, assumption, and role in the index. For all indicators, a relative score for the six lakes was allotted based on the performance of the lake. The summary of the indicator evaluation is shown in Table 8.

Data from primary (on-field/expert inputs) were collected in the form of interviews and survey responses. Data provided by the different government organizations were studied and prepared to use it for indicator evaluation. Similarly, secondary data obtained from the open data sources were prepared for indicator evaluation. Data collected from interviews are anonymized and summarized in the appendix. Thus, recordings and transcripts of the interviews would require consent from the interviewees for sharing. Similarly, responses to the surveys conducted on the field and with the experts in the Delphi method are anonymized and summarized in the appendix. Data archiving is not causing any known conflicts to the data suppliers. The collected data are stored and archived following the GDPR guidelines by the author on a personal drive protected by a password. The author has developed a readme file for the data repository which is providing information about each data set for its correct and complete interpretation when sharing or publishing data. The data repository along with the readme file is also submitted to the faculty ITC.

4.2.4. Multicriteria evaluation

For multicriteria evaluation, Definite Tool 3.1, developed by the Vrije Universiteit Amsterdam (VU) is used. Definite tool is a decision making software package that is based on a finite set of defined alternatives. The tool was developed to evaluate and contribute to improving decision making on the identified problem to address the set goals/objectives (VU, 2022).

The 6 selected lakes are set as alternatives in the tool. Dimensions, domains, and factors in the index are the groups of effects in the Definite tool. The developed multicriteria index (Figure 11), the role of indicators (cost/benefit) (indicated in Table 8), and the score of each indicator (based on indicator evaluation in Annex 6) for the 6 lakes were used as inputs to prepare the tool in the Definite software. Primary and Secondary data collected (Annex 3, Table 14) was used to evaluate the indicators. The indicator evaluation method was designed by the author. Lakes were scored for each indicator based on their relative performance. The summary of the evaluation method and its justification along with the data sources is mentioned in Annex 6. After the tool is ready using the above mentioned inputs, derived weights of the elements in the index using the Delphi method were added. The tool used the Weighted Summation[8] method to rank the alternatives (six lakes). To align the different measurement units, Interval[9] and Maximum[10] standardization methods were explored in the tool.

Using the aforementioned inputs (multicriteria index, indicator scores, weights of elements in the index) and tool settings (cost/benefit, MCA method, standardization method), the tool ranked the alternatives (six lakes) between 0 to 1. This demonstrates the sustainability index score (relative) of the lakes calculated by the tool based on the aforementioned inputs. Here, score 0 is interpreted as the lowest sustainability score and 1 as the highest sustainability score.

To evaluate the developed decision support tool and understand its applicability in practice, a panel discussion with 3 experts was organized. This contributed to understanding the usage of the tool in the study area as well as the possibility to use the tool in different contexts. The experts received discussion questions before the panel meeting and a short summary of the four steps of developing the decision support tool (Figure 7) was presented during the panel meeting. Followed by that, experts were asked questions about the developed tool which were shared with them prior to the discussion. The questions asked to the experts are listed in Annex 7 and the summary of the inputs received from the experts is presented in the results section 5.3.

4.3. Ethical Considerations, Risks, and Contingencies

The study largely depends on primary data collected by conducting semi-structured interviews and online surveys with stakeholders and experts. The participants at all stages of interaction were asked for their consent. In the case of interviews with the experts, their consent to participate and contribute to the study was taken through email conversations. The responses from the online survey sent to the experts (as a part of the Delphi method) were supported by a digital signature from the participants showing their consent to participate. For the interviews conducted by the research assistant on the field, verbal consent was taken from the participants.

[8] Weighted summation method standardizes all effects score and a score of the identified goal for selected alternatives are calculated by adding the multiplied standardized effects with its weight (Janssen & Van Herwijnen, 2006).
[9] In interval standardization method, effects of scores are linear interpolations between the worst (0) and best (1) effect score (Janssen & Van Herwijnen, 2006).
[10] In maximum standardization method, effect of scores is divided by the maximum value of the effect (Janssen & Van Herwijnen, 2006).

The interviews with the experts and stakeholders did not collect any personal information related to the identification of the person such as name, contact information, profile, etc. In the case of expert interviews, the summary of inputs was anonymized and does not share any personal information or profile of the experts. When all the interviews (with experts and on the field) were recorded, the participants were asked for their consent verbally and the recordings were used by the author to summarize the responses. The recordings were not shared or used to extract any personal information of the participants. Thus, the recordings and the transcripts can only be shared after taking consent from the participants. All the interviews conducted were summarized and are attached in the appendix of the thesis.

The interviews were designed based on a set of predefined questions which allowed the participants to communicate freely to some extent. This means that there was a risk of missing out on an important response/opinion if the semi-structured interview questionnaire missed incorporating some open-ended questions. Hence, some questions were designed in a manner that allowed free communication. Also, it is important to note that different personal opinions/biases may have affected the responses and hence influence the outcome of the interview.

The multicriteria index was developed based on a literature review and expert interviews. Nevertheless, there was a risk of missing out on an important factor, and hence it may have affected the overall results of the research. However, the study intended to explore and demonstrate the mechanism of the multicriteria decision support tool (which can be revised, altered, or changed as per context). In addition, the methodology adopted as part of the study may have multiple interpretations of the outputs and it can be miscommunicated if the process was confusing. For mitigation, all the steps involved as a part of developing the tool are transparently documented for easy communication.

5. RESULTS

The main objective of the study was to develop and apply a multicriteria decision support tool for 6 interlinked lakes in Ahmedabad to promote and support sustainable lake ecosystem planning and decision making. This chapter presents and explains the final outcomes from the applied methodology (Chapter 4) to achieve the main objective of the study. In the first sub-objective, existing planning approaches of interlinking lakes studied in the literature review (Chapter 2) were analyzed. The results (section 5.1) elaborate on the characteristics of different interlinking approaches, their strengths, gaps, and challenges. Based on the learnings from this, the second sub-objective focused on designing and applying a multicriteria decision support tool. The results in section 5.2 elaborate on how the decision support tool was developed. As a part of the third sub-objective, the potential of the developed tool for the planning and decision-making process was evaluated. For this, a panel discussion was conducted by the author with 3 experts. The results related to this sub-objective are summarized in section 5.3.

5.1. Sub-objective 1: To analyze existing planning approaches of interlinking lakes

Table 6 shows the summary of the different planning approaches of five studied cases (Chapter 2). The table shows the purpose of interlinking (overarching aim), its planning approach (adopted from literature), and interlinking (intervention) characteristics.

Table 6: Summary of different planning approaches of interlinking lakes (Developed by the author based on the literature review)

Case	Overarching Aim of interlinking	Planning Approach	Interlinking characteristics	References/Sources
Malmo	- Stormwater management - Reduce urban flooding	Nature-Based solution (NbS)	- Open interconnected network (environmental) - Interconnected network passing through the soft permeable landscape of green and blue spaces (environmental) - Nature-based solutions considering environmental factors (environmental)	(Barton, 2016; Niemczynowicz, 1999; Haghighatafshar et al., 2014; Stahre, 2002)
Copenhagen	- Stormwater management - Reduce urban flooding - Improve water quality	Flood resilient	- Closed interconnected piped network (environmental) - Interlinked network collecting stormwater from urban areas connected to the sea (environmental)	(Lindegaard, 2001; Barton, 2016; Haghighatafshar et al., 2014)
Udaipur	- Storage of rainwater - Minimum loss of water - Use lake front for recreational purposes	Rainwater Conservation and management	- Interconnected descending (man-made) lakes network (environmental) - Direct water from the urban catchment area into the lakes (social)	(Mirza, 2018; Razdan, 2005; Choudhary & Sharma, 2021; Nair et al., 2016)
Taoyuan	- Retore degraded ecosystem of ponds - Achieve maximum potential of water body socially and economically	Sustainable planning	- Reviving the lost interconnect open network using sustainable solutions - Restoring the use of the canals for transport (economic) - Maximizing the use of the waterfront as a public space (social) - Minimum intervention in the hydrological system of the ponds (environmental)	(Shih & Qiu, 2021; Huang et al., 2011)
Ahmedabad	- Stormwater management - Reduce urban flooding - Increase ground water table - Develop the lake for recreational use	Techno-planning solution	- Closed interconnected piped network (environmental) - Reclaim land around the lake for recreational activities (social)	Source: AUDA (Desai, 2020; Anand, 2014; Bal et al., 2011)

The table gives insight into the lake interlinking approach in terms of which factors under the three sustainability pillars were considered during the planning and implementation process of interlinking lakes to achieve the overarching aim (Figure 10). In addition, in reference to the factors (social, environmental, and economic) considered during the planning process, the nature of solutions (sustainable or unsustainable practices) adopted was also studied (Chapter 2). Hence, it is possible that the planning approach is considering social, environmental, and/or economic factors, however, the solutions adopted to do this can contribute to developing overall sustainability or drift away from it. This is discussed further in this section. Based on the literature review (Chapter 2) and understanding developed from Table 6 and Figure 10, the strengths, gaps, and challenges of each case are discussed in Table 7.

Taoyuan has a sustainable planning approach of interlinking ponds (Figure 10) to address the overarching aim of restoring the lost open interlinked network and achieving the maximum potential of the water economically and socially (Table 6). The benefit and strength of the open interconnected network is that it allows easy maintenance (Table 7). The interlinking considered relevant social, environmental, and economic factors, and interlinking was implemented using sustainable solutions. Hence, this contributed to increasing the overall sustainability of interlinked ponds. However, as indicated in Table 7, uncoordinated and unplanned urbanization can be a potential threat to maintaining the natural ecosystem of interconnected ponds.

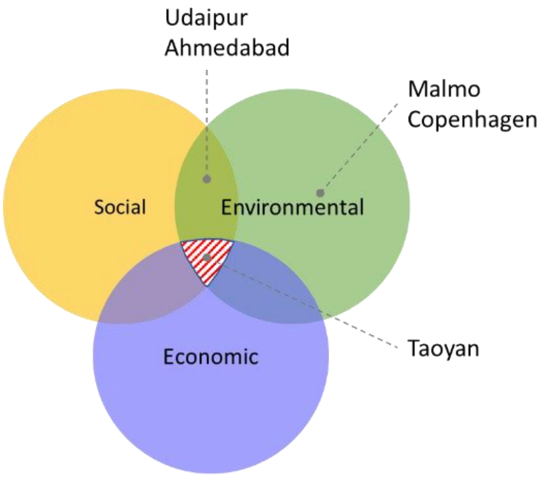

Figure 10: Sustainability of the planning approach (Developed by the author based on the literature review)

Udaipur and Ahmedabad considered social-ecological factors (Table 6, Figure 10) in the adopted planning approach of interlinking lakes for water management. On the one hand, Udaipur aimed to collect rainwater for storing and its usage and on the other hand, Ahmedabad aimed to collect the stormwater from the catchment areas to reduce water clogging in urban areas. The planning approach of interlinking lakes in Udaipur considered social and environmental factors and adopted sustainable solutions for interlinking (Table 7). Economic dependency on the lakes was developed contributing to increasing the overall sustainability of interlinked lakes. The techno-planning approach of interlinking lakes in Ahmedabad also considered social and environmental factors. However, contradicting the case of Udaipur, Ahmedabad followed some unsustainable solutions and practices of interlinking. For example, reclamation of land around the lake for recreational activities (in some interlinked lakes) was done using hard materials like concrete which is not considered a sustainable solution (discussed in detail in 3.3). In addition to this, not all relevant social, environmental, and economic factors were considered during the planning process which was the identified gap (Table 7).

Malmo and Copenhagen both focused on environmental factors (Figure 10) to reduce urban flooding. Malmo adopted an open interconnected network, and this was done by implementing nature-based solutions. Copenhagen had a flood resilient planning approach, and the interlinking was done by laying a closed (underground) piped network (Table 6). Copenhagen is studying the environmental impacts of the adopted planning approach and it is attempting to switch to more sustainable solutions (Table 7). The sustainable solutions of interlinking in Malmo make it the strength of the planning approach. However, the city is vulnerable to flooding and its mitigation is a growing concern and challenge (Table 7).

Table 7: Strengths, Gaps, and Challenges of planning approaches of interlinking (Developed by the author based on the literature review)

Case	Strengths	Gaps and Challenges	References/Sources
Malmo	- Nature-based solutions for interlinking - Open network: Easy maintenance - New urban development takes into consideration the interlinked network	- Rising water levels due to climate change in the open networks making the city vulnerable to flooding	(Barton, 2016; Niemczynowicz, 1999; Haghighatafshar et al., 2014; Stahre, 2002)
Copenhagen	- Attempts to interlink canals using sustainable solutions have been initiated - Environmental impacts of the planning approach and the interventions are studied	- Water quality has always been an issue - Release of household and industrial waste in the water without filtering.	(Lindegaard, 2001; Barton, 2016; Haghighatafshar et al., 2014)
Udaipur	- Interlinking was done using sustainable solutions - Social and economical dependency on the lake contributed to active usage of the lakes	- With increasing urbanization, the natural ecosystem of the lakes is disturbed - Attention is required to maintain interlinked lakes	(Mirza, 2018; Razdan, 2005; Choudhary & Sharma, 2021; Nair et al., 2016)
Taoyuan	- Interlinking was done using sustainable solutions - Open interconnected network: Easy maintenance - Multiple uses of canals as a waterfront for transportation, irrigation, and water storage - Considering relevant social, environmental, and economic factors during the planning process.	- Increasing urbanization is a potential threat to the natural ecosystem of the ponds (if urbanization is not planned and coordinated)	(Shih & Qiu, 2021; Huang et al., 2011)
Ahmedabad	- Successfully installed percolation wells to increase the overall groud water table	- Some of the relevant social, environmental, and economic factors were not considered. - Interlinking adopted some unsustainable solutions/practices - No monitoring and assessment were done to evaluate the planning approach	Source: AUDA (Desai, 2020; Anand, 2014; Bal et al., 2011)

5.2. Sub-objective 2: To design and apply a multicriteria decision support tool for interlinked lakes to promote and support sustainable lake ecosystem planning and decision making.

A multicriteria index was developed by identifying factors important to consider during the planning process of interlinking lakes mentioned in the literature (discussed in section 2.3). The developed index shown in (Figure 1) consisted of 16 factors and 22 indictors. With the support of 11 expert interviews, the index was validated and contextualized to the study area. Inputs from all 11 expert interviews are summarized in Annex 1, Table 11. Below is the list of key inputs received from all the experts during the interviews:

1. All the 11 experts supported and acknowledged the need for and importance of participatory planning in reference to lake development.
2. Common feedback received from all 11 experts was on the importance of governance (institution, legal and finance aspects). This includes factors like land use around the lake, land reclamation around the lake, development and management costs related to interlinking.
3. It was pointed out by almost 50% of the experts (Experts: 1,2,3,6,8) that environmental impact assessment of the interlinking project is very crucial to evaluate the planning approach.
4. Social factors like basic awareness, water education, and inclusion of all economic/social classes were suggested to be added to the index (Experts: 1,4,7,8,11).

5. Flood water management in urban areas is one of the important factors to be incorporated which investigates flood mitigation strategies and lake storage capacity (Experts: 7,11).
6. Other ecological factors like microclimate and lake edge characteristics were indicated as important factors to be added to the index (Experts: 3,5,7,10).

Based on the inputs from the expert interviews, the updated index (Figure 11) included 19 factors and 37 indicators. As it can be seen from Figure 11, the multicriteria index is designed in 4 hierarchies namely: dimensions, domains, factors, and indicators. The details on the meaning, importance, assumption of the factors in the index, indicators to measure these factors, its data sources, and computation method are listed in Annex 3, Table 14.

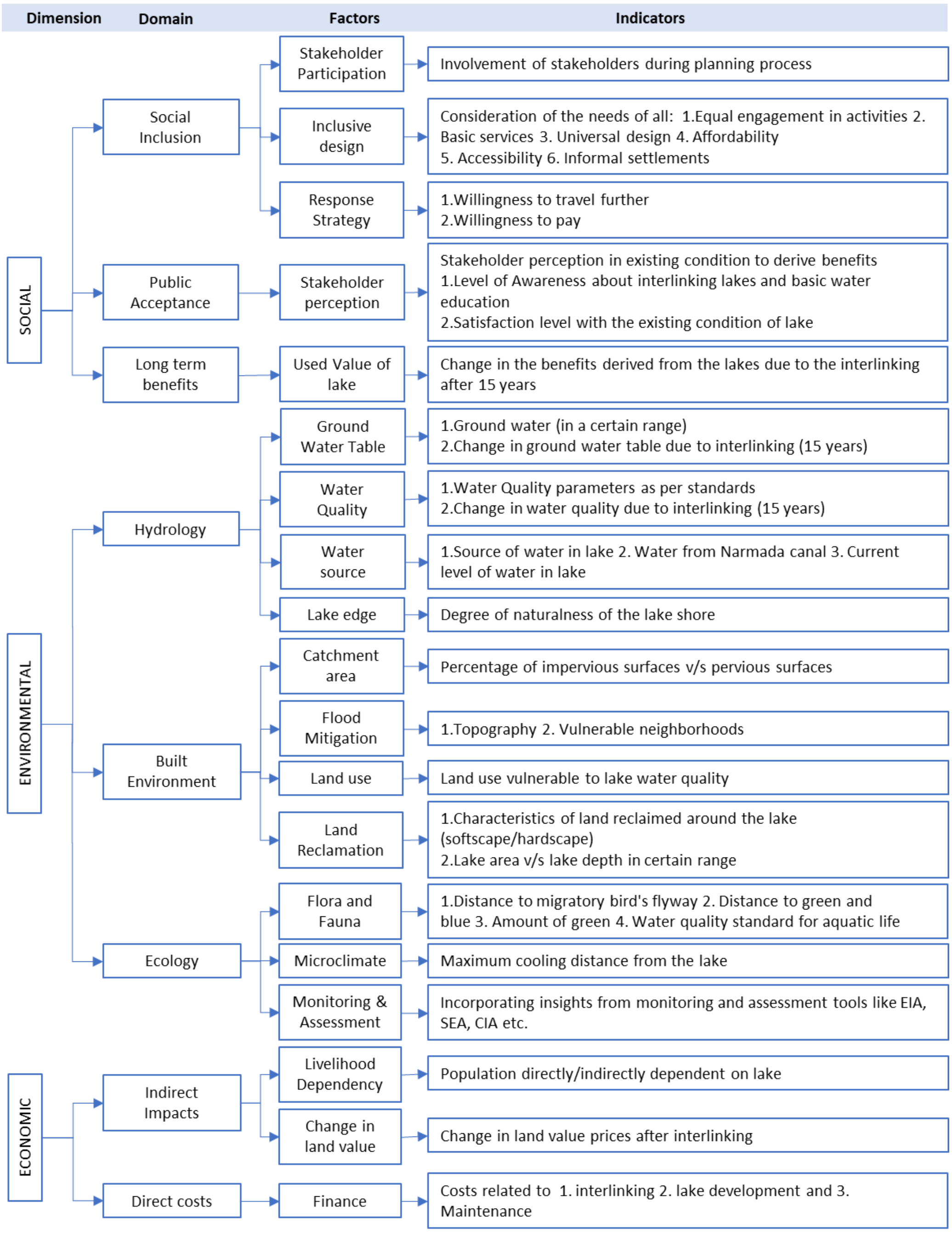

Figure 11: Multicriteria index (Developed by the author based on the literature review and expert interviews)

As discussed in the methodology section (4.2.2), the Delphi method was used to identify the weights of the factors in the index and other elements under the 4 hierarchies in the index and was calculated based on the results presented in this section. Multiple rounds of an online survey form were shared with 11 experts (Figure 8) and in the end, 70% consensus on the importance of factors amongst the experts was targeted for all factors. Due to the time limitation of the study, availability of time from the experts, and acknowledging the fact that the study requires inputs from the experts multiple times, 3 rounds of the survey were conducted. The response rate of 63.63% with 7 responses in each round was achieved. Responses by the experts in the 3 round is as shown in Annex 2, Figure 19. The level (percentage) of consensus on the importance of factors in the index amongst the experts in the three rounds is indicated in Figure 12.

