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Optimizing lake management: Strategy development based on potential goals and challenges using ISM and DEMATEL approach

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ABSTRACT

This paper aims to optimize lake management by developing strategies based on potential goals and challenges using the ISM-DEMATEL approaches. The study focuses on Lake Buyan, located in Buleleng Regency, Bali, Indonesia. Through in-depth interviews and focus group discussions involving experts and stakeholders, this research identifies six goal elements: Eco-tourism (G1), Eco-agrotourism (G2), Eco-spiritual tourism (G3), Water quality meets the standards (G4), Reduction of environmental pollution (G5), and Protection and preservation of sacred areas (G6). Additionally, eight challenge factors are identified: Lack of public knowledge about the lake (C1), Low community participation (C2), Low community attitudes and behaviors (C3), Lack of synchronization among relevant agencies and the community (C4), Economic vulnerable communities (C4), Weak human resources (C6), Weak law enforcement (C7), and Lack of strict and continuous monitoring (C8). Using the ISM-DEMATEL approach, this study reveals that G1, G2, G3, and G6 are the leverage factors among the goal elements, while G4 and G5 are the affected factors. In terms of the challenge elements, this research highlights C1, C4, C7, and C8 as leverage factors, while C2, C3, C5 and C6 are affected factors. Based on these findings, the development of the Lake Buyan management strategy prioritizes the leverage factors among the goal elements and addresses the leverage factors among the challenge elements.

1. Introduction

Lakes are invaluable natural resources that provide numerous ecological, economic, and recreational benefits to societies worldwide. These freshwater bodies are vital for biodiversity conservation, water supply, flood regulation, and recreational spaces {Cantonati et al, 2020., Dudgeon et al, 2006). However, lakes face an array of challenges resulting from human activities and environmental changes, threatening their ecological integrity and compromising the services they offer (Ho and Goethals, 2019). To ensure the long-term sustainability of aquatic ecosystems, effective lake management strategies are crucial, aligning with the Sustainable Development Goals (SDGs) set by the United Nations (Crane, 2022., Loucks and van Beek, 2017).

The SDGs, adopted by the UN in 2015, provide a comprehensive framework for addressing global challenges and promoting sustainable development across sectors (Moallemi et al, 2020). Sustainable lake management directly relates to several SDGs, reflecting the interconnectedness between aquatic ecosystem health and social, economic, and environmental goals. Firstly, SDG 6 emphasizes ensuring clean water and sanitation for all, which can be achieved by implementing effective lake management practices to safeguard water quality, protect drinking water sources, and promote sustainable water use (Arora and Mishra, 2022). Secondly, SDG 14 focuses on conserving marine and coastal ecosystems, and sustainable lake management strategies enhance ecological resilience, protect habitats, and contribute to aquatic biodiversity conservation (Unit B, 2019). Additionally, sustainable lake management contributes to SDG 15 by promoting integrated watershed management approaches that reduce pollution, erosion, and harmful substances discharged into lakes, thereby supporting terrestrial ecosystem conservation and sustainable land use (Loucks and van Beek, 2017., Mugagga and Nabasa, 2016). By incorporating sustainability, science, policy, and community engagement, sustainable lake management advances the achievement of multiple SDGs, ensuring the preservation and restoration of aquatic ecosystems and a more resilient future for lakes and dependent communities.

Lakes are found across the globe, representing diverse geographical regions and climates, and their existence plays a fundamental role in maintaining the overall health of our planet (Chen et al, 2022). These freshwater bodies come in various sizes, from small ponds and reservoirs to vast inland seas, and they serve essential functions that are vital for both human societies and the natural environment. Lakes play a vital role in water storage and supply, acting as reservoirs that regulate water flow in river systems and mitigate downstream flooding. They are essential sources of drinking, irrigation, and industrial water, supporting human survival and development. Lakes also hosts diverse ecosystems, providing habitats for various species and offering vital services like nutrient cycling and water purification. Additionally, lakes hold cultural and recreational value, serving as significant sites for indigenous communities and popular destinations for leisure activities. However, lakes face challenges from human activities and climate change, emphasizing the need for effective and sustainable management practices that integrate scientific knowledge and local expertise (Mishra et al, 2021).