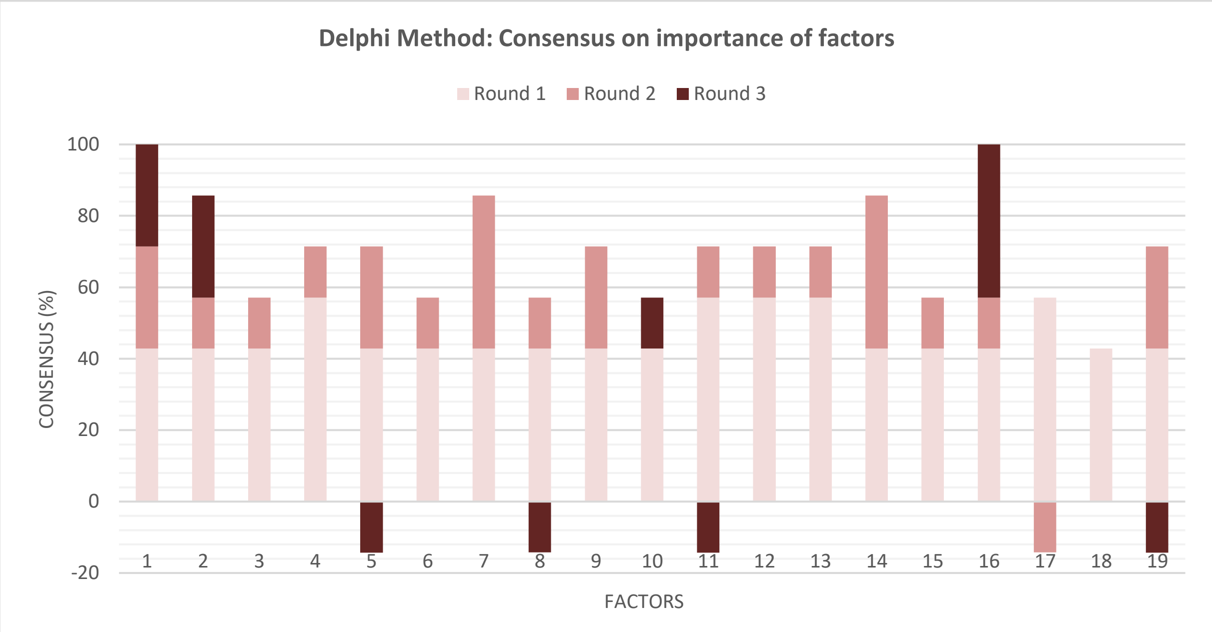

Figure 12: Level of consensus amongst experts in 3 rounds

Factors: 1. Stakeholder Participation 2. Inclusive Design 3. Response strategies 4. Stakeholder Perception 5. Used Value of lake 6. Ground Water Table 7. Water Quality 8. Water Source 9. Lake Edge 10. Catchment Area 11. Flood Mitigation 12. Land Use 13. Land Reclamation 14. Flora and Fauna 15. Microclimate 16. Monitoring and Assessment 17. Livelihood Dependency 18. Change in land value 19. Finance

At the end of 3 rounds, a targeted 70% consensus for all factors was achieved for 9 out of 19 factors. Overall, above 42% consensus and higher was achieved (Figure 12). Demonstrating the use of the Delphi method and using the results to identify the weights of elements in the index was considered satisfactory in this study even though the targeted consensus was not achieved for 10 factors.

As indicated in Figure 12, in the third round, consensus on the importance of 4 factors increased. For the remaining 15 factors, it either remained the same or decreased. For two factors in the index, factor 1: stakeholder participation and factor 16: monitoring and assessment tools, 100% consensus was reached where all experts ranked the factors by very high importance. Weights of the factors derived from the Delphi method are as shown in Annex 2, Table 12. The normalized weights entered in the Definite tool

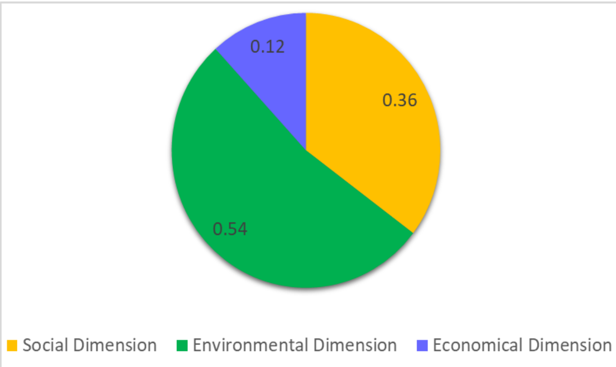

Figure 13: Derived weights of the 3 dimensions in the index

are indicated in Annex 2, Table 13. The derived weights of the three dimensions of sustainability are shown in Figure 13. The environmental dimension has the highest weight in the index (0.54) followed by the social dimension (0.36) and the economical dimension has the lowest weight (0.12).

The tool on the Definite software was prepared using the required inputs and tool settings (as mentioned in section 4.2.4) for MCE. The evaluation and relative scoring of the 37 indicators in the index is summarized and discussed in Annex 6. The summary of indicator evaluation which includes the role of the indicator (cost/benefit), unit of measurement (explained in Annex 6), and the relative score received by the six lakes for 37 indicators are indicated in Table 8. The scores highlighted in the table in red are the lowest scores received by the lake (as compared to other lakes) and the scores highlighted in green show the highest scores received by the lake (as compared to other lakes).

Table 8: Summary of indicator evaluation (Based on indication evaluation - Annex 6)

Dimension	Domain	Factors and Indicators	C/B	Unit	Memnagar	Vastrapur	Bodakdev	Thaltej	Prahaladnagar	Sarkhej
Social	Social Inclusion	1.Stakeholder Participation								
		Involvement of stakeholders during planning process	B	binary	no	no	no	no	no	no
		2.Inclusive Design								
		Equal engagement in activities	B	Score out of 7	3	5	7	3	4	3.5
		Basic services	B	Number of services out of 6	2	2.5	2.5	0.5	2.5	3
		Universal Design	B	Number of services out of 3	0	2	0	0	0	0
		Affordability	B	binary	yes	yes	yes	yes	yes	yes
		Accessibility	B	Score out of 5	2.5	3.5	2.5	2	2.5	1.5
		Informal settlements	C	binary	yes	no	no	yes	yes	yes
		3.Reponse Strategy								
		Willingness to travel further	B	Number of responses	19	10	28	20	24	25
		Willingness to pay	B	Percentage	70	66.7	20	53.3	40	53.3
	Public Acceptance	4.Stakeholder Perception								
		Level of awareness	B	Score out of 4	3	4	3	2	3	3.5
		Satisfaction level with existing condition of lake	B	Percentage	43.3	40	66.7	46.7	56.7	73.3
	Long term benefits	5.Used value of lake								
		Change in benefits derived from lakes	B	Percentage	86.7	96.7	93.3	83.3	90	83.3
Environmental	Hydrology	7.Water Quality								
		Water quality	B	Score out of 5	1.9	3.5	0	2.8	3.9	0.9
		Change in water quality	B	Score out of 13	5.5	7.5	0	5.5	6	5.3
		8.Water Source								
		Source of water	B	binary	no	no	no	no	no	no
		Prince and amount of water from narmada canal	B	binary	no	no	no	no	no	no
		Level of water	B	Percentage	0.3	0.3	0	0.5	0	0.3
		9.Lake edge								
		Degree of naturalness of lake edge	B	Score out of 1	0	0	0	1	0	1
	Built environment	10.Catchment area								
		Total pervious surfaces	B	Percentage	12	18	41	33	20	38
		11.Flood Mitigation								
		Topography and catchment area	B	Score out of 1	1	1	1	0.5	1	0.5
		Neighbourhoods vulnerable to flooding	C	Percentage	2	0.7	0	1.5	0.5	0
		12.Land use								
		Land use vulnerable to lake ecosystem	C	binary	no	no	no	no	no	yes
		13.Land Reclamation								
		Characteristics of land reclaimed around the lake	B	Percentage of softscape	30	60	90	70	60	100
		Lake area v/s lake depth in certain range	B	Score out of 2	0	0	1	1	0	2
	Ecology	14.Flora and Fauna								
		Distance to migratory birds flyway	C	km	17.11	16.68	15.6	14.22	17.96	18.68
		Amount of green and blue in catchment area	B	percentage	7.5	6	13	8	14	11
		Vegetation cover	B	Score out of 1	0.8	0.7	1	0	0.7	0
		Water quality standard for aquatic life (DO)	B	mg/l	5.3	7.95	3.6	5.6	5.7	3.95
		15.Microclimate								
		Maximum cooling distance	B	Score out of 2	1.1	1	1	0.5	0.7	0.3
		16.Monitoring and Assessment								
		Assessment details	B	binary	no	no	no	no	no	no
Economic	Indirect Impacts	17.Livelihood Dependency								
		Population directly/ indirectly dependent on lake	B	Number of different groups	3	6	5	4	5	2
		18.Change in land value								
		Increase in land value	C	Percentage	26.74	59.3	56.31	76.47	61.29	29.82
	Direct Impacts	19.Finance								
		Cost of interlinking	C	Rank	3	2	5	6	4	1
		Cost of development	C	INR in million	16.2	12.2	10	17	11.7	16.3
		Cost of maintenance	B	binary	no	yes	yes	no	yes	no

The sustainability (SI) scores derived from the tool based on the methodology discussed in chapter 4 is shown in Figure 14, and 15. Figure 14 and Figure 15 show the SI scores for the lakes using maximum and interval standardization methods, respectively. As it can be seen, the score for the lakes is similar in both standardization methods. However, the visible differences in scores using the interval standardization method are more prominent. Hence, for better understanding and interpretation results using the interval standardization method are visualized. Figure 16 shows the visualization of the sustainability index (SI) score of the six lakes along with the performance of each of the three dimensions (social, environmental, and economic).

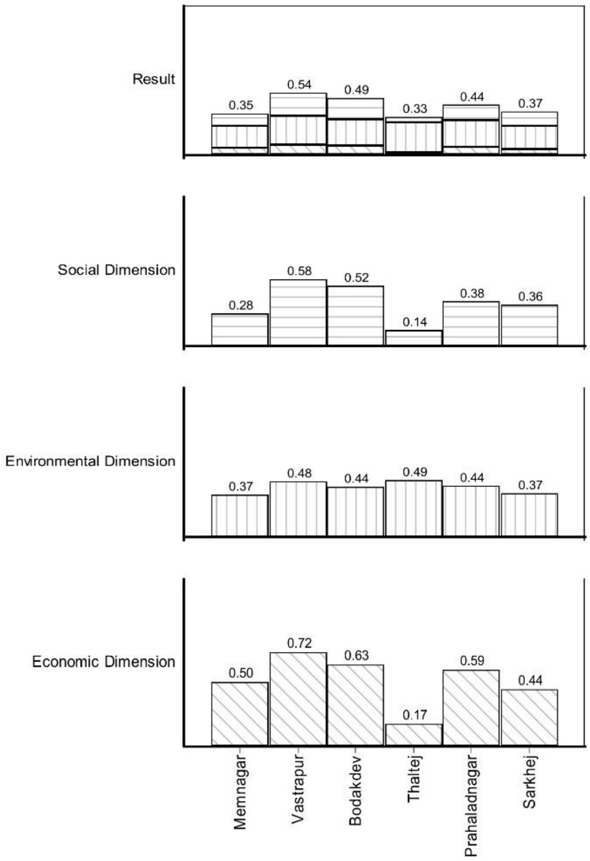

Figure 15: Sustainability index scores (Interval standardization)

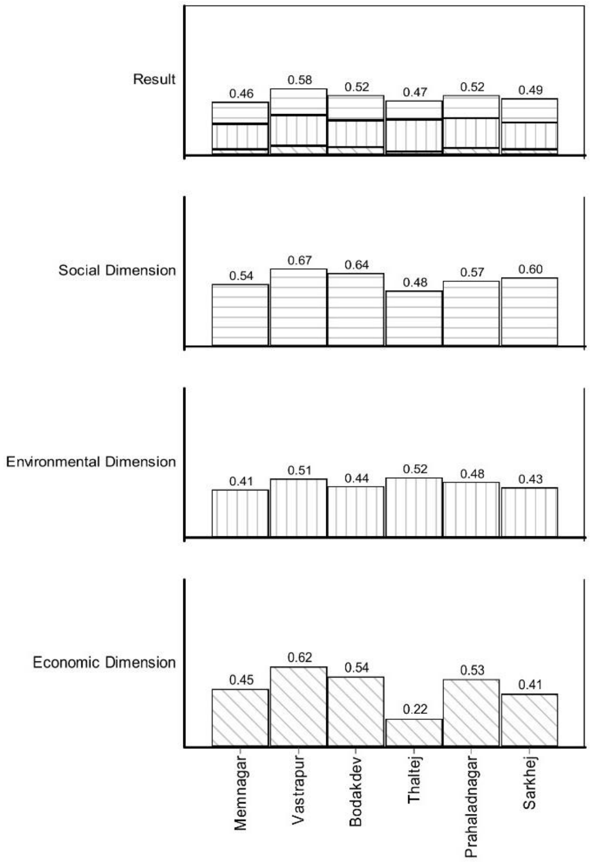

Figure 14: Sustainability index scores (Maximum standardization)

As indicated in Figure 15, Thaltej lake has the lowest SI score followed by Memnagar lake, and Vastrapur has the highest SI score followed by Bodakdev score. As it can be seen from Table 8, four indicators do not contribute to overall SI scores for all the lakes as these indicators received zero scores based on this performance (explained in Annex 6). These four indicators are (1) involvement of stakeholders in the planning process, (2) source of water, (3) price and amount of water from the Narmada canal, and (4) monitoring and assessment tools.

Below is a summary of insights from the tool based on the SI scores for each lake (Figure 16). The scores indicate the level of (relative) sustainability of the six lakes and the insights provided by the tool can be used for decision making in the further planning process.

Memnagar Lake

Memnagar received the second-lowest SI score of 0.35 (Figure 15). Out of 37 indicators, Memnagar lake has the lowest score in 14 indictors (about 38%). Memnagar lake is performing poorly in social and environmental dimensions. In the social dimension, indicators like equal engagement in activities, universal design, and informal settlements is contributing to this lower score. However, 70% of the respondents are willing to pay for the cause that could improve the condition of the lake (Annex 6, indicator 9). According to the on-field observations and interviews, the presence of informal settlements in the immediate proximity to the lake is contributing to a lower level of satisfaction (43.3%) of the respondents with the existing condition of the lake (Annex 6, indicator 11). Environmental factors like lake edge, catchment area, neighbourhoods flood mitigation, and land reclamation is performing poorly.

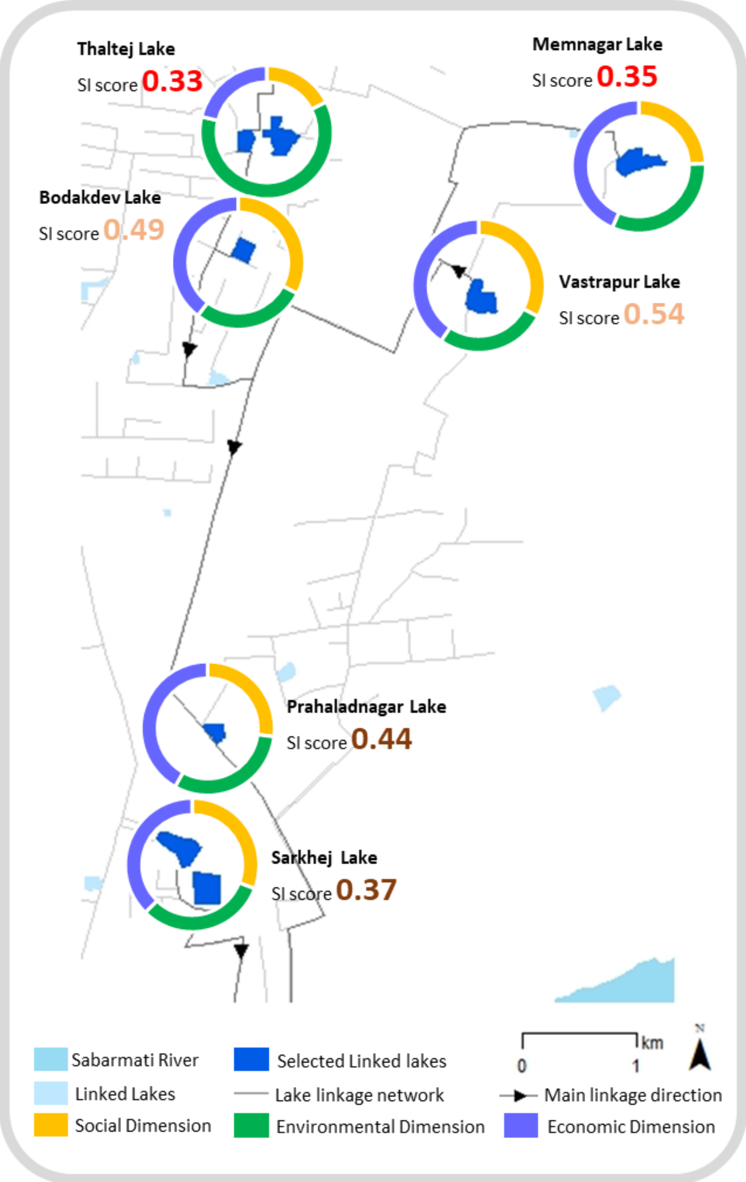

Figure 16: Sustainability scores (based on interval standardization)

Vastrapur Lake

Vastrapur lake is having the highest score in 12 out of 37 indicators (about 32%) as compared to other lakes (Table 8). The lake is scoring highest in social sustainability as well, however, it has the lowest score in the indicator investigating the satisfaction level of the users (Annex 6, indicator 11). Only 40% of interviewed users are satisfied with the existing condition of the lake. Contradictory to this, despite having lower satisfaction levels, only 10% of interviewed users are willing to travel further to access ecosystem services from other lakes in the city. This can be related to the better performance of the lake in terms of inclusive design as compared to other lakes (Annex 6). Vastrapur lake stands in the second position after Thaltej lake in the environmental dimension score. Water quality is reported to be improving in Vastrapur lake as compared to the other 5 lakes. However, some parameters are increasing/decreasing over the years which is affecting the water quality (Annex 6). The lake also receives a higher score in the economic dimension. The two factors, namely 'population economically dependent on the lake' and 'cost of maintenance' contribute to this (Table 8).

Bodakdev Lake

Bodakdev lake receives the second-highest SI score of 0.49 (Figure 16). Out of the total number of responses on the field, 66.7% of the users are satisfied with the existing condition of the lake (Annex 6, indicator 11). In the social dimension, the indicators 'universal design' and 'willingness to pay' are receiving lower scores. The lake has the highest number of activities to engage with equally for all age groups and gender (Table 8). Bodakdev lake has the highest percentage of permeable surfaces as compared to other lakes. In the economic dimension, the indicators 'cost of development' and 'cost of maintenance' score higher as compared to other lakes.

Thaltej Lake

Thaltej lake has the lowest SI score of 0.33 (Figure 16). The lakes received the lowest score as compared to other lakes in 15 out of 37 indicators (about 40%). The lake receives the highest score in the environmental dimension and has the lowest social sustainability score (Figure 15). The lower score in factors like inclusive design, level of awareness, and change in used value contributes to the lower sustainability score. However, about 66% of interviewed users of the lake are satisfied with the existing condition of the lake (Annex 6, indicator 11). The land surrounding the lake immediately is not (yet) constructed with materials like concrete and the natural lake edge is also not (yet) disturbed. Unlike other lakes, Thaltej lake retains water round the year. These factors contribute to the lake having a higher environmental score (Table 8).

Prahaladnagar Lake

Prahaladnagar lake has an SI score of 0.44 (Figure 16). In the social dimension, indicators like universal design and the presence of informal settlements are contributing negatively to the overall score. In addition, in the environmental dimension, the indicators assessing lake edge characteristics, level of water, and lake edge v/s lake depth are scored as 0 for this lake. The lake has received the highest score in the indicator which looks into the amount of green spaces around the lake (Table 8). For other indicators in the index, the lake receives average scores.

Sarkhej Lake

Sarkhej lake receives the SI score of 0.37 (Figure 16). In the social dimension, the satisfactory level indicator scores highest as compared to other lakes. Out of all respondents, 73.3% of the respondents were satisfied with the existing condition of the lake (Table 8). Since the lakes are interlinked, water quality is a very important factor as the change in the quality of water in one lake will affect all the connected lakes. As it can be seen in Figure 15, Sarkhej lake is the last node (lake) in the interlinked network. Also, it was observed that the lake has the lowest score in both indicators related to water quality (Annex 6, Indicator 19, 20). Polluted water from all the lakes in the network is linked to this lake deteriorating its water quality over time.

5.3. Sub-objective 3: To discuss the potential of the tool for the planning and decision making process

Using the tool as described in the methodology, the developed multicriteria decision support tool generates the SI score and dimension score based on indicator evaluation (Figure 16). The SI score demonstrates the (relative) degree of sustainability of interlinked lakes based on their existing condition. Hence, based on the scores, the tool can aid in prioritizing lakes and the dimension that requires attention to improve the overall sustainability of the interlinked lakes. The tool can also be used to identify the indicators/factors under the defined dimensions that do not perform well as compared to other lakes. Identifying such factors can provide insights into further planning and decision making. Based on the generated results by the tool (elaborated in the previous chapter), Table 9 mentions the underperforming factors/indicators (as compared to other lakes) that received the lowest score under each dimension for the selected six lakes (based on Table 8). These can be used as potential starting points to improve the overall sustainability of interlinked lakes.

Table 9: Factors/indicators underperforming (based on Table 8)

Lake	Social Dimension	Environmental Dimension	Economic Dimension
Memnagar	- Stakeholder participation - Equal engagement in activities - Universal design - Informal settlements	- Source of water - Price and amount of water from the Narmada canal - Lake edge - Catchment area - Neighbourhoods vulnerable to flooding - Land reclamation - Monitoring and assessment	- Cost of development - Cost of maintenance
Vastrapur	- Stakeholder participation - Willingness to travel further - Satisfaction level with the existing condition of the lake	- Source of water - Price and amount of water from the Narmada canal - Lake edge - Lake area v/s lake depth - Amount of green and blue in the catchment area - Monitoring and assessment	-
Bodakdev	- Stakeholder participation - Universal design - Willingness to travel further	- Source of water - Price and amount of water from the Narmada canal - Level of water - Lake edge - Water quality standard for aquatic life - Monitoring and assessment	-
Thaltej	- Stakeholder participation - Equal engagement in activities - Basic services - Universal design - Informal settlements - Level of awareness - The used value of the lake	- Source of water - Price and amount of water from the Narmada canal - Topography and catchment area - Vegetation cover - Monitoring and assessment	- Increase in land value - Cost of interlinking - Cost of maintainence
Prahaladnagar	- Stakeholder participation - Universal design - Informal settlements	- Source of water - Price and amount of water from the Narmada canal - Level of water - Lake edge - Lake area v/s lake depth - Monitoring and assessment	-
Sarkhej	- Stakeholder participation - Universal design - Accessibility - Informal settlements - The used value of the lake	- Water quality - Source of water - Price and amount of water from the Narmada canal - Topography and catchment area - Vulnerable land use - Vegetation cover - Maximum cooling distance - Monitoring and assessment	- Population directly/indirectly dependent on the lake - Cost of development - Cost of maintainence

As it was mentioned in the results, Thaltej lake receives the lowest SI score. Hence, to improve the overall sustainability of the lake, Table 9 shows which factors that are currently underperforming can be focused on under each dimension. The lake receives the lowest score in the social dimension as compared to other lakes. Therefore, to improve the social sustainability of the lake, the following decision making insights can be inferred from the results derived from the multicriteria decision support tool:

1. The local government should allow, encourage, and support stakeholder participation during the planning process.
2. The lake can have more activities to engage with in and around the lake for all age groups and gender
3. Basic services like public toilets, drinking water, information desk/chart/map, suggestion box, safety precautions, waste bins, etc. should be provided by the local authorities around the lake
4. The aspects of universal design (ramps, allocated parking, and allocated toilets) should be provided for equal access to all.
5. Informal settlements around the lake and temporary hawkers should be provided with better living conditions.
6. The local schools and institutions around the lake should participate and contribute to increasing awareness about the lake.
7. The used value of the lake has reduced over years and hence, the lost values linked to the lake should be revived.

Memnagar and Sarkhej lakes have scored lowest in environmental dimension (Figures 15 and 16). For example, in Memnagar lake, to improve the environmental sustainability of the lake, the following decision making insights can be inferred from the results derived by the multicriteria decision support tool:

1. The dependency of water on more sustainable solutions should be increased.
2. During the lake development, the natural lake edge should be preserved to protect its natural ecosystem and hard materials like concrete should not be used.
3. The amount of permeable surfaces in the catchment area of the lake should be increased to reduce urban flooding and increase ground water recharge.
4. Land reclaimed around the lake for recreational purposes should be done using sustainable solutions.
5. Monitoring and assessment tools should be used at different stages to evaluate the planning approach.

Similarly, for other lakes, such decision making insights can be derived from the multicriteria decision support tool. The inputs from the experts in the panel discussion focusing on: (1) Understanding the applicability and usage of the tool in practice and (2) Incorporating the decision making insights in practice during the planning process is summarized in Table 10.

Table 10: Panel Discussion with experts on the potential use of the tool in practice| Summary

Experts/Topic of discussion	Inputs from the experts
Local experts (Experts: 8, 10) on the first impression of the results (based on the study area knowledge)	- The output from the tool depends on the factors (as inputs). It **depends on how the index is designed** based on the defined goal. For example, it would be different for an ecologist v/s an engineer. - Indicators under the **social dimension** depend on interviews with the users of the lake. Hence, it **depends on how people perceive the usage and condition of the lake, which is usually more focused on their engagement with the lake for recreational purposes**.

	For example, Thaltej lake in people's opinion is an undeveloped lake as compared to Vastrapur lake. However, Thaltej lake from an ecologist's point of view can be a very thriving lake as it has its own ecosystem and retains water round the year.
Round 1 (Experts 6, 8, 10) on the first impression of the tool	- The tool **gives an aggregate score** of the index along with merging the conflicting interests between factors in the index. The **conflicts are not understood by the tool**. For example, an ecological purpose for a lake would mean that there should be no recreation. - The tool provides a sustainability index score. However, it is up to the user what is interpreted and derived from these scores. The tool **directly does not give planning insights**, but it gives insights like prioritizing the vulnerable lakes, and factors that are performing poorly. - The representation of the results from the tool should somewhere in the aggregation have to find the convergence point where a **matrix is developed based on the qualitative** (perceived aspects) **and quantitative** (actual condition) **measures in the index.** This can give more focused insights into decision making.
Round 1 (Experts 6, 8, 10) on the usefulness of the sustainability index scores and their purposes	- The sustainability index scores can assist in making sure that people **understand the multi-variate parameters** that need to be considered before arriving at a decision on a planning lake interlinking. - The tool can be very insightful and can reduce a lot of biases in the planning process. However, its **use and application** in a fast-growing city like Ahmedabad **can be challenging**. As it requires time to use the tool from developing the list of important factors, deciding on its relative importance, data collection, and followed by analysis. - The tool can be used for decision making insights. However, the local authorities themselves might not adopt the tool as it can be a lot of work along with other development projects in the city. **A tool like this would be best used by consultants** who can advise the local authorities based on the results.
Round 2 (Experts 6, 8, 10) on the use of the tool in practice	- The **use of the tool in practice largely depends on the understanding of the tool** by the experts as public consultation can be subsumed under the results the tool provides. In addition, it is also important for the participants to have a basic understanding of the tool. - The extensive methodology used to develop the tool **requires funding and unbiased researchers**. - The tool ca**n be used by people representatives for a transparent and unbiased process**. For this **understanding of the tool, relevant information on lake interlinking and related data should be accessible**. This can increase public participation and the local authorities cannot ignore but include the tool in the planning process.
Round 3 (Expert 8) on the use of the tool in different stages of planning in Ahmedabad	The tool should be used in the planning process; however, it can be challenging. The use of the tool **requires funding for researchers/scientists and abundant data** to measure the index in an unbiased manner. However, by introducing the tool, if this method can initiate constructing a data repository for lakes, it would be a good starting point.
Round 3 (Expert 6) on the use of the tool in a different context (Bangalore, India)	The tool will **help the users think beyond the recreational usage of the lake**. However, in the case of Bangalore, where lake communities are very active, it is important to communicate the understanding of the tool in simple terms.
Round 3 (Expert 10) on advantages and disadvantages (room for improvement) of the tool	Advantages: The tool provides **the flexibility** to define the goal and incorporate context-specific relevant factors. Room for improvement: To understand public opinion, it would be **better to reach out to a larger group of participants** in a way where the responses are anonymized for more honest answers.
Round 4 (Experts 6, 8, 10) on increasing stakeholder participation in Ahmedabad	- The **local authorities need to encourage and allow citizens to express their opinions**, **take responsibility** for the local lakes, and **not assume the role of users** of the services. - In addition to the local authorities along, **other institutions play a vital role** in encouraging the citizens to involve in the planning process. - **Basic water education in schools** and encouraging students to engage with local lakes are very crucial.

6. DISCUSSION

This chapter reports on the interpretation and discussion of the results. The chapter is structured in three parts and focuses on discussing: (1) Leanings from literature review and expert inputs to develop the multicriteria index (2) the Design and application of the multicriteria decision support tool in the study area and (3) Potential use of the tool in practice.

6.1. Developing the multicriteria index: Learnings from literature review and expert inputs

Developing a multidimensional index based on literature review and expert inputs allows incorporating a wide range of relevant and context-specific factors which are important to consider for a balanced and sustainable solution for interlinking lakes. The literature review in the study incorporated studying global literature for two purposes: (1) To understand and analyze existing planning approaches of interlinking lakes and, (2) To identify and understand factors that are important to consider during different stages of interlinking lakes for sustainable lake ecosystem.

It was concluded in the literature review (Chapter 2) that the interlinking of lakes is multidimensional and it should be done by adopting sustainable solutions to achieve defined multiple objectives and also protect and enhance the natural lake ecosystem. Hence, the sustainability of interlinked lakes not only depends on what planning approach is adopted but also on what kind of solutions are adopted as part of this approach. In Copenhagen, an underground closed piped network is used to interlink lakes while considering environmental factors for stormwater management to reduce urban flooding faces challenges of maintenance (Lindegaard, 2001; Haghighatafshar et al., 2014; Barton, 2016). Whereas, in Malmo, to achieve the same objective of stormwater management and reduce urban flooding, interlinking was done through an open network using nature-based solutions (Barton, 2016; Niemczynowicz, 1999; Haghighatafshar et al., 2014; Stahre, 2002). This approach as well is considering environmental factors, with a similar overarching aim like Copenhagen, but is more sustainable.

However, considering all relevant social, environmental, and economic factors is important to ensure the overall sustainability of interlinked lakes (Shih & Qiu, 2021; Bal et al., 2011; Anand, 2014). Hence, a multicriteria index was developed based on the literature review (Figure 1) which included factors from global literature that were cited to be important to consider during lake development. Nevertheless, as important as it is to study global literature, it was considered equally important to validate and contextualize the index to the study area. After the expert interviews were conducted, the updated index (Figure 11) was more specific to the issues and challenges faced by the interlinked lakes in Ahmedabad.

Similar factors were grouped together for better understanding and other relevant factors that were missing were added to the index. For example, factors like lake edge characteristics, land reclamation characteristics, microclimate, monitoring, and assessment, specific to the case study area were added. Common feedback received from the expert interviews was that the two factors namely: (1) stakeholder participation and (2) monitoring and assessment were very important and should not be ignored in the planning process of interlinking lakes in Ahmedabad.

Developing the detailed multicriteria index ensures that relevant and important factors for interlinking are considered in the planning process. The index provides flexibility to incorporate multiple factors with contradicting purposes based on the defined goal. For example, population dependent on the lake for livelihood is economically sustainable, however, it may not be environmentally sustainable (Experts: 6, 8, 10).

6.2. Design and application of multicriteria decision support tool in the study area

To evaluate the developed index, the multi-criteria analysis approach provides the opportunity to do this in different ways (Tsoutsos et al., 2009). In this study, the design and application of the multicriteria decision support tool show the contribution of different (social, environmental, and economic) factors to the overall sustainability of interlinked lakes. The tool considered and incorporated the opinions and inputs from stakeholders and experts at different stages.

After contextualizing the multicriteria index to the study area based on expert inputs, the weights of the factors in the index were determined by consensus-building exercise among the experts (Delphi Method). The two factors namely (1) stakeholder participation and (2) monitoring and assessment were ranked of highest importance by the experts with 100% consensus. As mentioned earlier, this was common feedback from experts.

As a part of the Delphi method, the online survey and responses from the experts were shared anonymously. This means that the experts could see the answers of other experts anonymously. A key advantage of doing this anonymously is that it avoids direct confrontation and records the honest opinions of the experts. On the other hand, constructive confrontation gives room for insightful discussions (Cafiso et al., 2013). Direct (discussion) or indirect (including reasons for changing/not changing the answers in the survey) communication between the experts was not included in this study due to the time limitations. However following Cafiso et al., 2013, it is believed that such communications can prove to be effective.

While the Delphi method requires considerable time, using this method has shown that it can bring experts from different backgrounds with different perspectives on one platform to trigger meaningful direct/indirect communication. Unlike in a planning approach where the experts are consulted separately, using the Delphi method promotes collaborative planning and contributes effectively to achieving the identified goal (Dalkey, 1969). When using the Delphi method in this research, it was observed that in round 3, the experts did not change their answers a lot as compared to round 2. A moderated focus group discussion could address the aforementioned two challenges. However, gathering 11 (or more) experts at the same time is equally challenging, and using an online survey can give a possibility to capture more expert opinions as they can participate in their own time.

After developing the multicriteria index and identifying the weights of the factors based on their relative importance, data related to these is required to measure the index. Abundant data is required which is based on primary and secondary data sources. Data collection for a multicriteria index like this is very rigorous and the absence of data can be one of the reasons contributing to not being able to use this method. However, by introducing the tool, if this method can initiate the construction of a data repository for lakes, it would be a good starting point to be able to study the lakes more, trigger more evidence-based discussion, and monitor the condition of the lakes.

Based on the collected data, the computation method was designed to measure and score 37 different indicators in the index (for 6 lakes) having different data types (qualitative and quantitative), data sources, and measuring units. Using the list of factors, their weights, and indicator scores as inputs, multicriteria evaluation can be done on multiple platforms. Using a tool like Definite, helped with easy calculation and allows to alter weights and run an analysis with different standardization methods for a better understanding of the results. The SI scores are relative scores that allow a comparison of the six selected lakes. It is important to note that the tool does not provide direct planning insights. The tool provides decision making insights based on the existing condition of the lake which can include prioritizing the lake and/or identifying vulnerable lakes and possible areas of improvement.

As shown in the results, Thaltej lake receives the lowest SI score and Vastrapur lake receives the highest SI score. Thaltej lake scored highest in the environmental dimension as compared to other lakes. Based on the local knowledge of the study area, it was not expected by the author that Thaltej lake scored highest in the environmental dimension and Vastrapur received the highest SI score. Local experts in the panel discussion also agreed with this hypothesis. Vastrapur lake (Figure 18) is considered a successful interlinking pilot project, however, the interlinking and development approach (as discussed in chapter 3) is under constant debate and criticized by the experts (Bal et al., 2011; Anand, 2014; Desai, 2020). Thaltej lake (Figure 17) is the only lake out of the six selected lakes which is not developed, and it is surrounded by informal settlements and temporary hawkers that contribute to polluting the lake.

Figure 18: Vastrapur lake (Source: Research Assistant)

Figure 17: Thaltej lake (Source: Research assistant)

Hence, based on methodology, design, and inputs in the multicriteria decision support tool, the results deviate from the assumption mentioned by the author as well as local experts. To attempt to understand this deviation, it is important to understand and reflect on the developed tool. The SI scores are aggregated scores of the design index based on the defined goal. Vastrapur receives the highest score in the social dimension. Social factors largely depend on how people perceive the lake which is usually more focused on users' engagement with the lake and other recreational activities (Experts 6, 8, 10). Hence, the users prefer going to a developed like Vastrapur rather than going to an un-developed lake like Thaltej. With higher social engagement, direct and indirect economic activities start linking with the lake. This explains the reason behind the highest SI score for Vastrapur.

Unlike other lakes, Thaltej lake retains water round the year. The lake is not developed and converted into a 'concrete pool' (Desai, 2020) like it is done in Vastrapur and other lakes. Thaltej lake has its own ecosystem which is not (yet) completely destroyed. However, its natural ecosystem is degrading with rapid and uncoordinated urbanization, pollution by residents around the lake, and other factors. Hence, even though the lake is not developed like other lakes, the higher score in the environmental dimension of Thaltej lake represents that the lake has high environmental potential, and it is possible to revive, enhance and protect its natural ecosystem.

From the discussion and interpretation of results obtained from the tool, it can be concluded that interlinking lakes are multidimensional, and the overall sustainability of the lakes depends on several social, environmental, and economic factors. However, in Ahmedabad, the interlinking project is seen as a techno-planning solution that does not consider all relevant social, environmental, and economic concerns related to these lakes. Interlinked lakes have a complex network that is connected spatially. Environmental factors like water quality affect the water quality in other connected lakes (Anand, 2014). This can disturb the social and economic factors of other interlinked lakes and as a result, affect the overall sustainability of the lakes. The tool, however, does not explicitly capture these interdependencies between the lakes.

It is important to note that the results from the multicriteria decision support tool largely depend on the methodology adopted, input factors, its weights, and the data collected. Hence, in addition to developing and applying the tool, it is important to understand that it is possible to interpret the outputs from the tool in multiple ways which should be done critically for incorporating the insights from the tool into the decision making and planning process.

6.3. Potential use of the tool in practice

To understand and explore the applicability and usage of the tool in practice and incorporating the decision making insights in practice during the planning process, a panel discussion with experts was conducted by the author. This section discusses the inputs from the experts in the panel discussion. The purpose of the developed multicriteria decision support tool was to evaluate the sustainability of interlinked lakes in Ahmedabad to provide insights for decision making during planning processes.

The development of the tool using a multicriteria analysis approach provides flexibility to design the index which includes context-specific factors and can be based on the defined goal. The tool allows the user to understand and incorporate multivariate parameters that need to be considered before or during the planning process of interlinking lakes. The tool will help the users think beyond the recreational usage of the lake and encourage them to include relevant factors that can be left out otherwise (Experts 6, 8, 10). This was observed to be crucial to understand as the planning approach of interlinking lakes in Ahmedabad focused on physical factors of interlinking and not all social, environmental, and economic factors were considered in the planning process. Moreover, it was found that a recent that focused on developing an assessment tool for effective management of water bodies in India (NIUA & UNESCO, 2022), focused on only some physical factors of the lake and did not consider social, economic, and other environmental factors.

In addition to using a multidimensional tool considering all dimensions of sustainability, it is equally important that the interpretation of outputs from the tool and incorporating the insights in decision making is done critically. The output of the tool is an aggregated SI score, and this score depends on factors included in the index, relative weights of the factors, data collection, and others. Calculating the aggregated SI score merges the conflicting interest between factors and these conflicts are not understood or flagged by the tool. The understanding of the conflicting interest in the tool is masked by the compensation between costs and benefits of the factors in the index. During the analysis, this can be understood at the dimension level of the tool. But these conflicts cannot be understood by the tool in the overall sustainability index score (Experts: 6, 8, 10).

The decision support tool can provide decision making insights and reduces biases in the planning process. The tool can be used at different stages of the planning process. However, the use and application of the tool in a fast-growing city like Ahmedabad can be challenging (Experts: 6, 8, 10). This is because it requires time to use the tool from developing the list of important factors, deciding on its relative importance, data collection, and followed by analysis. Due to this reason, the local authorities themselves might not adopt the tool as it can be a lot of work along with other development projects in the city. A tool like this would be best used by researchers/scientists who can advise the local authorities.

Using a decision support tool can increase public participation and the local authorities cannot ignore but include the tool in the planning process. To successfully achieve this, an understanding of the tool, funding opportunities, and unbiased researchers are required (Experts: 6, 8, 10). In addition, the use of the tool in practice largely depends on the understanding of the tool by the users (local authorities, researchers, scientists, experts, and participants) as the tool provides a number (sustainability index score) as output. Its interpretation and insights derived from the scores would depend on the decision makers.

7. CONCLUSION AND RECOMMENDATIONS

7.1. Conclusion

Current experimental approaches of interlinking lakes to achieve multiple objectives practiced globally do not yet consider the multidimensionality of the planning approach and have several uncertainties and challenges. Therefore, in order to address the gap of understanding the multidimensionality of interlinked lakes, the main aim of the research was to develop and apply a multicriteria decision support tool for interlinked lakes to promote and support sustainable lake ecosystem planning and decision making. The study demonstrated a systematic, expert knowledge-based implementation of a multicriteria analysis based decision support tool to assess the sustainability of interlinked lakes in Ahmedabad, India. Ahmedabad was taken as a case study in this research because the interlinking of lakes in the western part of the city is being experimented with and facing several uncertainties and challenges which is raising conflicts on the development approach among planning authorities and other stakeholders.

The process of designing, applying, and exploring the potential use of the developed tool contributed to understanding the social, environmental, and economic importance of the lakes. In addition to this, the systematic assessment of the degree of sustainability of interlinked lakes can inform planning approaches with the aim to maintain the overall sustainable lake ecosystem. In summary, the study addressed the identified knowledge gap and has two major contributions:

1. A conceptual tool to evaluate the degree of sustainability of interlinked lakes was developed by designing: (a) a multicriteria index, (b) a method of deriving weights of elements in the index, and (c) the computation method to measure different indicators.
2. Insights into the effects of using such a comprehensive evaluation method considering relevant social, environmental, and economic factors on the overall sustainable lake ecosystem by incorporating multi-objective negotiations between different stakeholders when planning interlinking lakes.

The key findings of the research are concluded for the defined 3 sub-objectives:

7.1.1. Existing planning approaches of interlinking confined water bodies like lakes/ponds

It was learned from the literature review that the interlinking of lakes is multidimensional and can be addressed in multiple ways to achieve the overall sustainability of the lakes. However, by adopting a methodology like multicriteria analysis based decision support tool to systematically evaluate the degree of sustainability, the overall sustainability of interlinked lakes can be ensured if the mechanism of the tool is well understood, applied, and interpreted. In this sub-objective, different cases of interlinking were studied by understanding the adopted planning approach. Based on this, the sustainability of the planning approach and the interlinked lakes was analyzed. From the different cases of interlinking confined water bodies studied as a part of the research, it was found that the overall sustainability of interlinked lakes can be achieved by adopting one of the two below-mentioned planning approaches:

1. The planning approach considering all relevant social, environmental, and economical factors during the planning process, and the interlinking implemented by adopting sustainable solutions.
2. The planning approach considering only some relevant factors based on the overarching aim of interlinking lakes, and the interlinking implemented by adopting sustainable solutions.