Indonesia, known for its natural beauty and diverse ecosystems, harbors numerous lakes, including those in Bali, which are vital to the socio-religious fabric of local communities, reflecting their deep cultural connections. Bali, the "Island of the Gods," boasts lakes like Batur, Bratan, Buyan and Tamblingan, holding immense cultural, religious, and socio-economic value. Considered sacred, these lakes are pilgrimage sites and centers of worship, with Balinese temples adorning their shores. They support agriculture, provide livelihoods through fishing, and attract tourism (Sumarya et al, 2020). However, challenges such as population growth, tourism, and environmental degradation threaten the lakes' sustainability. Recognizing their significance, efforts integrate cultural values into lake management, preserving ecological integrity while respecting heritage. The harmonious coexistence of human activities, spiritual beliefs, and lake preservation ensures ecological balance, livelihoods, and a sense of identity among the Balinese people.

The development of effective and sustainable lake management strategies relies on the involvement of all stakeholders through integrated approaches. Collaboration and active participation from local communities, government institutions at different levels, scientific and academic institutions, non-governmental organizations, civil society groups, and the private sector are essential (Kumar et al, 2020., Widyatmika and Bolia, 2023). Engaging local communities allows for the incorporation of traditional knowledge, local perspectives, and aspirations, fostering ownership and stewardship (Arantes et al, 2022., Torrents-Ticó et al, 2021). Government institutions provide regulatory frameworks, coordination across sectors, and resource allocation. Scientific institutions contribute expertise, research, and evidence-based decision-making (Ruangpan et al, 2021). NGOs, civil society groups, and the private sector offer support, responsible practices, and innovative solutions. Open dialogue and participatory approaches facilitate inclusive decision-making processes, ensuring consensus-based solutions that balance ecological integrity, socio-economic development, and cultural values (Raymond et al, 2022., Purvis et al, 2019). By involving all stakeholders, we can achieve effective and sustainable lake management that addresses complex challenges and preserves the ecological sustainability and socio-cultural significance of lakes.

The diverse aspects of lake management have been subject to extensive research efforts, ranging from water quality and pollution control to ecological conservation and restoration (Yang et al, 2016). Through multidisciplinary studies, scientists have advanced our understanding of the complex interactions within lake ecosystems and have provided valuable insights for the development of comprehensive and sustainable lake management strategies. By incorporating the findings from this research, policymakers, practitioners, and stakeholders can make informed decisions to ensure the preservation and effective management of lakes for the benefit of both human societies and the environment.

The involvement of stakeholders in the development of a lake management strategy is crucial, considering both the goals to be achieved and the challenges to be addressed. Stakeholders, including local communities, government institutions, scientific organizations, non-governmental organizations, and the private sector, possess valuable knowledge, perspectives, and expertise that can contribute to the formulation of effective and inclusive strategies. By engaging stakeholders in the decision-making process, a broader range of interests and concerns can be considered, leading to more comprehensive and context-specific approaches (Smyth et al, 2021). Furthermore, involving stakeholders fosters a sense of ownership, cooperation, and shared responsibility, increasing the likelihood of successful implementation and long-term sustainability of the lake management strategy. It ensures that the strategy aligns with the needs and aspirations of different stakeholders and promotes a collaborative approach that integrates diverse perspectives to tackle the complex challenges facing lakes. There is a limited amount of research specifically focused on developing lake management strategies that involve relevant stakeholders, particularly for lakes with specific cultural significance to the surrounding communities. Therefore, this study focuses on the development of lake management strategies based on goals and challenges, involving relevant stakeholders, utilizing the Interpretive Structural Modeling (ISM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) methods.

The next section will present a literature review related to the development of lake management strategies involving relevant stakeholders and various methods used.