The study develops a multicriteria decision support tool based on the first planning approach (considering relevant social, environmental, and economic factors). However, it was found from the literature review that the second planning approach can also be used to achieve the overall sustainability of interlinked lakes if sustainable solutions are adopted during implementation. For example, Udaipur and Malmo considered social and environmental factors during the planning approach and the implementation adopted sustainable solutions; the economic values were linked with the lakes over years and hence improved the overall sustainability of interlinked lakes. In addition, it was also observed that minimum interventions in lakes have proved to be successful in preserving the natural ecosystem of the lakes.

In reference to the case study area, it was concluded from the literature review that not all relevant social, environmental, and economic factors are considered during the planning process of interlinking lakes in Ahmedabad. In addition, the implementation of interlinking does not yet adopt sustainable practices and solutions. Hence, the lakes in Ahmedabad can benefit from using a multicriteria decision support tool to develop a sustainable planning approach of interlinking lakes by considering all relevant social, environmental, and economic factors combined with designing sustainable practices and solutions.

7.1.2. Design and application of multicriteria decision support tool

The decision support tool developed and designed in the context of the case study area of Ahmedabad gives a relative sustainability index score for the selected 6 interlinked lakes. The SI score indicates the degree of sustainability of the lake based on the factors considered in the developed multicriteria index. The design and application of the multicriteria decision support tool is mainly a 4 step process:

1. Design multicriteria index considering relevant social, environmental, and economic factors to promote and support sustainable lake ecosystem.
2. Derive/identify weights of the elements (dimensions, domain, factors, indicators) in the index.
3. Collect data of the indicators in the index to measure the overall sustainability of interlinked lakes.
4. Apply the tool based on the collected information and inputs and interpret, also with the experts, the results for decision making insights.

Stakeholder participation and expert inputs were included in all above mentioned 4 steps. This was done in multiple ways like conducting expert interviews, using the Delphi method, and conducting interviews with stakeholders on site (like users of the lakes, institutions around the lake, and government representatives). Interacting with different stakeholders during fieldwork helped to contextualize the indicators in the index and provided insights into their different opinions and preferences on the state of the lakes. In addition, the study has shown that involving local experts can contribute to identifying/validating factors relevant to the study area and developing consensus based on their importance. Incorporating stakeholder and expert inputs in the decision support tool allowed participatory planning process which is currently being neglected.

The study has also developed a conceptual model demonstrating the design of the tool and methodology to measure the indicators in the multicriteria index. The design of the methodology to score the indicators for multiple factors from a variety of sources having different data types can be adopted and re-used for future studies on interlinking lakes. The implementation of the developed multicriteria decision support tool in practice can be used in follow-up studies that support a balanced and sustainable development of interlinked lakes through participatory planning. By using this tool, new insights are gathered for decision making as it draws on multiple factors which can be neglected otherwise.

7.1.3. Potential use of the tool in practice

The potential use and applicability of the developed tool in the existing planning approach of interlinking lakes are discussed in this section. The SI scores, score of each dimension, and indicators in the index can provide decision making insights for future planning to improve the overall sustainability of interlinked lakes. By using this tool, the cumulative impacts of multiple factors in the index can be included with the existing planning approach.

Adopting the developed tool in practice can incorporate the multiple objectives of interlinking in the planning process and address the existing challenges of interlinking. However, with the current pace of urbanization, it can be challenging to adopt this tool in practice as the design and application of the tool can be time-consuming and requires abundant data. Nevertheless, to ensure the overall sustainability of interlinked lakes and protect their natural ecosystem, the local authorities must re-evaluate their current interlinking approach.

Using the multicriteria decision support tool at different stages of planning not only provides the assessment of the interlinking approach but can also give insights for future planning. These insights can also aid in re-evaluating the lake development approach. In addition, the inclusion of participatory planning supported by the tool provides the possibility to incorporate inputs and opinions from local experts and other stakeholders. In addition, the tool can inform the implementation of sustainable practices like NbS. To summarize, the tool provides insights ranging at different scales of interventions and can navigate policy recommendations regarding lake interlinking and lake development.

7.2. Limitations of the study

The limitations encountered at different stages of research are explained and listed below:

- The design of the multicriteria index could have missed out on some important factor/s relevant to the study area. However, the main aim of the research is to demonstrate the design and application of the multicriteria decision support tool.
- The results largely depend on the weights of the elements in the index which was derived using the Delphi method. The derived weights are based on the consensus of the 7 experts who participated in the Delphi method which cannot be validated. In addition, due to the reasons mentioned in 5.2, the targeted 70% consensus was not achieved for all factors in the index making it uncertain.
- Data collection was done by a research assistant and the researcher coordinated the fieldwork systematically to avoid any miscommunication. However, since the researcher could not visit the study area for the fieldwork herself, it is considered a limitation.
- The field observations were recorded by the research assistant in the morning and evening times for two days at each lake and it is possible that some important observation regarding activities at the lake was missed due to limited time spent at the lake.
- Another limitation is that due to the lack of data availability, two indicators related to the ground water table could not be evaluated and had to be removed from the index during evaluation. In addition to this, in some cases, proxy indicators were used.
- The study focuses on developing a systematic methodology to understand the multidimensionality of interlinking lakes and the SI scores derived as a result of using the developed multicriteria decision support tool can have multiple interpretations; it is also possible that the study missed out on some factors.

7.3. Avenue for future research

For exploring and further validating the developed multicriteria decision support tool, future research can focus on applying the tool using temporal data in Ahmedabad and/or in a different study area. Based on the decision-making insights from the tool, future research can focus in detail on incorporating these insights into the planning process. More specifically, future research can focus on exploring design solutions by adopting sustainable practices such as NbS to incorporate the decision making and planning insights from the tool. Future research can also be navigated in the direction of exploring community-driven approaches to manage the lakes in a sustainable manner.

7.4. Recommendations

Based on the learnings, observations, and key findings from this research focusing on interlinked lakes in Ahmedabad, below are the 5 key recommendations that should be considered for follow-up research and in the planning process:

1. Based on the field interviews with the users of the lake, it appeared that users mainly evaluated the condition of the lake based on their benefits, e.g., use of the lake for recreational purposes. In order to make users more aware, communication (by the experts and planning authorities) about the multi-dimensional value of the lakes could contribute to increasing their awareness and help change their perspectives.
2. Government and public institutions should contribute to increasing and creating community awareness about local lakes in the neighbourhood. This can be done by providing, promoting, and supporting financial and/or non-financial opportunities for students, researchers, scholars, activists, and lake enthusiasts to study or engage with the lakes in the city.
3. Planning authorities should adopt an inclusive planning approach by incorporating expert knowledge and stakeholder inputs in the planning and implementation process of interlinking lakes.
4. The planning approach of interlinking lakes should consider relevant social, environmental, and economic dimensions of the lake, and interventions in and around the should be done using sustainable practices.
5. A multicriteria analysis based decision support tool should be adopted for a comprehensive evaluation of the interlinked lakes to enable monitoring and assessment of the planning approach at different stages.

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Appendix

Annex 1: Summary of expert interviews

Table 11 is the summary of inputs received from all the experts during the interviews:

Table 11: Inputs from experts | Summary

Expert	Summary of interview
Expert 1	1. The index can incorporate **the governance aspect.** For example: (a) lake definition and nomenclature (b) EIA rules and guidelines **2. Awareness under the social dimension**. It can be known and measured in several ways (a) installation of water meters - public acceptance for the notion to pay for water and save water (b) decreasing number of lakes and their deteriorating condition (c) Monetary aspects - costs of the development and water grabbing **3. Financial aspect:** The index should incorporate a monetary aspect of the project from its development to management 4. **Source of water**: Water grabbing-investing crores in buying Narmada water which is needed in Saurashtra
Expert 2	**1. STIFLE (Social, Technology, Institution, Finance, Legal, Ecological)** - finance and legal are important dimensions, Legal is relatively more important. One of the main reasons Interlinking currently is failing is the legal aspects - Does not fall under the area required to carry out EIA under mandatory requirements. **2. Land use around the lake** is an important factor to consider as it will affect the lake. Land use/Landcover map or development plan
Expert 3	1. Index should incorporate **legal factors.** (a) How and why land is reclaimed around the lake? (b) EIA needed 2. **Urban heat island effect**. As Ahmedabad experiences heat waves, temperatures around the lake can be controlled. UHI as a guiding factor to plan blue and green spaces 3. In line with the previous point, **a Land use map** should be added 4. **Silting affects the water quality and water life**: Current issue and steps for management?
Expert 4	1. **Used value and ecosystem services of the lake** - socio-ecological factor (benefits from the lake) 2. **Social inclusion and equity - all age groups, gender, and also economic classes.** Currently, gentrification observed after lake development
Expert 5	1. **Maintenance** after interlinking is equally important-hence interlinking should be done by forecasting its maintenance cycle and also considering the financial aspect of maintenance. 2. **Landcover/Land use map** **3. Green space** around the lake is important to maintain the natural aquifers.
Expert 6	**1. STIFLE** (Social, Technology, Institution, Finance, Legal, Ecological) - finance and legal are important dimensions 2. Benefits from the lake can give insight into the relative importance and degree of urgency to revive (**Ecosystem services**)
Expert 7	1. In the context of Ahmedabad, **encroachment** around the lake is a major issue/concern and cannot be ignored 2. **Social inclusion of all economic classes** as well. For example - all lower-middle-class families moved after the development of Vastrapur lake 3. **General awareness** - in some places in Ahmedabad, people living very close to the lake connect their wastewater line/sewage lines which connect to the main interlinking pipes due to a lack of awareness 4. **Ground water recharge - should also investigate the cycle of maintenance.** Currently, the structure of recharge is broken, and water quickly percolates in the ground hence water does not remain in the lake. 5. **Storage capacity** - what is the total storage capacity and how does it relate to flood risk management. 6. **Flood water management**: Are the flooding areas connecting to the lakes? 7. **Green spaces** around the lake are important to map to manage a sustainable lake ecosystem
Expert 8	1. **Institution as an additional domain** missing in the index (lake nomenclature) and **policies/guidelines** for the lakes (EIA) under the governance 2. **Nomenclature of the lake** in the different administrative boundaries should also be considered as in Ahmedabad this is not very clear yet. Lake is still considered as 'land' or 'park' or 'green space' 3. **Awareness** is the most important and first step to achieving a sustainable lake ecosystem as it must be a collaborative effort making water education must 4. The interlinking physically should not be seen as an engineering solution. The best solution to save the natural ecosystem of the lake is to not disturb it. **Solution**-' Garden in the lake' and not 'lake in the garden' 5. **Evaluation at different stages** - Environmental Impact Assessment (EIA)
Expert 9	1. **Land use/Landcover** - Lakes with industries around (e.g., Sola Lake) will be contaminated by runoff water and ground water, and hence considering the land use map is very crucial 2. **Administrative Boundaries** are important too. Some lakes are in the gamtaal region in the degrading condition

	3. **Financial aspect**: The index should incorporate a monetary aspect of the project from its development to management 4. **Urban growth trends:** Lakes are being engulfed in the city limits and it affects the lake with haphazard development around it. If planned, it would give time to plan for sustainable solutions.
Expert 10	1. **Hydrological factors** as separate domain - Water profile, urban catchment, Ground water recharge, water management 2. Ecological factors like **microclimate** considering the climate of Ahmedabad should be in the index 3. **Administrative** as a separate domain (governance) with the masterplan, land use, landcover data 4. Cultural importance factor needs to be clearer and more defined. Most of the lakes in Ahmedabad have lost do not hold their cultural importance and most of the lakes are now seen as service and amenity. 5. **Land Reclamation** in Ahmedabad is an important factor. Currently done using concrete and hard landscape which should be done in a more sustainable way (soft landscape) 6. **Lake edge characteristics** (Ecological factor) affect the natural ecosystem of the lake. Soft edge v/s hard
Expert 11	1. One of the main purposes of interlinking was flood water management. **Flood risk areas** over the years should also be included to make informed decisions. 2. **Gentrification and relocation of informal settlements** to a large extent were seen due to this project. This aspect cannot be ignored in Ahmedabad 3. **Financial aspect**: The index should incorporate a monetary aspect of the project from its development to management 4. **Sustainable methods/alternatives** to treat the water naturally to improve and manage lake **water quality and its ecosystem**

Annex 2: Weights of factors

Figure 19: Responses of experts on importance of factors (3 rounds)

Factors: 1. Stakeholder Participation 2. Inclusive Design 3. Response strategies 4. Stakeholder Perception 5. Used Value of lake 6. Ground Water Table 7. Water Quality 8. Water Source 9. Lake Edge 10. Catchment Area 11. Flood Mitigation 12. Land Use 13. Land Reclamation 14. Flora and Fauna 15. Microclimate 16. Monitoring and Assessment 17. Livelihood Dependency 18. Change in land value 19. Finance

Table 12: Weights of factors based on consensus between experts

Factors	Score (highest consensus)	Meaning of score level	Weights
Stakeholder Participation	5	Very High Importance	0.08
Inclusive Design	5	Very High Importance	0.08
Response strategies	4	High Importance	0.04
Stakeholder Perception	5	Very High Importance	0.08
Used Value of lake	5	Very High Importance	0.08
Ground Water Table	3	Medium Importance	0.03
Water Quality	5	Very High Importance	0.08
Water Source	4	High Importance	0.04
Lake Edge	4	High Importance	0.04
Catchment Area	4	High Importance	0.04
Flood Mitigation	3	Medium Importance	0.03
Land Use	4	High Importance	0.04
Land Reclamation	4	High Importance	0.04
Flora and Fauna	5	Very High Importance	0.08
Microclimate	4	High Importance	0.04
Monitoring and Assessment	5	Very High Importance	0.08
Livelihood Dependency	4	High Importance	0.04
Change in land value	4	High Importance	0.04
Finance	4	High Importance	0.04

Factors: 1. Stakeholder Participation 2. Inclusive Design 3. Response strategies 4. Stakeholder Perception 5. Used Value of lake 6. Ground Water Table 7. Water Quality 8. Water Source 9. Lake Edge 10. Catchment Area 11. Flood Mitigation 12. Land Use 13. Land Reclamation 14. Flora and Fauna 15. Microclimate 16. Monitoring and Assessment 17. Livelihood Dependency 18. Change in land value 19. Finance

Table 13: Normalized weights for the tool

Weight	Dimension	Weight	Domain	Weight	Factors	Weight	Indicators
0.36	Social	0.56	Social Inclusion	0.40	Stakeholder Participation	1.00	1.Involvement of stakeholders during planning process
				0.40	Inclusive Design	0.16	1.Equal engagement in activities
						0.16	2.Basic services
						0.16	3.Universal design
						0.16	4.Affordability
						0.16	5.Assessibility
						0.16	6.Informal settlements presence and relocation (if relocated)
				0.20	Response strategies	0.50	1.Willingness to travel further
						0.50	2.Willingness to pay
		0.22	Public Acceptance	1.00	Stakeholder Perception	0.50	1.Awareness
						0.50	2.Level of satisfaction
		0.22	Long term benefits	1.00	Used Value of lake	1.00	1.Change in used value
0.54	Enviornmental	0.31	Hydrology	0.00	Ground Water Table	0.00	1.Ground water table
						0.00	2.Change in ground water table
				0.50	Water Quality	0.50	1.Water quality
						0.50	2.Change in water quality
				0.25	Water Source	0.33	1.Source of water from rain, storm water, Narmada canal
						0.33	2.Price of water from Narmada canal, Amount of water from Narmada canal, change in these over years
						0.33	3.Level of water
				0.25	Lake Edge	1.00	1.Degree of naturalness of the lake shore
		0.29	Built Environment	0.27	Catchment Area	1.00	1.Percentage of impervious surfaces v/s pervious surfaces
				0.20	Flood Mitigation	0.50	1.Topography
						0.50	2.Vulnerable neighbourhoods
				0.27	Land Use	1.00	1.Vulnerable land uses
				0.27	Land Reclamation	0.50	1.Characteristics of land reclaimed around the lake (softscape/hardscape)
						0.50	2.Lake area v/s lake depth in certain range
		0.39	Ecology	0.40	Flora and Fauna	0.25	1.Distance to migratory birds flyway
						0.25	2.Distance to green and blue
						0.25	3.Green in the lake
						0.25	4.Water quality standard for aquatic life
				0.20	Microclimate	1.00	1.Temperature maps
				0.40	Monitoring and Assessment	1.00	1.Assessment details
0.12	Economic	0.67	Indirect impacts	0.50	Livelihood Dependency	1.00	1.Population directly/ indirectly dependent on lake
				0.50	Change in land value	1.00	1.Jantri rates
		0.33	Direct impacts	1.00	Finance	0.33	1.Cost of interlinking
						0.33	2.Cost of development
						0.33	3.Cost of maintenance

Annex 3: Factors and Indicators details

The meaning and importance of the factors and its assumption are discussed in Table 14. Indicators to measure these factors along with their source and computation methods are also discussed in Table 14. This was designed based on the literature review (chapter 2) and expert inputs. Taking this table as reference, evaluation, and analysis of 37 indicators is included in Annex 6.

Table 14: Factor and indicator details

<table>
<tr><td colspan="3">Dimension: Social | Domain: Social Inclusion
Factor: Stakeholder Participation</td></tr>
<tr><td>Meaning and importance</td><td colspan="2">Interlinked lakes are socially sustainable if there is social inclusion in the planning process by including stakeholder participation (Design/Planning PROCESS).</td></tr>
<tr><td>Assumption</td><td colspan="2">If there was stakeholder participation in the planning process, the lake is socially inclusive and receives a higher score based on the degree of involvement.</td></tr>
<tr><td>Indicator/s</td><td>Source</td><td>Computation Method</td></tr>
<tr><td rowspan="2">1. Degree of involvement of stakeholders during the planning process (Benefit)</td><td>1. Interview with stakeholder – Corporator of the ward</td><td rowspan="2">Interview analysis with literature support</td></tr>
<tr><td>2. Other literature and project reports</td></tr>
<tr><td colspan="3">Dimension: Social | Domain: Social Inclusion
Factor: Inclusive Design</td></tr>
<tr><td>Meaning and importance</td><td colspan="2">Inclusive design, taking into consideration the needs of different age groups, gender, economic classes, and informal settlements is important for social inclusion (Design/Planning OUTCOME).</td></tr>
<tr><td>Assumption</td><td colspan="2">The lake has a more socially inclusive design if more variety of needs is considered in the design. If all age groups, gender, economic classes, and informal settlements are considered, it is an inclusive design that contributes to increasing social sustainability.</td></tr>
<tr><td>Indicator/s</td><td>Source</td><td>Computation Method</td></tr>
<tr><td>1. Equal engagement in activities (Benefit)</td><td>On filed observation 1</td><td>Considers 7 elements in terms of equal distribution of:
1,2 Age group (morning and evening)
3,4. Gender (morning and evening)
5.6.7 Total number of activities and Number of activities to engage (morning and evening)</td></tr>
<tr><td>2. Basic Services (Benefit)</td><td>On filed observation 3</td><td>Provision of (present/absent):
1. Public toilets
2. Drinking water point
3. Information desk/information chart/map
4. Suggestion box
5. Safety precautions
6. Waste collection bins</td></tr>
<tr><td>3. Universal Design (Benefit)</td><td>On filed observation 4</td><td>Provision of (presence/absence):
1. Ramps to access all areas
2. Allocated parking for handicapped
3. Toilets for handicapped</td></tr>
<tr><td>4. Affordability (Benefit)</td><td>On filed observation 2</td><td>Equal distribution of paid and unpaid activities</td></tr>
<tr><td rowspan="2">5. Accessibility (Benefit)</td><td>1. On filed observation 10</td><td rowspan="2">Presence of (present/absent):
1. Footpath
2. Bike Lane
3. Public transport (Bus/auto)
4. Road network connectivity
5. Parking facilities</td></tr>
<tr><td>2. Open Streep map</td></tr>
<tr><td>6. Informal Settlements (Cost)</td><td>On filed observation 9</td><td>Presence/ absence of informal settlements within a 0.5 km radius of the lake</td></tr>
<tr><td colspan="3">Dimension: Social | Domain: Social Inclusion
Factor: Stakeholder Response Strategies</td></tr>
<tr><td>Meaning and importance</td><td colspan="2">Interlinked lakes are socially inclusive if everyone has the possibility and flexibility for response strategies to access benefits from lakes</td></tr>
<tr><td>Assumption</td><td colspan="2">Lakes are more socially inclusive if people from all different social groups can derive different benefits from lakes (To what extent can people fulfill their needs). The more people have the flexibility for different response strategies, the more socially inclusive and more socially sustainable it is.</td></tr>
<tr><td>Indicator/s</td><td>Source</td><td>Computation Method</td></tr>
<tr><td>1. Willing to travel further (Benefit)</td><td>On filed observation 1,2</td><td>Considers from which neighbourhood and how frequent people visit the lake and how far, how often are they willing to travel to other lakes</td></tr>
</table>

<table>
<tr><td colspan="2">2. Willingness to pay (Benefit)</td><td>On filed interview with users of the lake 4</td><td>Considers the flexibility in degree of willingness to pay through:
1. Development taxes
2. Betterment charges
3. User charges or fees</td></tr>
<tr><td colspan="4">Dimension: Social | Domain: Public Acceptance
Factor: Stakeholder Perception</td></tr>
<tr><td>Meaning and importance</td><td colspan="3">Interlinked lakes are socially sustainable if there is public acceptance of the development which is defined by the level of Awareness (about interlinking lakes and basic water education) and Satisfaction level (with the existing condition of the lake).</td></tr>
<tr><td>Assumption</td><td colspan="3">More awareness and more satisfaction will increase public acceptance contributing to increasing social sustainability.</td></tr>
<tr><td colspan="2">Indicator/s</td><td>Source</td><td>Computation Method</td></tr>
<tr><td colspan="2" rowspan="2">1. Level of Awareness (Benefit)</td><td>1. Interview with stakeholders – Schools</td><td rowspan="2">Degree of involvement and responsibility of schools for creating and spreading awareness on lakes</td></tr>
<tr><td>2.Other literature</td></tr>
<tr><td colspan="2">2. Level of Satisfaction (Benefit)</td><td>On filed interview with users of the lake 5</td><td>Level of satisfaction perceived by the users of the lake (Satisfied, partially satisfied, not satisfied)</td></tr>
<tr><td colspan="4">Dimension: Social | Domain: Long-term benefits
Factor: Used value of the lake</td></tr>
<tr><td>Meaning and importance</td><td colspan="3">If people have the possibility to derive the same/more benefits (used value) over years (for example: after 15 years), the interlinked lakes are socially sustainable.</td></tr>
<tr><td>Assumption</td><td colspan="3">If users derive the same or more benefits from the lakes, the interlinked lakes are socially sustainable. If not, the used value of the lake has been reduced.</td></tr>
<tr><td>Role</td><td>Benefit</td><td>Weight</td><td></td></tr>
<tr><td colspan="2">Indicator/s</td><td>Source</td><td>Computation Method</td></tr>
<tr><td colspan="2">1. Change in used value of the lake (Benefit)</td><td>On filed interview with users of the lake 3</td><td>Interview analysis on:
1. Amount of time user is visiting the lake
2. Change in activities of engagement in the said time.</td></tr>
<tr><td colspan="4">Dimension: Environmental | Domain: Hydrology
Factor: Ground Water Table</td></tr>
<tr><td>Meaning and importance</td><td colspan="3">Interlinking lakes are hydrologically sustainable if there is a rise in the groundwater table in a certain range due to interlinking.</td></tr>
<tr><td>Assumption</td><td colspan="3">The groundwater table in a certain range that is suitable to recharge the ecosystem conditions is sustainable. However, it should not exceed a certain range that can lead to flooding</td></tr>
<tr><td colspan="2">Indicator/s</td><td>Source</td><td>Computation Method</td></tr>
<tr><td colspan="2">1. Ground water table (Benefit)</td><td rowspan="2">Central Ground Water Board (CGWB)</td><td>The groundwater table in a certain range</td></tr>
<tr><td colspan="2">2. Change in the groundwater table (Benefit)</td><td>Change (Increase/Decrease) in groundwater table over years</td></tr>
<tr><td colspan="4">Dimension: Environmental | Domain: Hydrology
Factor: Water Quality</td></tr>
<tr><td>Meaning and importance</td><td colspan="3">A certain level of water quality (as per the standards) is to be maintained in the interlinked lakes for its hydrological sustainability</td></tr>
<tr><td>Assumption</td><td colspan="3">A certain range of water quality for its usage and maintaining the natural ecosystem. Every improvement in water quality is making the sustainability of the lake better.</td></tr>
<tr><td colspan="2">Indicator/s</td><td>Source</td><td>Computation Method</td></tr>
<tr><td colspan="2">1. Water quality (Benefit)</td><td rowspan="2">Gujarat Environment Management Institute (GEMI), Gandhinagar</td><td>Water quality in a certain range</td></tr>
<tr><td colspan="2">2. Change in Water Quality (Benefit)</td><td>Change (increase/decrease) in water quality standards over the years</td></tr>
<tr><td colspan="4">Dimension: Environmental | Domain: Hydrology
Factor: Water Source</td></tr>
<tr><td>Meaning and importance</td><td colspan="3">Interlinked lakes are hydrologically sustainable if the source of water in the lakes is natural (example: rainwater)</td></tr>
<tr><td>Assumption</td><td colspan="3">The more the lake is filled with water naturally, the more sustainable it is. More water is bought from other sources, less water is filled in a natural way from rainwater</td></tr>
<tr><td colspan="2">Indicator/s</td><td>Source</td><td>Computation Method</td></tr>
<tr><td colspan="2">1. Source of water in the lake (Benefit)</td><td>Other secondary open data sources</td><td>Distribution of amount of lake filled from different sources:
1. Rainwater
2. Stormwater channels
3. Narmada canal</td></tr>
<tr><td colspan="2">2. Water from Narmada Canal (Benefit)</td><td>Sardar Sarovar Narmada Nigam Limited (SSNNL), Gandhinagar</td><td>Amount of water and the price trends of water from the Narmada canal over the years</td></tr>
<tr><td colspan="2">3. Level of water (Benefit)</td><td>On filed observation 5</td><td>The current level of water in the lake (empty/partially full/full)</td></tr>
</table>

Dimension: Environmental | Domain: Hydrology **Factor: Lake Edge**		
Meaning and importance	Interlinked lakes are hydrologically sustainable if the lake edge is preserved and enhanced to maintain the natural ecosystem of the lake	
Assumption	The higher the naturalness of lake shore characteristics, the more the natural water ecosystem is maintained/enhanced	
Indicator/s	**Source**	**Computation Method**
Degree of naturalness of lake edge (Benefit)	On field observation 6	Degree of naturalness (hardscape/ softscape/semi-hard scape) and its distribution (percentage).
Dimension: Environmental | Domain: Built Environment **Factor: Catchment Area**		
Meaning and importance	Interlinked lakes are sustainable if the built environment around the lake has certain water catchment area characteristics that allow water to flow into the lake or percolate inside the ground	
Assumption	If there are less impervious surfaces (softscape) in the catchment area to increase groundwater percolation and reduce run-off, it is more sustainable	
Indicator/s	**Source**	**Computation Method**
Percentage of impervious v/s permeable surfaces (Benefit)	Other secondary open data sources	The distribution between impervious v/s permeable surfaces
Dimension: Environmental | Domain: Built Environment **Factor: Flood mitigation**		
Meaning and importance	Interlinked lakes are environmentally sustainable if there are flood mitigation strategies in place to control floods in urban areas	
Assumption	If the surrounding urban areas are connected to the lakes to control flooding, and if the number of vulnerable neighbourhoods is reduced over years, it is more sustainable	
Indicator/s	**Source**	**Computation Method**
1. Topography and catchment area (Benefit)	Other secondary open data sources	Catchment area v/s capacity of the lake in a certain range
2. Vulnerable neighbourhoods (Cost)	Ahmedabad Municipal Corporation (AMC)	1. Location of vulnerable neighbourhoods in close proximity to the lake 2. Change in (increase/decrease) number of vulnerable neighbourhoods over years
Dimension: Environmental | Domain: Built Environment **Factor: Land use**		
Meaning and importance	For the interlinked lakes to be environmentally sustainable, it is important to take into consideration land use around the lake that can be vulnerable to lake water quality and its natural ecosystem.	
Assumption	If the surrounding land use is affecting the water quality of the lake, it is not sustainable	
Indicator/s	**Source**	**Computation Method**
Vulnerable land uses (Cost)	Ahmedabad Urban Development Authority (AUDA)	Land uses vulnerable to lake ecosystem in close proximity
Dimension: Environmental | Domain: Built Environment **Factor: Land Reclamation**		
Meaning and importance	Interlinked lakes are more sustainable if land reclamation is done in a sustainable way	
Assumption	If the land reclamation is done in ways that do not affect the natural ecosystem of the lake (for example soft landscape (and not using hard landscape and concrete), it is more sustainable. If the depth of the lake is increased beyond a certain range, it affects the natural ecosystem of the lake and it is not sustainable	
Indicator/s	**Source**	**Computation Method**
1. Characteristics of land reclaimed (Benefit)	On field observation 7	Characteristics of land reclaimed (hardscape/semi-hard scape/ soft scape)
2. Lake area v/s lake depth (Benefit)	Ahmedabad Urban Development Authority (AUDA)	Lake area v/s lake depth in a certain range
Dimension: Environmental | Domain: Ecology **Factor: Flora and Fauna**		
Meaning and importance	Interlinked lakes are more sustainable if the flora and fauna (green cover, aquatic life, migratory birds) in and around the lake is preserved	
Assumption	The presence of green spaces, trees, local/migratory birds, and aquatic life contributes to maintaining the natural ecosystem of the lake and increasing ecological sustainability	
Indicator/s	**Source**	**Computation Method**
1. Migratory flyway (Cost)	Other secondary open data sources	Distance to migratory flyway
2. Amount of green and blue in the catchment area (Benefit)	Other secondary open data sources	Distance to green and blue

3. Green in the lake (Benefit)	Other secondary open data sources	Amount of green cover in and around the lake
4. Aquatic life to sustain (Benefit)	Gujarat Environment Management Institute (GEMI), Gandhinagar	Water quality standards for aquatic life to sustain
Dimension: Environmental | Domain: Ecology **Factor: Microclimate**		
Meaning and importance	Interlinked lakes are more sustainable if the lake and the green spaces around it affect the microclimate around the lake	
Assumption	If the cooling capacity due to the lake (green and blue) is more, it is more sustainable	
Indicator/s	**Source**	**Computation Method**
The cooling capacity of the lake (Benefit)	Other secondary open data sources	The cooling capacity of the lake is due to the presence of water and green cover in and around the lake.
Dimension: Environmental | Domain: Ecology **Factor: Monitoring and Assessment**		
Meaning and importance	Use of monitoring and assessment tools like Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), Cumulative Impact Assessment (CIA), etc., at different stages of interlinking and incorporating the insights from the tool is important to ensure the environmental sustainability of lakes.	
Assumption	The use of monitoring and assessment tools and incorporating the insights is important to ensure the environmental sustainability of lakes.	
Indicator/s	**Source**	**Computation Method**
Assessment details (Benefit)	Other secondary open data sources	Monitoring and assessment tools (used/not used). Investigating if the insights were incorporated and how this was done
Dimension: Economic | Domain: Indirect Impacts **Factor: Livelihood Dependency**		
Meaning and importance	Lakes are economically sustainable if there is direct/indirect dependency of livelihood on the lakes.	
Assumption	Interlinked lakes are economically sustainable as a means to maintain and revive the cost of maintenance and development if there is a dependency of livelihood on the lake	
Indicator/s	**Source**	**Computation Method**
Population directly/indirectly dependent on the lake (Benefit)	On filed observation 8	Population directly/indirectly dependent on the lake (number of people, dependency)
Dimension: Economic | Domain: Indirect Impacts **Factor: Change in Land Value**		
Meaning and importance	An increase in land value prices due to interlinking lakes and their development is not economically sustainable	
Assumption	If the land value prices have increased due to interlinking lakes which can lead to gentrification and social exclusion, it is not sustainable	
Indicator/s	**Source**	**Computation Method**
Change in land value prices (Cost)	Other secondary open data sources	Change in land value prices over years
Dimension: Economic | Domain: Direct costs **Factor: Finance**		
Meaning and importance	Interlinked lakes are economically sustainable if the finance related to development and maintenance costs has a logical balance	
Assumption	If the development and management finance have cost-effective solutions, it is economically more sustainable	
Indicator/s	**Source**	**Computation Method**
1. Cost of interlinking (Cost)	Ahmedabad Urban Development Authority (AUDA) and Other secondary open data sources	The financial investment for interlinking lakes
2. Cost of lake development (Cost)		The financial investment for developing the lakes
3. Cost of maintenance (Benefit)		Financial costs related to maintenance of interlinked network and lake itself Proxy: Presence of PPP arrangement

Annex 4: Data collection details

1. On field Observations

On filed observations included 10 aspects of lakes to be observed on-site which are mentioned below.

1. Number and types of activities to engage in by all age groups and gender.
2. Is visiting the lake and engaging in all activities affordable to all equally? Distribution of pain/unpaid activities and their amount if paid.
3. Is there a provision of basic services? (Like public toilets, drinking water points, information desk/ information chart or map, suggestion box, safety precautions like lifeguard/safety railing around the lake/water depth indication/other safety features, waste collection bins)
4. Are all the areas of the lake accessible equally to a wide range of abilities (barrier-free accessibility) This includes aspects like provision of ramps to access all parts of the lake, provision for allocated parking, and toilets for the handicapped?
5. What is the existing water level in the lake?
6. What are the characteristics and nature of the edge of the lake? (Softscape/Hardscape, it's material and approximate percentage)
7. What are the characteristics of land reclaimed around the lake? (Softscape/Hardscape, it's material and approximate percentage)
8. Population directly/indirectly dependent on the lake.
9. Is there a presence of informal settlements around the lake?
10. Are there parking facilities around the lake for visitors to park their vehicles?

2. On-field interviews with users of the lake

On-field interviews with 30 users included the following 5 questions:

1. From which neigbourhood have you traveled from to visit the lake? How often do you visit?
2. Which other lakes do you visit apart from this one? And how often?
3. What kind of activities do you engage with in/around the lake? Since how many years do you visit the lake? Has that changed as compared to before 10-15 years?
4. Are you willing to pay for the development and maintenance of lakes? If yes, how would you prefer to pay? (Through development taxes, betterment charges, or user charges or fees?) If yes, how much should it be?
5. Are you satisfied with the existing condition of the lake? What are the expectation and desired activities they would like to engage with?

3. Interview with other stakeholders – Corporator

An interview with one corporator of these three wards was conducted to ask the following 8 questions about the selected lakes:

1. How many and which wetlands are there in your ward?
2. Have there been any benefits from the interlinking project in your ward?
3. One of the main aims of Interlinking lakes was to reduce urban flooding and water clogging in urban areas. Has water clogging and flooding reduced after interlinking was done? When and where this ward has faced the problem of flooding and water clogging from 2001 to 2020? (Year and ward)
4. Was the ward office and residents of the ward consulted before the interlinking project was executed?
5. Should the office and people be consulted before executing such big projects? If no, why, and if yes, how?
6. How do residents in the ward associate with the lakes?
7. Are there any active groups you know of that engage in spreading/creating any sort of awareness about the lake?
8. How do you maintain the lake and what are the costs related to maintenance?

4. Interview with other stakeholders – School

An interview was conducted with social science teachers and 3 questions were asked as below:

1. As a part of curricular or extra-curricular activities (for example as a part of the environmental club), do the students at your school engage with/visit wetlands in Ahmedabad?
2. Does your school contribute to increasing/creating awareness about the local wetlands?
3. Does the school curriculum have a basic education on water and wetlands? What are your opinions about the importance of this?

5. Contacting government organizations for existing data

Following government organizations were contacted for existing data:

1. Ahmedabad Urban Development Authority (AUDA)
    a. Comprehensive Development Plan 2021
    b. Land use map 2021 in a 1 km radius around the selected lakes
    c. Interlinking network plan
    d. Interlinking costs
    e. Lake development costs
    f. Lake capacity: Lake area and depth
2. Ahmedabad Municipal Corporation (AMC)
    a. Urban areas vulnerable to flooding and water clogging (temporal data)
3. Central Ground Water Board (CGWB)
    a. Ground water table (temporal data)
4. Gujarat Environment Management Institute (GEMI)
    a. Water quality for selected lakes
5. Sardar Sarovar Narmada Nigam Limited (SSNNL)
    a. Details about water from the Narmada canal (amount/price) (temporal data)

6. Other secondary open data sources

Following secondary open data sources were used:

1. Open Street Map (OSM)
2. Google Earth
3. Scientific Literature – Paper, articles, news articles, etc.

Annex 5: On-field work plan

Table 15: On-field | Work plan

Date/Day	Time	Tasks completed
4/4/2022 Monday	7:00 AM - 11AM	Vastrapur Lake 1. Morning Photographs 2. Morning Field Observations 3. Morning Interviews (n=2)
	11:30 AM - 1:30 PM	1 school in Vastrapur
	5:00 PM - 8:30 PM	Vastrapur Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=10)
5/4/2022 Tuesday	7:00 AM - 11:30 AM	Vastrapur Lake 1. Morning Photographs 2. Morning Field Observations 3. Morning Interviews (n=10)
	1:00 PM - 2:45 PM	1 school in Vastrapur
	3:30 PM - 5:00 PM	AUDA
	5:45 PM - 8:45 PM	Vastrapur Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=8)
6/4/2022 Wednesday	10:00 AM - 1:00 PM	AUDA
	1:30 PM - 4:00 PM	AMC
	5:30 PM - 8:15 PM	Memnagar Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=4)
7/4/2022 Thursday	7:00 AM - 9:30 AM	Memnagar Lake 1. Morning Photographs 2. Morning Field Observations 3. Morning Interviews (n=4)
	10:00 AM - 11:00 AM	1 school
	11:45 AM - 2:00 PM	AMC
	3:00 PM - 3:30 PM	1 school in Memnagar
	4:30 PM - 7:00 PM	Procuring online data, Calling AMC, and ward offices
8/4/2022 Friday	7:00AM - 11:00AM	Memnagar Lake 1. Morning Photographs 2. Morning Field Observations 3. Morning Interviews (n=4)
	12:30 PM - 3:00 PM	Central Ground Water Board Ahmedabad
	3:30 PM - 5:00PM	Vastrapur irrigation office
	5:30 PM - 8:00 PM	Memnagar Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=3)
9/4/2022 Saturday	6:30 AM - 10:30AM	Sarkhej Lake 1. Morning Photographs 2. Morning Field Observations 3. Morning Interviews (n=7)
	11:00 AM - 4:30 PM	2 schools in Sarkhej
	5:00 PM - 7:30 PM	Sarkhej Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=3)
10/4/2022 Sunday	7:30 AM - 10:00 AM	Sarkhej Lake 1. Morning Photographs 2. Morning Field Observations 3. Morning Interviews (n=5)
	9:00 AM - 2:00 PM	Procuring online data and uploading data collected until now on drive
	5:00 PM - 7:30 PM	Sarkhej Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=5)
11/4/2022 Monday	8:30 AM - 11:30 AM	GEMI, Gandhinagar - Water quality data
	11:45 AM - 2:00 PM	SSNNL, Gandhinagar - Narmada Canal data
	2:45 PM - 3:30 PM	GEER, Gandhinagar - Flora and Fauna Data
	5:30 PM - 8:15 PM	Memnagar Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=5)
12/4/2022 Tuesday	11:30 AM - 12:15 PM	Thaltej corporator office
	12:45 PM - 1:45 PM	1 school - Thaltej
	3:00 PM - 5:00 PM	AMC
13/4/2022 Wednesday	7:30 AM - 11:00 AM	Bodakdev Lake (Mahakali Lake) 1. Morning Photographs 2. Morning Field Observations 3. Morning Interviews (n=6)
	2:30 PM - 4:30 PM	Bodakdev corporator office
	4:30 PM - 5:00 PM	1 school - memnagar

	5:00 PM - 6:00 PM	Revenue Department
	6:15 PM - 7:15 PM	Bodakdev Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=4)
14/4/2022 Thursday	7:30 AM - 11:30 AM	Bodakdev Lake (Mahakali Lake) 1. Morning Photographs 2. Morning Field Observations 3. Morning Interviews (n=6)
	1:00 PM - 3:00 PM	Calling schools and corporators
	4:00 PM - 6:15 PM	Bodakdev Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=4)
	6:30 PM - 9:00 PM	Thaltej Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening interviews (n=2)
15/4/2022 Friday	7:30 AM - 10:00 AM	Thaltej Lake 1. Morning Photographs 2. Morning Field Observations 3. Morning Interviews (n=6)
	10:30 AM - 12:30 PM	1 school - Memnagar
	1:00 PM - 2:30 PM	Corporator interview - Thaltej
	3:30 PM - 7:45 PM	Thaltej Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=8)
16/4/2022 Saturday	6:15 AM - 7:30 AM	Thaltej Lake 1. Morning Photographs 2. Morning Field Observations 3. Morning Interviews (n=64)
	7:45 AM - 11:00 AM	Prahalad Nagar Lake 1. Morning Photographs 2. Morning Field Observations 3. Morning Interviews (n=7)
	1:30 AM - 3:30 PM	Revenue Department - Jantri rates
	5:00 PM - 8:00 PM	Prahaladnagar Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=5)
17/4/2022 Sunday	5:30 AM - 7:30 AM	Kakaria lake 1. Morning Photographs
	8:00 AM - 11:00 AM	Prahaladnagar Lake 1. Evening Photographs 2. Evening Field Observations 3. Morning Interviews (n=4)
	12:30 PM - 2:00 PM	Jantri rates compiling for 6 lakes
	3:00 PM - 5:30 PM	Compiling and sending all data collected
	6:00 PM - 8:30 PM	Prahaladnagar Lake 1. Evening Photographs 2. Evening Field Observations 3. Evening Interviews (n=4)
18/4/2022 Monday	8:30 AM - 11:30 AM	5 schools in Bodakdev
	11:30 AM - 1:30 PM	Meeting with corporator Bodakdev
	3:15 PM - 6:30 PM	AMC
19/4/2022 Tuesday	8:30 AM - 10:30 AM	3 schools in Memnagar
	11:30 AM - 1:30 PM	Meeting with corporator Sarkhej
	3:00 PM - 4:30 PM	CGWB
20/4/2022 Wednesday	8:30 AM - 10:45 AM	2 schools in Thaltej
	11:30 AM - 1:30 PM	2 Schools in Bodakdev
	2:00 PM - 2:30 PM	CGWB
	4:00 PM - 6:45 PM	Compiling and sending all data collected

Annex 6: Indicator evaluation and analysis repository

The evaluation and analysis of indicators based on data collected are discussed in this section. The evaluation is used as input in the Definite tool. The factors related to the indicators, their source of data, and the computation method are discussed in Annex 3, Table 14.

Social Dimension

1. Degree of involvement of stakeholders during the planning process

The interlinking of the lakes project is a 'techno-planning' solution to the urban flooding issue in Ahmedabad (Anand, 2014). There was no project report or other literature found that discussed the involvement of stakeholders during the planning process. From the 3 interviews conducted with the ward corporator, a common point known was that the ward office and residents were informed about the project before execution. People were informed by the corporators themselves and through advertisements in the local newspapers. However, stakeholders were not involved during the planning process of any of the selected lakes. Hence, in this indicator, the degree of involvement of stakeholders during the planning process for all the selected lakes is considered nil.

2. Equal engagement in activities

Based on the field observations in two days, the total number of activities, and activities in the morning and evening for the selected lakes are as shown in Figure 20. Higher the number of activities, the more the engagement. For activities equal to or higher than 7 is given a full score (1) and less than that is given a half score (0.5). For age group distribution (Figure 21), if any group occupied equal to or higher than 40% of the total distribution, it was considered an unequal distribution. Similarly, for gender distribution (Figure 22), any gender group occupying equal to or higher than 70% was considered an unequal distribution. Based on this justification, the total score for the 7 elements for each lake is shown in Table 16.

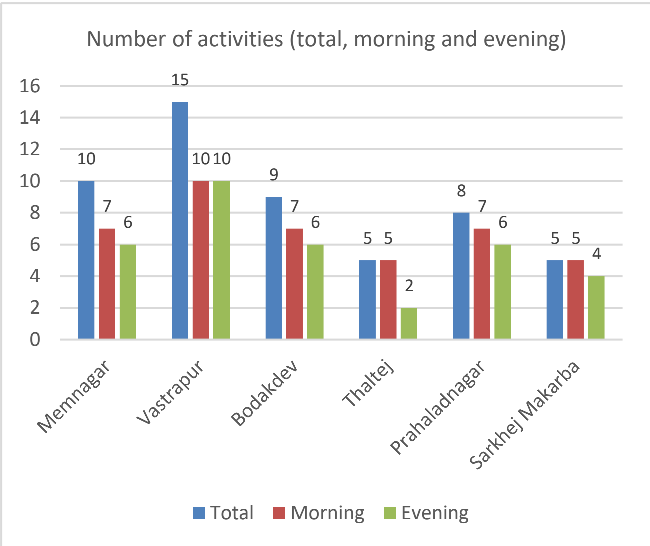

Figure 20: Number of activities (morning and evening)

As it can be seen from the table, Bodakdev lake has the highest score of 6.5. It was observed that this lake is known as the 'mahila lake' (meaning: women's lake). This means that between noon to evening six o'clock, only women are allowed entry to the lake premises. This initiative by the local government has been found to be well appreciated by women. They come with their kids and engage in several activities during the day. During the interview with the users of the lake, it has been found to be inconvenient for men. However, it was observed that as compared to other lakes, this initiative is one of the major reasons to maintain the age group and gender distribution balance and increase the overall engagement.

Memnagar, Thaltej, and Sarkhej lakes have the lowest score. Having higher number of activities to engage with, Memnagar lake performs poorly due to unequal age group and gender distribution. According to the field observations, Thaltej and Sarkhej had lower number of activities, unequal age group distribution, and unequal gender distribution in the morning. Thaltej lake is interlinked but not developed yet and hence except for the market around the lake edge and due to the existing poor condition of the lake, there is not much engagement of users with the lake. It is assumed that Sarkhej lake recorded lower activities as the fieldwork was done during the month of Ramadan. A large part of the community living around the lake followed the fast and hence there were not many activities observed during the day.

Table 16: Equal engagement in activities

	Age group distribution		Gender distribution		Number of activities			Total Score
	Morning	Evening	Morning	Evening	Total	Morning	Evening	(out of 7)
Memnagar	No	No	No	No	10	7	6	2.5
Vastrapur	No	No	Yes	Yes	15	10	10	5
Bodakdev	Yes	Yes	Yes	Yes	9	7	6	6.5
Thaltej	No	No	No	Yes	5	5	2	2.5
Prahaladnagar	No	No	No	Yes	8	7	6	3.5
Sarkhej	No	No	No	Yes	5	5	4	2.5

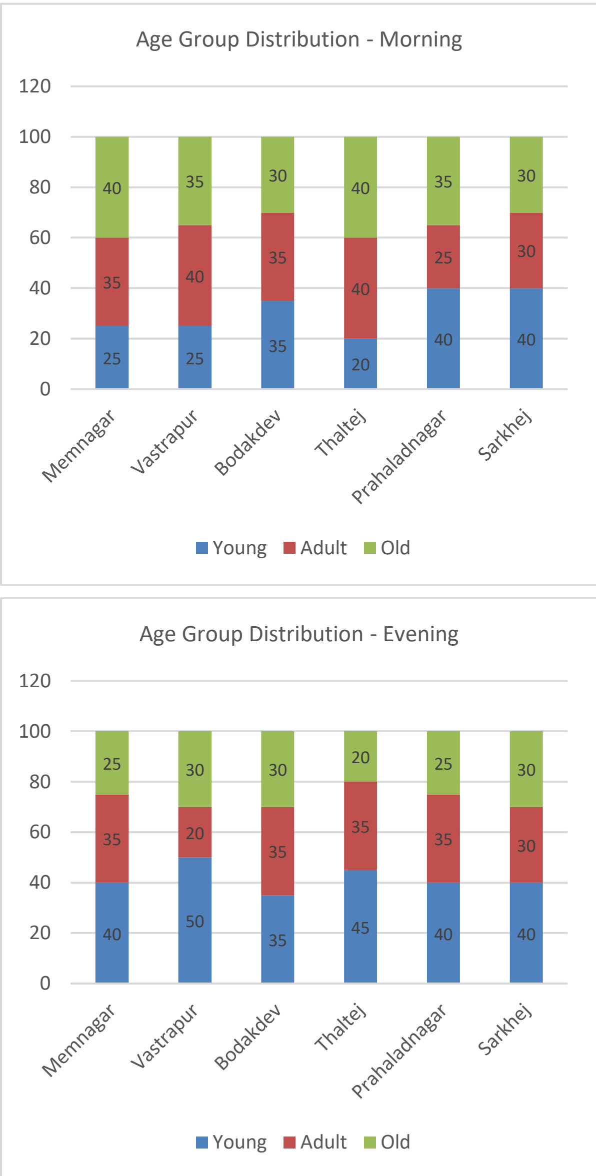

Figure 21: Age group distribution (morning and evening)

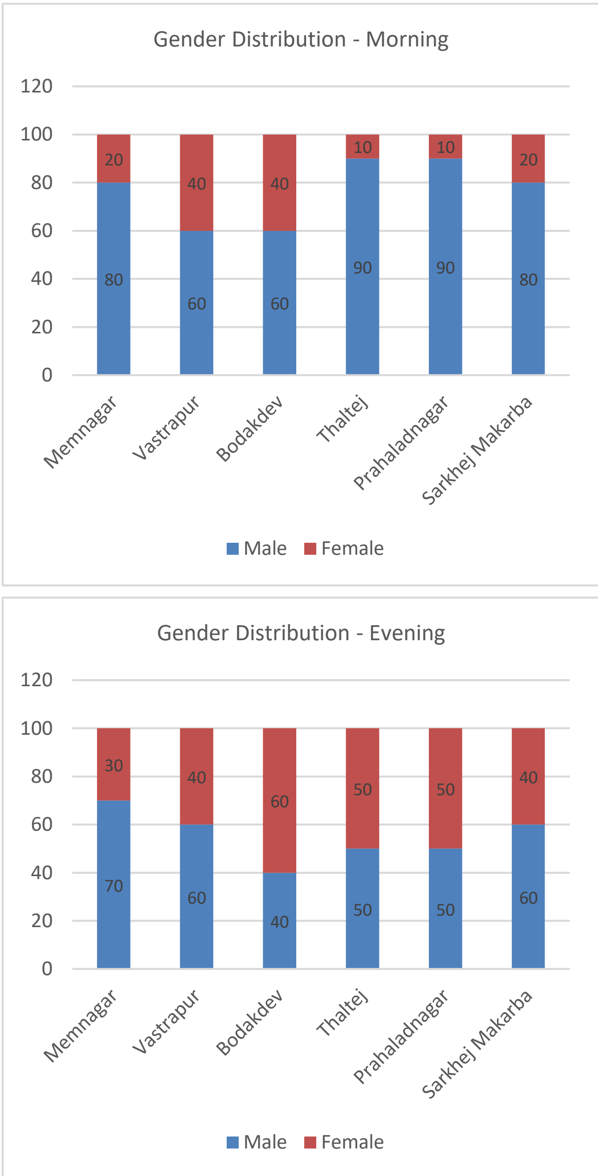

Figure 22: Gender distribution (morning and evening)

3. Basic Services

Out of the 6 basic services listed and observed on the field, the scoring of each lake is as shown in Table 17. The score is based on the presence/absence of the listed services, their condition, and usage. For appropriate and good conditions of the basic services, a full score (1) is given. But in case the service is not operational or in poor condition, a 0.5 score is given. As it can be seen from Table 17, the overall performance of all six lakes is poor or average. None of the selected lakes have scored higher than 50%. Thaltej lake has the least score of 0.5.

Table 17: Basic services in the selected lakes

	Public toilets	Drinking-Water	Information desk/chart/map	Suggestion box	Safety precautions	Waste bins	Total Score out of 6
Memnagar	Yes (Not in usable condition)	No	No	No	Yes (only safety railing present)	Yes	2
Vastrapur	Yes	No	No	No	Yes (safety railing, water depth indications present)	Yes	2.5
Bodakdev	Yes (Not in usable condition)	Yes (Not operational)	No	No	Yes (only parapet present)	Yes	2.5
Thaltej	Yes (only male toilet)	No	No	No	No	No	0.5
Prahaladnagar	No	No	Yes	No	Yes (only parapet)	Yes	2.5
Sarkhej	Yes	Yes	No	No	No	Yes	3

4. Universal Design

Out of the 3 aspects of the universal design listed and observed on the field, the scoring of each lake is as shown in Table 18. The score is based on the presence/absence of the listed aspects, their condition, and usage. For appropriate and good condition of the services, a full score (1) is given. But in case the service is not operational or not in poor condition, then a 0.5 score is given.

Table 18: Universal Design in the selected lakes

	Ramps	Allocated Parking	Allocated Toilets	Total
Memnagar	No	No	No	0
Vastrapur	Yes	No	Yes	2
Bodakdev	No	No	No	0
Thaltej	No	No	No	0
Prahaladnagar	No	No	No	0
Sarkhej	No	No	No	0

5. Affordability

All the activities in the selected lakes are unpaid (free) except Vastrapur lake has recreational activities like boating and rides for kids which are paid. However, the distribution of paid and unpaid activities in all the selected lakes is affordable to all.

6. Accessibility

Accessibility was evaluated by assessing 5 elements as shown in Table 19 within a 500 m buffer of the selected lake (Figure 23). These elements include the provision of footpaths, bike lanes, public transport, road network connectivity, and parking facilities. The score is based on the presence/absence of the listed aspects, their condition, and usage. For appropriate and good conditions of the basic services, a full score (1) is given. But in case the service is not operational or in poor condition, then a 0.5 score is given.

Figure 23: Accessibility elements within 500 m buffer (Source: OSM)

Table 19: Accessibility in the selected lakes

	Footpath	Bike lane	Public transport	Road network connectivity	Parking facilities	Total Score out of 5
Memnagar	No	No	Yes	Yes	Yes: Waste dumped in the parking area	2.5
Vastrapur	Yes: Partly occupied by local vendors	Yes: Not fully connected	Yes	Yes	Yes: Partly occupied by local vendors	3.5
Bodakdev	No	No	Yes	Yes	Yes: Partly occupied by ongoing construction	2.5
Thaltej	No	No	Yes	Yes	No	2
Prahaladnagar	No	No	Yes	Yes	Yes: Partly occupied by local vendors	2.5
Sarkhej	No	No	Yes: Not very frequent	Yes	No	1.5

As it can be seen from Table 19, all the lakes except Vastrapur do not have footpaths and biking lanes in 500 m buffer. The total score of these lakes is below 50%. Vastrapur lake has the highest accessibility as compared to others. Sarkhej lake on the other hand has the lowest score. Access to Public transport and road network connectivity in the 500 m buffer around the lakes is recorded to be present. However, public transport from sarkhej lake is not very frequent as compared to other lakes. Allotted parking facilities in Thaltej and Sarkhej lakes is not present and for the other lakes, it is occupied by local vendors, ongoing construction work, or used as a waste dumping area.

7. Informal Settlements

Based on the field observations, informal settlements (squatter settlements/temporary settlements) were present within a 500 m radius of Memnagar, Thaltej, Prahaladnagar, and Sarkhej lake.

8. Willingness to travel further

The total number of responses willing to travel further to visit a lake is shown in Table 20. A higher willingness to travel further shows the possibility of higher flexibility for the residents to benefit from different ecosystem services from different lakes in the city.

Table 20: Willingness to travel further

	Visiting a lake from a different neighbourhood	Visiting lakes in a different neighbourhood	Total number of responses willing to travel further
Memnagar	2	17	19
Vastrapur	3	7	10
Bodakdev	8	20	28
Thaltej	0	20	20
Prahaladnagar	4	20	24
Sarkhej	5	20	25

As indicated in Table 20, Bodakdev recorded the highest number of responses that are willing to travel further to other lakes. Vastrapur on the other hand has the lowest number of responses for the same. It is important to take a note that from the total of 30 responses, not a single user traveled to Thaltej lake from a different neighbourhood (other than Thaltej). Bodakdev which is the 'mahila lake' (women's lake) has the highest number of users visiting from another neighbourhood (other than Bodakdev).

9. Willingness to pay

Figure 24 shows the responses from users of the lake on willingness to pay for the development and management of the lake through development taxes, user charges, or betterment charges. Memnagar and Vastrapur lakes have the highest number of responses that are willing to pay through one or more ways (mentioned above). Common feedback recorded during the field interview with the users of the lake was that they were willing to pay if the lake was developed as per their needs and maintained well after that. Only 20% of the respondents were willing to pay in the Bodakdev lake. About 67% of the respondents were satisfied with the existing condition of the lake and they believed it is not required for them to contribute. In the case of Sarkhej lake, about 53% of respondents were willing to pay however, common feedback recorded was that they should not be asked to pay, and since Sarkhej lake is a historic lake, the entry fee for outsiders (not local community) should be charged.

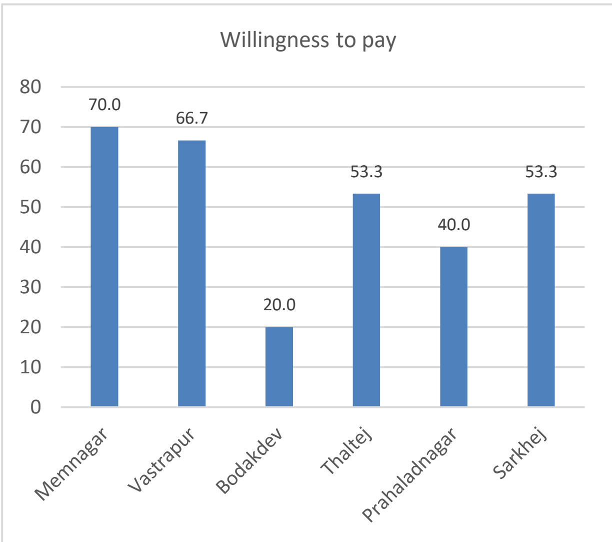

Figure 24: Willingness to pay

10. Awareness

Table 21 shows how schools contribute to increasing and creating awareness about local/city lakes in Ahmedabad. Two schools within a 3km radius were selected and an interview with the principal or social science teacher was arranged. As indicated in Table 21, all the selected and interviewed schools have basic water education as part of the course curriculum. This focuses on social and environmental aspects of water composition, the water cycle, and the importance of water. In the case of engaging in activities at lakes, emphasis was laid on activities at lakes in the same neighbourhood (local lakes). If the school organizes activities for students in the local lake, a full score (1) is given and for other city lakes, a half score is given (0.5). Vastrapur and Sarkhej lakes have the highest overall score. On the other hand, Thaltej lake has the lowest score. During the interviews, a common concern from the school authorities about the safety of students during the visit to the lake was flagged.

Table 21: Awareness

	School 1		School 2		Total Score out of 4
	Involved in curricular/extracurricular activities with local or other city lakes	Basic Water Education is part of the curriculum	Involved in curricular/extracurricular activities with local or other city lakes	Basic Water Education is part of the curriculum	
Memnagar	No	Yes	Yes | Memnagar	Yes	3
Vastrapur	Yes Vastrapur and other city lakes	Yes	Yes Vastrapur (only once in route of a rally)	Yes	3.5
Bodakdev	Yes Bodakdev and other	Yes	No	Yes	3
Thaltej	No	Yes	No	Yes	2
Prahaladnagar	Yes Other city lakes	Yes	Yes Other city lakes	Yes	3
Sarkhej	Yes Sarkhej	Yes	Yes Other city lakes (Kakaria)	Yes	3.5

11. Level of Satisfaction

Figure 25 shows responses from the users of the lake on the level of satisfaction with the existing condition of the lake. About 73% of respondents in Sarkhej lake are satisfied with the existing condition of the lake. Only 5 respondents (Table 14) were visiting Sarkhej lake from other neighbourhoods. The rest of the 25 respondents were visiting the lake from the same neighbourhood. Most of these are visiting the lake since their childhood and during the interviews, it was recorded that, the users are attached to this public place and largely satisfied.

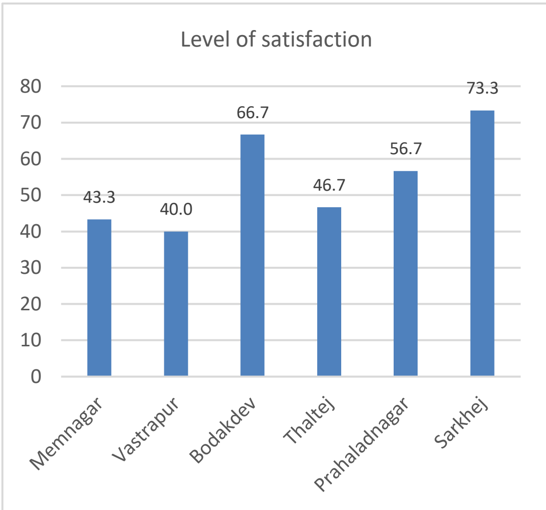

Figure 25: Level of satisfaction

On the other hand, only 40% of respondents are satisfied with the existing condition of Vastrapur lake. Issues that came into focus during the interview were related to the lake not having water round the year, the lake not being maintained and cleaned regularly, the bad smell of the water, and the round-the-year use of infrastructure and amenities. Similarly, about 43% of respondents are satisfied with the existing condition of Memnagar lake. Similar issues related to cleanliness, maintenance, and foul smell from water were discussed. In addition to that, the objectionable environment created by the informal settlements in close proximity to the lake which includes dumping waste, and grazing cows in the lake were flagged.

12. Change in used value

Figure 26 shows the responses from users of the lake on the change in the used value of the lake over years. The same used value or more is considered sustainable. Table 22 shows the percentage of responses with the same/more used value of the lake. Respondents who were visiting the lake for the first time were not asked this question.

Table 22: Same/more used value of the lake

	Used value of the lake (same and more) (percentage of responses)
Memnagar	86.7
Vastrapur	96.7
Bodakdev	93.3
Thaltej	83.3
Prahaladnagar	90
Sarkhej	83.3

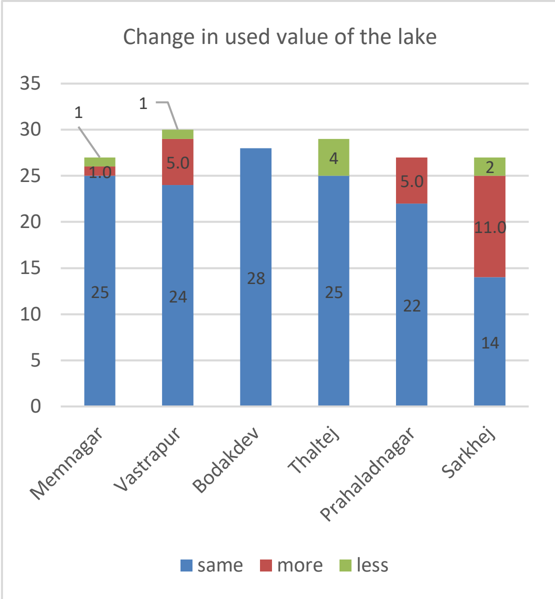

Figure 26: Change in the used value of the lake

Vastrapur lake has the highest percentage as indicated in Table 16. Out of 30, the used value of the lake has increased for 5 respondents. These respondents have been visiting Vastrapur lake for 15-22 years. All the respondents in Bodakdev lake believed that the used value of the lake has remained the same. In sarkhej lake, 11 out of 30 respondents who have been visiting the lake for 25-40 years believe that the used value of the lake has increased. During an interview with these respondents, it was told that there were large forest areas around the lake about 40-50 years ago and the lake was not easily accessible. After that, due to the development of surrounding areas, road connectivity improved, and the residents could access the lake and engage in different activities. However, according to, 2 respondents who have been visiting the lake for 17-20 years, the used value of Sarkhej lake has decreased.

Environmental Dimension

13. Ground Water Table

Central Ground Water Board (CGWB) has piezometers installed at different locations in Ahmedabad city. The recent groundwater table for all the lakes except Vastrapur is not known. Piezometer details located near Vastrapur lake and groundwater level in 2019 are shown in Table 23. The average groundwater level recorded in Ahmedabad is 67 mbgl (Tandon, 2021). The annual water level near Vastrapur lake is deeper (lower) than the city average. In addition, post-monsoon, water level depth is 85.5mgbl (Figure 27). If the groundwater level is close to the city average, it is sustainable and contributes to increasing the overall groundwater table of Ahmedabad. As the recent groundwater table for other lakes is not known, it cannot be assessed and scored. Therefore, this indicator is removed from the index in the Definite tool.

Table 23: Vastrapur lake piezometer details (Source: CGWB)

Well ID	W230218072314702
Location	23°2'18" N 72°31'47" E
Aquifer Type	Semi-Confined
Readings	Four times a year in January (winter), May (summer), August (Monsoon), November (post Monsoon)
Groundwater level 2019 (Annual average in mbgl)	90.445

14. Change in Ground Water Table

As mentioned above, groundwater table details for all lakes except Vastrapur lake are not known. Piezometer details located near Vastrapur lake are shown in Table 23. Groundwater level recorded four times a year (indicated in Table 23) from 2010 to 2018/19/20 is shown in Figure 27. As it can be seen, the overall groundwater table in all the four readings is raised from 2010 to 2018/19/20. Hence, Vastrapur lake is given a full score (1). During monsoon time readings, the water level has increased by 13.7% in 9 years and during summertime readings, it has increased by 11.1% in 10 years. As the change in the groundwater table for other lakes is not known, it cannot be assessed and scored. Therefore, this indicator is removed from the index in the Definite tool.

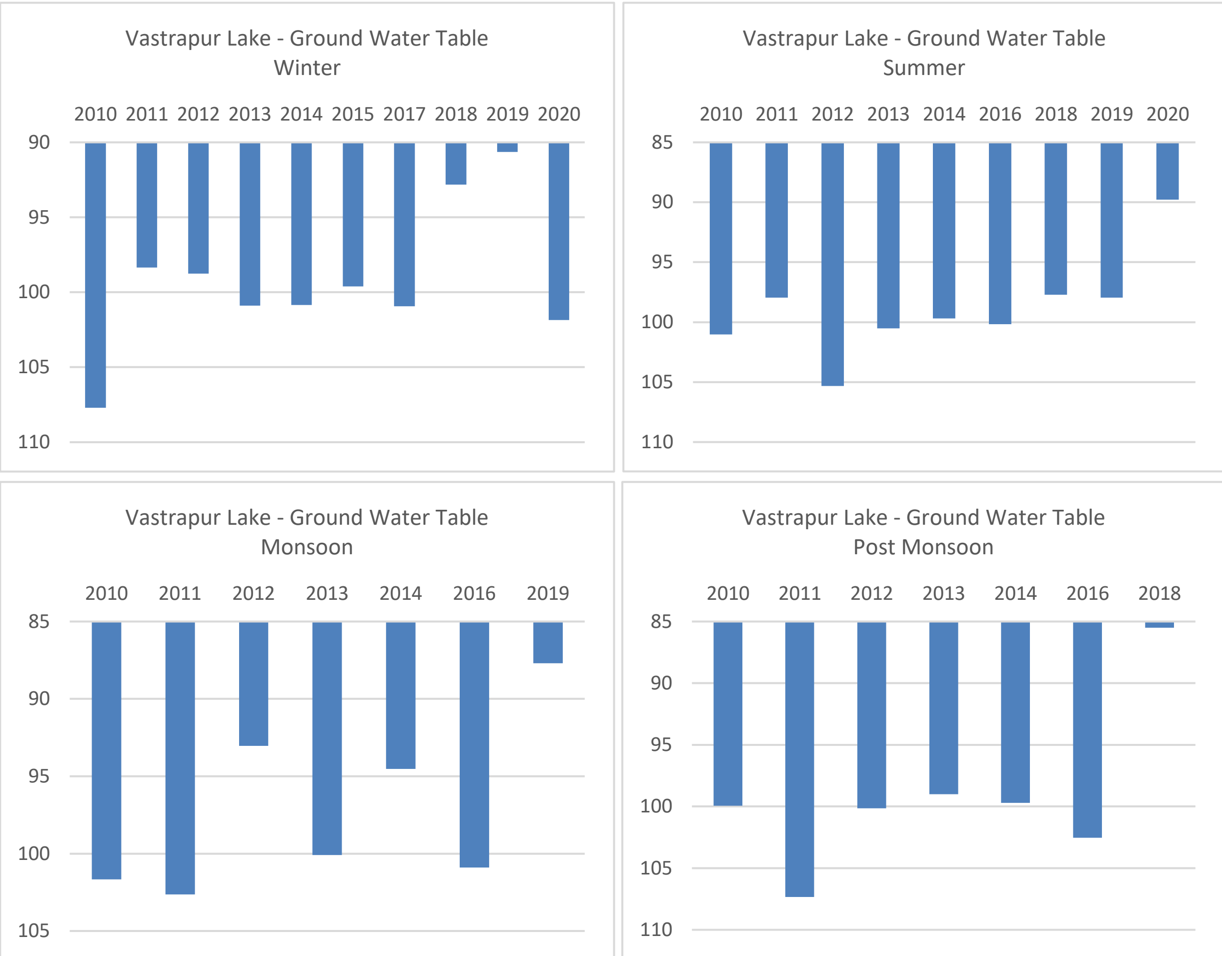

Figure 27: Vastrapur Lake | Change in the groundwater table (mgbl) (Source: CGWB)

15. Water Quality

The water quality of the selected lakes is assessed by the rating of 4 indices and the tropical state of the lake. The ranking of the lakes for each of these 5 measures is shown in Table 24 (Source: GEMI). The total relative score for the lakes is calculated based on the ranking of each measure according to the description in Table 25. As computed in Table 18, the total relative scores of each lake are indicated out of 5. Sarkhej has the lowest score of 0.9. WAWQI measure which assesses the water quality for drinking purposes indicates that the water in sarkhej lake is very poor. CCME WQI measure for all the lakes is marginal, however, lakes are scored relatively. Prahaladnagar lake has the highest score of 3.9. Based on the total relative score, the lake that scores more has better water quality measures and hence, is more sustainable. Water quality data for Bodakdev lake was not available from GEMI. However, during the field observation, it was observed that the Bodakdev lakebed has dried out and does not have water. Hence, due to the aforementioned reasons, Bodakdev lake is scored nil.

Table 24: Water quality measure (Source: GEMI)

	WAWQI	CCME WQI	MI	PI	CTSI	Total Relative Score (out of 5)
Memnagar	38.53 Good	58.435 Marginal	5.310 Threshold of warning	3.094 Strongly affected	86.451 Hypereutrophic (Highly nutrient-rich lake)	1.9
Vastrapur	16.57 Excellent	47.0065 Marginal	1.557 Threshold of warning	2.664 Moderately affected	91.188 Hypereutrophic (Highly nutrient-rich lake)	3.5
Bodakdev	Not known					
Thaltej	45.12 Good	54.965 Marginal	3.647 Threshold of warning	2.589 Moderately affected	89.93 Hypereutrophic (Highly nutrient-rich lake)	2.8
Prahaladnagar	29.67 Good	63.01 Marginal	2.333 Threshold of warning	2.767 Moderately affected	99.812 Hypereutrophic (Highly nutrient-rich lake)	3.9
Sarkhej	76.34 Very Poor	52.7625 Marginal	5.885 Threshold of warning	2.8625 Moderately affected	85.377 Hypereutrophic (Highly nutrient-rich lake)	0.9
Score as per ranking	Score 1	Score 0.7	Score 0.5	Score 0.3	Score 0.1	

Table 25: Water quality measures legend (Source: GEMI)

Weighted Arithmetic Water Quality Index (WAWQI)[11]	0-25	Excellent water quality
	26-50	Good water quality
	51-75	Poor water quality
	76-100	Very Poor water quality
	Above 100	Unsuitable for drinking purposes
Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI)[12]	95-100	Excellent
	80-94	Good
	65-79	Fair
	45-64	Marginal
	>100	Poor
Metal Index (MI)[13]	MI value >1 is a threshold of warning, The higher the concentration of metal compared to its respective MAC value, the worse the quality of the water.	
Pollution Index (PI)[14]	<1	No effect
	1-2	Slightly affected
	2-3	Moderately affected
	3-5	Strongly affected
	>5	Seriously affected
Carlson Tropic State Index (CTSI)[15]	0-40	Oligotrophic aquatic ecosystem (Low ecological productivity)
	40-50	Mesotrophic (Moderate ecological productivity)
	50-70	Eutrophic (High ecological productivity)
	70-100+	Hypereutrophic (highest ecological productivity).

[11] The weighted arithmetic WQI method was applied to assess water suitability for drinking purposes (Source: GEMI).
[12] The CCME WQI comprises three factors and these are combined to produce a single value (between 0 and 100) that describes water quality (Source: GEMI).
[13] Metal Index (MI) is determined for present status of total trend evaluation of lake (Source: GEMI).
[14] Pollution Index (PI) is calculated based on individual metal and categorized into 5 classes (Source: GEMI).
[15] The trophic state index introduced by has globally been accepted to assess the biological health of aquatic ecosystems (Source: GEMI).

16. <u>Change in Water Quality</u>

To evaluate the change in water quality of lakes, 13 parameters as shown in Table 26. These parameters measured during the post-monsoon period in 2013 (Source: Anand, 2014) and 2021 (Source: GEMI) are compared. If the change in parameters is increasing/decreasing to reach the permissible range, it is considered sustainable. The lakes are scored out of 14 and their ranking calculation is shown in the table. As it can be seen from the table, all the lakes have received a score less than 54%. Vastrapur has received the highest score of 7.5. For all the lakes, conductivity levels are increasing and fluctuations in this can affect the survival and growth of aquatic life. COD and BOD (except Thaltej) are increasing for all lakes which shows the presence of nutrients that support microbial activities (Anand, 2014). Sarkhej lake has the lowest score of 5.3. Water quality data on selected 14 parameters for Bodakdev lake was not available. Moreover, during the field observation, it was observed that the Bodakdev lakebed has dried out and does not have water. Hence, due to the aforementioned reasons, Bodakdev lake is scored nil.

Table 26: Change in the water quality (Source: (GEMI); (Anand, 2014))

	Parameters			Memnagar		Vastrapur		Thaltej		Prahladnagar		Sarkhej	
		Units	Permissible Limits	2013 Post monsoon	2021 Post monsoon	2013 Post monsoon	2021 Post monsoon	2013 Post monsoon	2021 Post monsoon	2013 Post monsoon	2021 Post monsoon	2013 Post monsoon	2021 Post monsoon
1	pH	-	6.5 to 8.5	8.31	8.66	8.35	9.57	8.28	7.74	8.36	8.35	8.29	8.81
2	Conductivity	µS/cm	2000	609.00	1072.00	548.33	918.5	357.50	1507.00	228.00	1494.50	509.00	951.00
3	Total Dissolved Solids	mg/l	2000	555.67	587.00	382.00	481	518.00	817.00	300.00	781.00	365.33	507.00
4	Chloride as Cl	mg/l	1000	119.60	143.48	119.90	148.95	149.45	231.96	59.90	247.42	126.27	168.94
5	Turbidity	NTU	10	14.97	205.35	3.83	83	38.25	65.00	21.45	40.50	20.87	158.50
6	Oil & Grease	mg/l	10	3.04	0.08	2.07	0.09	BDL	0.12	BDL	0.12	BDL	0.16
7	Total Hardness	mg/l	600	126.67	215.00	116.67	110	155.00	255.00	105.00	245.00	110.00	167.50
8	Calcium Hardness	mg/l	100	73.33	130.00	83.33	40	75.00	145.00	65.00	120.00	63.33	70.00
9	Magnesium Hardness	mg/l	200	53.33	85.00	33.33	70	65.00	110.00	40.00	125.00	46.67	97.50
10	Ammonical Nitrogen NH3-N	mg/l	50	4.29	8.75	1.68	1.86	1.40	18.16	0.50	3.52	0.50	1.71
11	Chemical Oxygen Demand (COD)	mg/l	250	78.65	149.49	52.10	92.2	84.80	140.87	40.43	60.05	47.17	147.03
12	Dissloved Oxygen (DO)	mg/l	3	6.57	5.3	10.40	7.95	7.75	5.60	5.30	5.70	9.90	3.95
13	Biochemical Oxygen Demand (BOD)	mg/l	30	BDL	5.30	5.03	6.1	7.25	BDL (DL=3)	1.60	6.40	4.10	6.40
14	Total Coliform	MPN/100ml	0	1600.00	1600.00	>1600	900	>1600	160.00	41.00	1600.00	555.00	1600.00
			Total Score out of 13		5.5		7.5		5.5		6		5.3
Score 0	Increase/decrease away from and out of permissible range				Score 0.5	Increase/decrease away from and in permissible range							
Score 0.3	Increase/decrease towards and out of permissible range				Score 1	Increase/decrease towards and in permissible range							

17. <u>Source of water</u>

Interlinked lakes have three main sources of water in Ahmedabad (1) Rainfall (2) Stormwater channels (3) Water bought from the Narmada canal (north of Ahmedabad city) Catchment areas of the lakes are connected to a network of underground laid pipes. Storm water from this catchment area flows through this network into the lakes (Anand, 2014). Experts are concerned about the Narmada canal as the source of water to fill up the lakes as it is not sustainable (Bal et al., 2011). Lakes filling up from the first two sources are considered natural and sustainable. However, the two sources are not enough to completely fill up the lakes naturally. Increasing impervious surfaces in the catchment area due to unorganized urbanization and fluctuating rainfall trends are some of the reasons for this. During the fieldwork, it was observed that not all the lakes were filled with water. Hence, it can be concluded that water is not released into the lakes bought from the Narmada canal into all the lakes round the year. The distribution of the amount of water filling up the lake from the three sources is not known. Nevertheless, it can be concluded that the dependency on the Narmada canal as a source of water for all the selected lakes is not sustainable.

18. <u>Price and amount of water from Narmada Canal</u>

As the distribution between 3 sources of water to fill the lakes is not known, the exact amount of water bought from the Narmada canal cannot be known. The amount of water to buy from the Narmada canal has increased over a period of 10 years (2011 to 2021) (Source: SSNNL) due to some factors like increasing uncoordinated urbanization (less permeable surfaces), increasing temperature (more evaporation), and fluctuating rainfall. The price of water from the Narmada canal was Rs. 1.61/ cubic meter in 2011 which increased to Rs. 3.80 in 2021(Source: SSNNL). Hence, for all the lakes, with the increasing price and amount of water from the Narmada canal it can be concluded that it is not a sustainable solution.

19. Level of Water

The level of water observed during the fieldwork conducted during the summertime in the month of April 2022 is indicated in Table 27. Bodakdev and Prahaladnagar lakes were observed to be empty with dried lakebeds and the other lakes had water that had a foul smell. The score of each lake, based on the level of water is shown in Table 27.

Table 27: Level of water

	Level of water Summer 2022	Other observations Summer 2022	Score
Memnagar	Very low	The water is smelling bad Wastewater/Graywater released into the lake without processing	0.3
Vastrapur	Very low	The water is smelling bad	0.3
Bodakdev	Empty	Lakebed had dried out	0
Thaltej	Almost full	The water is smelling bad Wastewater/Graywater released into the lake without processing Other waste dumped in the lake	0.5
Prahaladnagar	Empty	Lakebed had dried out	0
Sarkhej	Very low	The water is smelling bad Wastewater/Graywater released into the lake without processing	0.3

20. Degree of naturalness of lake edge

As a part of field observations, the naturalness of the lake edge was observed (Table 28). It was observed that in some lakes like Memnagar, Vastrapur, Bodakdev, and Prahaladnagar, the natural lake edge was not preserved, and the lake edge was manually built using materials like concrete. This is not considered sustainable for the natural lake ecosystem and hence scored 0. The natural lake edge of Thaltej and Sarkhej lake is preserved (not developed) and hence scored 1.

Table 28: Naturalness of lake edge

	Natural/Seminatural Softscape (%) Stone/Soil	Hardscape (%) Concrete	Score
Memnagar	0	100	0
Vastrapur	0	100	0
Bodakdev	0	100	0
Thaltej	100	0	1
Prahaladnagar	0	100	0
Sarkhej	100	0	1

21. Total impervious v/s pervious surfaces

Total impervious v/s pervious surfaces in the catchment area of the selected lakes are shown in Figure 28 (Source: Anand, 2014). Residential, commercial, mixed-use land uses, and roads are considered impervious surfaces, and open spaces like parks vacant land, and parks were considered pervious surfaces. More the pervious surfaces, more water is recharged into the ground naturally reducing urban flooding and decreasing the amount of urban pollutants

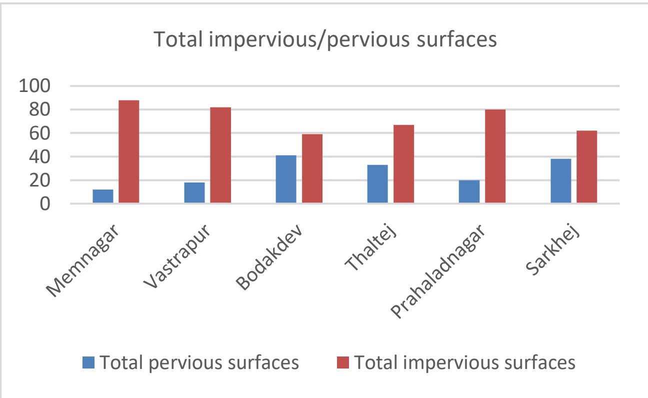

Figure 28: Total impervious v/s pervious surfaces (Anand, 2014)

flowing into the lake through the impervious land uses in the catchment area. As it can be seen from the figure, catchment areas of all the selected lakes have more than 50% of impervious surfaces. The higher the percentage of pervious surfaces, the more sustainable it is. Bodakdev has the highest pervious surfaces and Memnagar has the lowest.

22. <u>Topography and catchment area</u>

The topography of Ahmedabad city is relatively flat with a slope of 0.13% from north to south. The catchment area v/s capacity of the lake is as shown in Figure 29 (Source: AUDA). With the increasing capacity of the lake, the hydrological catchment area of the lake should increase in a linear relationship to fill the lake naturally. As it can be seen from the figure, Sarkhej and Thaltej lakes have a higher capacity and lower catchment areas. These lakes are given a half score (0.5). Other lakes that have relatively higher catchment areas as per their capacity are given a full score (1).

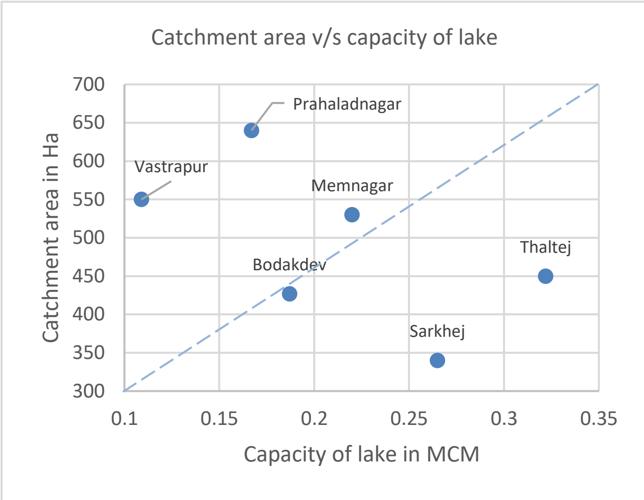

Figure 29: Catchment area v/s capacity of lakes (Data Source: AUDA)

23. <u>Neighbourhoods vulnerable to floods</u>

To identify neighbourhoods vulnerable to flooding, urban water logging density and water logging complainants were considered to evaluate the neighbourhoods around the selected lakes. This is indicated in Figure 30, with selected lakes highlighted in the western part of the city (Source: Thakur, 2020). From Figure 30, water logging density for the selected lakes is evaluated as high, moderate, low, and very low and scored 1, 0.7, 0.5, and 0.0, respectively. Similarly, water logging complaints from Figure 30, are evaluated as the presence/absence of registered complaints in the neighbourhoods around the selected lakes scored 1 and 0, respectively. Table 29 shows the evaluation and scoring based on these two parameters along with the final score out of 2. Here, the lower the score, the less vulnerable the neighbourhood, and the more sustainable it is. The table shows that Bodakdev and Sarkhej are the least vulnerable neighbourhoods as compared to others. This also relates to indicator 21, in which it was observed that these two neighbourhoods have more pervious surfaces, and hence, there is less urban waterlogging. On the other hand, Memnagar is the most vulnerable neighbourhood with high water logging density and registered water logging complaints.

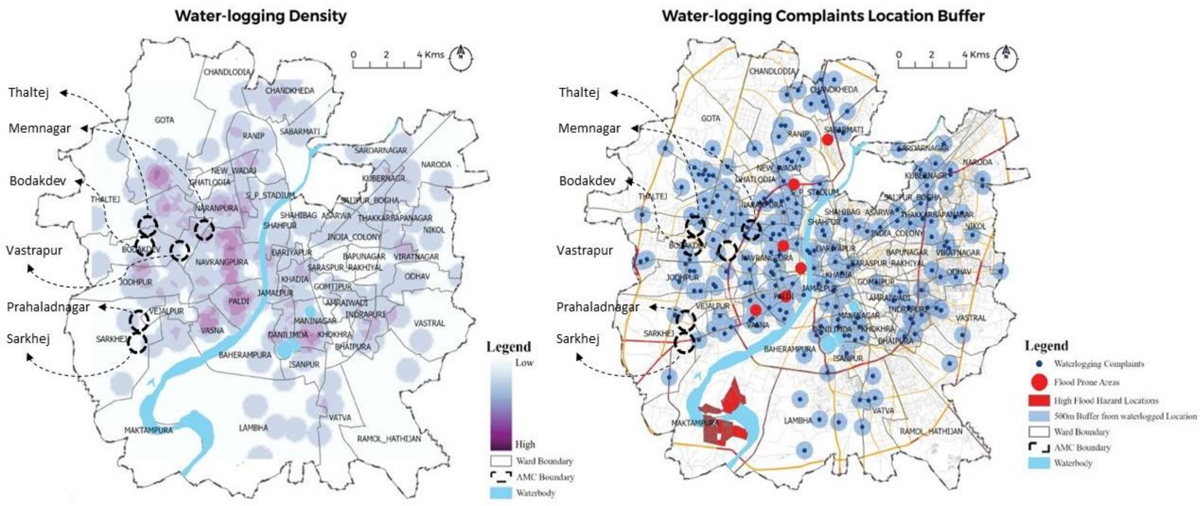

Figure 30: Neighbourhoods vulnerable to floods (Source: Thakur, 2020)

Table 29: Neighbourhoods vulnerable to flooding

	Water logging Density (Source: Thakur, 2020)	Water logging complaints in location buffer (Yes/No) (Source: Thakur, 2020)	Score (out of 2, lower the better)
Memnagar	High	Yes	2
Vastrapur	Moderate	No	0.7
Bodakdev	Very Low	No	0
Thaltej	Low	Yes	1.5
Prahaladnagar	Low	No	0.5
Sarkhej	Very low	No	0

24. Land use vulnerable to lake ecosystem

Allocated land use by AUDA, 2021 was studied to identify land uses vulnerable to lake ecosystem in 500m buffer around the selected lakes. Land uses involving industrial land use were considered vulnerable. For all the lakes, except Sarkhej, industrial land use was not found in the mentioned buffer. In sarkhej lake, commercial + industrial land use is present in the immediate proximity to the lake.

25. Characteristics of land reclaimed around the lake

During the development of the lake, immediate land around the lake is reclaimed and recreational activities and other amenities are developed in this area (Bal et al., 2011). This approach is debatable, however, this reclamation done using natural materials is considered sustainable. Characteristics of land reclaimed in the immediate periphery around the lake were observed on the field. This is indicated in Figure 31. The higher the percentage of softscape, the more sustainable it is. As indicated in Figure 31, the immediate land around the lake was observed to be natural, and on the other hand, Memnagar lake had the highest percentage of hardscape in the immediate periphery around the lake. Sarkhej lake is considered a relatively undeveloped/underdeveloped lake as compared to other selected lakes. Other developed lakes have a higher percentage of hardscape materials used. However, out of these, Bodakdev has the least percentage of hardscape materials used in the immediate periphery.

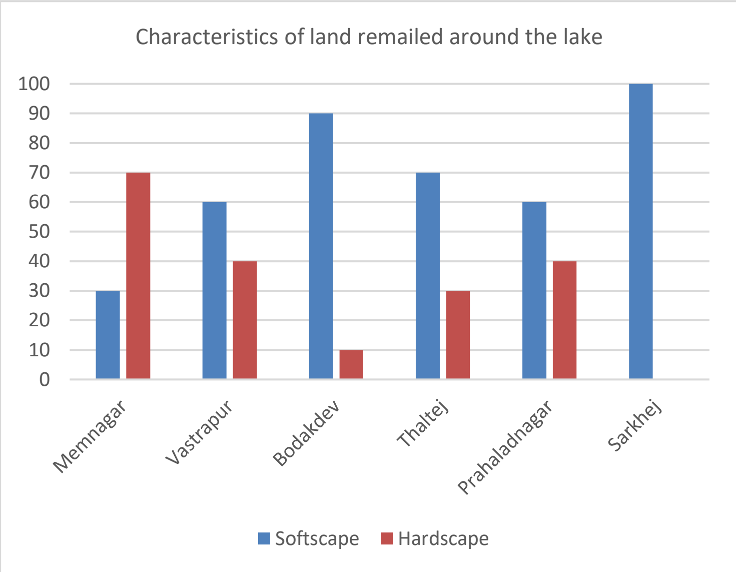

Figure 31: Characteristics of land reclaimed around the lakes

26. Lake area v/s lake depth

As mentioned in indicator 25, the land is reclaimed around the lake and hence, the effective lake area is reduced during the development of lakes. This approach of lake development among the experts has raised concerns about disturbing the natural process of the lake and it is not considered sustainable (Bal et al., 2011). Change in the area of natural boundary and boundary after development is not known. Hence, the element of the lake area is evaluated in Table 30 by the justification that if the lakebed is reclaimed, it is not sustainable and received a score of 0. Also, during the development of the lake, for better percolation, the lake bed was excavated and the effective depth of the lake was increased (Bal et al., 2011). Lake depth can affect vegetation growth and aquatic life. The maximum depth of the lake should range between 1.2m to 2.4m which gradually decreases at the lake edge up to 0.9mm to support vegetation growth and aquatic life (Crabb, 2022). Modification of lake contour after development is not known. Lake depth is evaluated in Table 30, by considering the maximum depth in the above-mentioned range. As indicated in the table, Sarkhej lake has the highest score as its lakebed is not (yet) reclaimed and the depth of the lake can support aquatic life. Memnagar, Vastrapur and Prahaladnagar lakes have zero score. Vastrapur lake is reported to have issues regarding survival of aquatic life (Desai, 2020). Lake depth could be one of the reasons behind reported dying fishes in the lake.

Table 30: Lake area and lake depth

	Lake area evaluation Lakebed reclaimed (Yes/No)	Maximum Lake Depth (m)evaluation (Source: (Anand, 2014)) Maximum depth in rage (Yes/No)	Score (Out of 2)
Memnagar	Yes	-3 (No)	0
Vastrapur	Yes	-4 (No)	0
Bodakdev	Yes	-1 (Yes)	1
Thaltej	No	-4 (No)	1
Prahaladnagar	Yes	-3 (No)	0
Sarkhej	No	-2.5 (Yes)	2

27. Distance to migratory birds flyway

The Thol bird sanctuary situated 40km from Ahmedabad is recently recognized by the Ramsar Convention as a wetland of international importance (Ghosh, 2022). Migratory birds from all over the world visit the Thol lake. The birds have been observed to stop at some lakes in Ahmedabad, like Shilaj lake on the western side of the city. Lakes in Ahmedabad can be a potential location for migratory birds to visit if the natural environment of the lake is not disturbed. The closer the lake to the Ramsar site, the better it is. Figure 32 indicates this distance and among the selected lakes, Thaltej and Bodakdev lakes are the closest to Thol. This indicator along with indicators 28, 29, and 30, can indicate the status of biodiversity in the selected lakes.

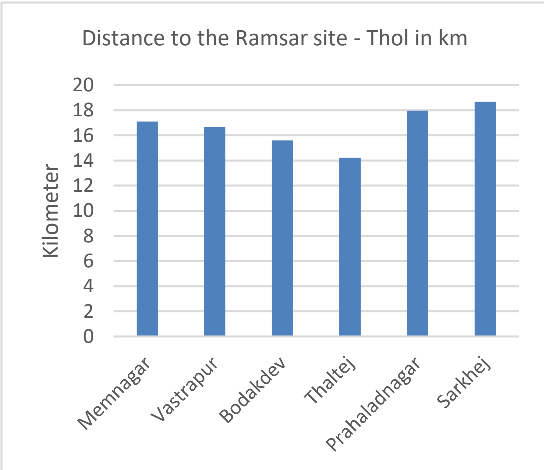

Figure 32: Distance to the Thol Ramsar site (Source: Google earth)

28. Amount of green and blue in the catchment area

Green and blue spaces near the lake help to maintain the natural ecosystem of the lake. This includes open spaces like parks and other water bodies in the catchment area of the lake (Figure 33). Higher the amount of green and blue, it is more sustainable. As shown in Figure 33, Prahaladnagar and Bodakdev have the highest percentage of such spaces in their catchment area. On the other hand, Vastrapur has the lowest amount of such spaces. In general, for all the lakes, the amount of green and blue spaces in the catchment area is very low.

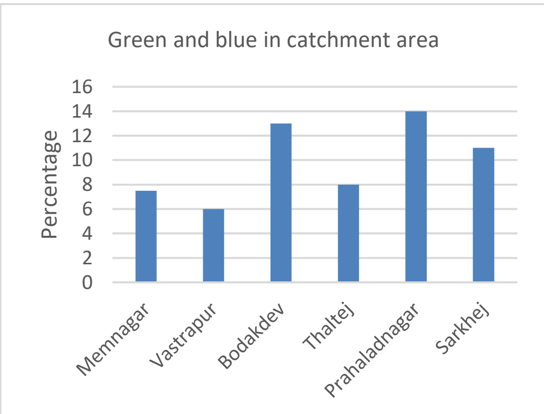

Figure 33: Amount of green and blue in catchment area (Source: (Anand, 2014))

29. Vegetation Cover

Vegetation cover around the selected lakes is partial shoreline vegetation with shrubs and trees (Source: GEMI). However, the field observations recorded are shown in Table 31. It was observed that Bodakdev lake had relatively larger and maintained vegetation cover. Volunteers and government representatives were giving away tree saplings to the visitors. Memnagar, Vastrapur, and Prahaladnagar had partial vegetation cover. It was observed that gardeners in Vastrapur and Prahaladnagar lakes maintain the vegetation cover. In Memnagar, it was observed that local residents are involved in maintaining the vegetation cover and also growing more trees around the lake. Thaltej and Sarkhej had relatively low vegetation cover. Based on these observations, scores for each lake are shown in Table 31.

Table 31: Vegetation cover

	Observation	Score
Memnagar	Partial vegetation cover, local residents maintaining and growing more trees	0.8
Vastrapur	Partial vegetation cover, a gardener working to maintain the vegetation cover	0.7
Bodakdev	Most green among the selected lakes, also well maintained	1
Thaltej	Very low vegetation cover	0
Prahaladnagar	Partial vegetation cover, a gardener working to maintain the vegetation cover	0.7
Sarkhej	Very low vegetation cover	0

30. Water quality for aquatic life

The presence of Dissolved Oxygen (DO) in water is important for the survival of aquatic life as it consumes dissolved oxygen to survive. As per water quality standards, DO should be more than 3 mg/l for aquatic life to survive inside water. This water quality parameter to evaluated to assess the water quality standards in the selected lakes (Table 32). As it can be seen from the table, DO is above 3 mg/l. However, it is important to note that DO is decreasing for all lakes except Prahaladnagar (Indicator 16). Here, the higher the amount of DO, the more it is considered more sustainable.

Table 32: Dissolved Oxygen in selected lakes (Source: GEMI)

	Dissolved Oxygen (DO) mg/l Reading details: 2021, Post Monsoon
Memnagar	5.3
Vastrapur	7.95
Bodakdev	3.6 (Not known for 2021, This reading is for 2014 Source: (Anand, 2014))
Thaltej	5.6
Prahaladnagar	5.7
Sarkhej	3.95

31. Maximum cooling distance

For evaluating this indicator, proxy measurement is used. It is assumed that cooling distance increases with an increasing amount of green and blue space in and around the lake. This means that the higher the amount of water in the lake, the more its effect on the cooling distance. Similarly, the more the amount of vegetation cover around the lake, the more its effect on the cooling distance. For these two elements of measurements, indicators 19 and 29 are taken into consideration (Table 33). A total score out of 2 is calculated from these elements in Table 33. Here, it is assumed that the higher the score, the more the cooling distance. Memnagar, Vastrapur, and Bodakdev have higher scores and Sarkhej has the lowest score.

Table 33: Cooling Distance

	Level of water, Summer 2022 Score out of 1	Vegetation cover, Summer 2022 Score out of 1	Total Score Out of 2
Memnagar	0.3	0.8	1.1
Vastrapur	0.3	0.7	1
Bodakdev	0	1	1
Thaltej	0.5	0	0.5
Prahaladnagar	0	0.7	0.7
Sarkhej	0.3	0	0.3

32. Monitoring and assessment details

Monitoring and assessment tools at different stages of project design and implementation should be done. Incorporating the insights from such tools is very important for the decision making process and for protecting the natural ecosystem of the lakes. No such tools have been found to be used in the case study area. Hence, all lakes in this indicator are scored nil.

33. Population directly/ indirectly dependent on the lake

During the fieldwork over 2 days, the number of people directly/indirectly dependent on the lake was observed. The higher the number of people economically dependent on the lake, the more the used value of the lake, and hence people's engagement with the lake is more. Also, as these people are economically dependent on the lake, they have a sense of responsibility and belongingness to the lake and hence they are important stakeholders of the lake. The different groups of people observed to be dependent on the lake are shown in Table 34. Vastrapur has the highest number of different groups dependent on the lake. Vastrapur lake had the highest number of activities to engage (indicator 2), hence was observed to be more active as compared to other lakes. Memnagar and Sarkhej have relatively low scores.

Table 34: Population dependent on the lake

	Different groups	Dependence
Memnagar	3	Tea stall workers, cleaning staff, cow grazers from the village
Vastrapur	6	Food vendors, Breakfast vendors, watchmen, staff operating rides, cleaning staff, water purification plant staff
Bodakdev	5	Amul dairy shop staff, tea stall workers, caretaker, gardener, watch(women)
Thaltej	4	Food vendors, vegetable market vendors, shops around the lake, auto stand
Prahaladnagar	5	Amul dairy shop staff, cleaning staff, gardener, fruit vendors, watchman
Sarkhej	2	Watchman, Food vendors (soda shop)

34. Increase/Decrease in land value

Jantri rates are the rates of land, buildings, and properties decided by the government. Gujarat government last revised the Jantri rates in 2011 (Dave, 2021). Before that, in 2006, the government revised the Jantri rates that were implemented in 2008. In the revision in 2011, rates were increased 3 times as compared to in 2008 and the state government had to face protests from people (Shah, 2012). However, the gap between government rates and market rates is very high (Dave, 2021). As the Jantri rates have not been revised since 2011 and due to the gap between market and government rates, to understand the real scenario, change in market rates is evaluated in this indicator. The change in land value over time for the neighbourhoods is shown in Table 35. As it can be seen, for all the neighbourhoods, land value has increased in the given time. Thaltej has recorded the highest increase of 76.47% and Memnagar has recorded the least increase of 26.74%. This increase can be affected by several factors which can have negative impacts like gentrification. Hence, more fluctuations and more increase in land value is not considered sustainable for all.

Table 35: Change in land value (Source: (99acres, 2022))

	Price change over time (10 years: 2012 – 2022)
Memnagar	26.74% increase
Vastrapur	59.30% increase
Bodakdev	56.31% increase
Thaltej	76.47% increase
Prahaladnagar	61.29% increase
Sarkhej	29.82% increase

35. Cost of interlinking

The total cost of interlinking for the first phase of the project was estimated as shown in Table 36. The area of the storm drainage network for each lake is shown in Table 37. Here, it is assumed that the higher the proposed area of the storm network, the cost for particulars 2 and 3 in Table 36 will increase and hence, the higher the cost for the lake. Based on this justification, lakes are ranked in Table 37, where the lower the rank, the less the cost.

Table 36: Estimated cost of the interlinking project, first phase (Source: AUDA)

Sr no	Particulars	Estimated cost in crores (INR)
1	Interlinking of lakes	64.41
2	Catchment Drain from neighbourhoods to the lake	21.33
3	Strom Drain (Cronic Spots)	15.48
	Total cost	101.22
	Add contingency	3.53
	Grand Total	104.75 Crores

Table 37: Area of storm drainage network proposed (Source: AUDA)

	Area of storm drainage network proposed (Ha)	Rank
Memnagar	140	3
Vastrapur	113	2
Bodakdev	193	5
Thaltej	436	6
Prahaladnagar	160	4
Sarkhej	-	1

36. Cost of development

The estimated cost of reviving and developing the lakes is shown in Table 38. This involves lake excavation and restoration of lake storage, construction of percolation wells in the lakebed, and development in the immediate periphery of the lake which includes landscaping, recreational activities, etc. Lower the cost of development is considered more economically sustainable. As it can be seen from the table, Memnagar and Sarkhej have the highest estimated costs and Bodakdev has the lowest. It is important here to note that these are the estimated costs, and the actual costs of development are not known.

Table 38: Estimated cost of lake development (Source: (Mahadevia & Brar, 2008))

	Total estimated cost (In INR in million)
Memnagar	16.2
Vastrapur	12.2
Bodakdev	10
Thaltej	17
Prahaladnagar	11.7
Sarkhej	16.3

37. Cost of maintenance

The estimated maintenance cost per year is 73.14 lakhs (Source: AUDA). The minimum cost of maintenance is considered sustainable. Costs related to maintaining the interlinking network and the lakes itself is not known for each lake. Vastrapur, Bodakdev, and Prahaladnagar lakes are maintained by the company Amul. This is a public-private partnership (PPP) arrangement. In this, public spaces are given to a private company like Amul, and they look after the maintenance of the lake. In return, Amul sets up a kiosk for running its business. This is considered a sustainable solution to increase the used value of the lake and maintain the lake. Details regarding the maintenance of the other three lakes that do not have PPP are not known.

Annex 7: Panel discussion details

The panel discussion had 4 rounds of questions asked to the experts. Each round accounted for 10 minutes. The questions asked to the experts in 4 rounds as listed below:

Questions: Round 1 (To all 3 experts, open question)

1. What is your first impression of the tool?
2. Are the patterns of the sustainability scores useful for the planning process?
3. For which purposes can it be useful in the planning process?

Questions: Round 2 (To all 3 experts, open question)

1. What are the requirements to use this tool in planning practice?
2. Do you think this tool could be adopted?
3. What would be the reasons for that? What would be needed for the tool to be adopted? What are the reasons it may not be adopted?

Questions: Round 3

1. To Expert 8: In the case of Ahmedabad, they are planning to interlink over 40 lakes in phase 2 of the project. As you mentioned in our meetings, there is no evaluation (like EIA) of the interlinking, and this is considered a successful project. Can a tool like this be incorporated at different stages of planning?
2. To expert 6: Lake communities in Bangalore have been successful in reviving lakes and restoring their natural ecosystem. How do these communities consider multiple social, environmental, and economical factors? Can a tool like this make an addition to the current planning approach/process, how?
3. To expert 10: You have been studying both the cases of Ahmedabad and Bangalore closely and you have also worked on the interlinking project at AUDA. This is seen as a hydrological and engineering project in the case of Ahmedabad. If you were to use the tool in either/both cases, what would be the two most interesting things about the tool, and what would be the two things that you would like to improve upon?

Questions: Round 4 (To all 3 experts, open question)

1. The bottom-up approach being experimented in Bangalore with community initiates is successfully reviving water bodies in Bangalore. We have a pool of experts and institutions like CEE, CEPT, etc. in Ahmedabad. Why is such an approach not used in Ahmedabad? What needs to be done to bring that to Ahmedabad?