Literature review

The focus of this study is the development of lake management strategies based on the potential goals and possible challenges, employing the ISM and DEMATEL approaches. Through a comprehensive review of the literature, this section aims to highlight the contributions and findings of previous research in developing sustainable lake management strategies.

Lake management strategies

Lakes are important natural resources that provide numerous physical, biological, environmental, and socio-economic functions. Effective lake management strategies are essential to ensure the preservation and sustainable utilization of these valuable ecosystems. This literature review aims to explore the existing body of research focused on lake management strategies, with a specific focus on the physical, biological, environmental, and socio-economic aspects of lakes. By examining the findings and insights from previous studies, this review seeks to identify key approaches and best practices in managing lakes to promote their ecological integrity, biodiversity, and socio-economic benefits.

Lakes fulfill multiple functions, encompassing their physical, biological, environmental, and socio-economic aspects. Their physical function involves water storage, flow regulation, and flood mitigation, requiring strategies such as lake-level management and watershed protection (Rather and Dar, 2020). Preservation of the biological function necessitates maintaining water quality, conserving habitats, and managing nutrients and invasive species. The environmental function entails adopting sustainable land-use practices to minimize pollution and sedimentation, while socio-economic benefits include water supply, recreation, and tourism, which require balancing economic development with environmental conservation (Ho and Goethals, 2019., Crane, 2022).

Strategies like stakeholder engagement and traditional ecological knowledge integration aim to ensure sustainable lake utilization while supporting local livelihoods (McGregor et al, 2023).

Many research demonstrates the multi-faceted nature of lake management strategies, encompassing the physical, biological, environmental, and socio-economic aspects of lakes. The findings from previous research provide valuable insights into the diverse approaches and best practices employed to promote the sustainable management of lakes. By understanding and incorporating these strategies into future lake management efforts, it is possible to ensure the long-term ecological integrity, biodiversity conservation, and socio-economic well-being associated with these vital natural resources.

Strategy development

Over the years, various methodological approaches have been employed to develop effective strategies for managing lakes, addressing the physical, biological, environmental, and socio-economic functions of these ecosystems. This section presents a review of the literature on lake management strategy development, focusing on the incorporation of different methods, including the ISM-DEMATEL approach.

Lake management strategies encompass addressing water quality, biodiversity conservation, habitat restoration, and socio-economic considerations. Integrated approaches are crucial, as highlighted in the research, to consider the interconnections between physical, biological, environmental, and socio-economic factors. The literature emphasizes the goals of enhancing water quality, preserving ecological integrity, promoting sustainable resource use, and ensuring community well-being (Attri et al, 2013).

Studies have utilized multi criteria decision analysis in water and lake management strategy development, identifying critical factors, assessing interrelationships, and prioritizing them (Abdullah et al, 2021., Schuwirth et al, 2018). These approaches offer a deeper understanding of lake ecosystem dynamics, supporting effective management strategies. ISM and DEMATEL integration provides qualitative and quantitative analysis, facilitating a systematic approach to tackle challenges and harness lake management potential. By combining these methods, researchers and practitioners gain insights into complex interactions, informing comprehensive and targeted strategies.

The integration of ISM and DEMATEL offers a robust framework for understanding the complexity of lake ecosystems, identifying key factors, and prioritizing actions. By leveraging these methodological approaches, stakeholders can develop comprehensive and effective strategies to address the physical, biological, environmental, and socio-economic aspects of lake management, ensuring the long-term sustainability and well-being of these valuable ecosystems.

Research gaps

The literature review highlights a critical research gap in the field of lake management strategy development: the limited integration of traditional ecological knowledge held by local communities living around lakes. While existing studies emphasize the importance of incorporating stakeholders' perspectives and valuing lake ecosystems, there is a scarcity of research specifically addressing the integration of traditional ecological knowledge into lake management strategies. Traditional ecological knowledge encompasses the cumulative knowledge, practices, and beliefs developed by communities over generations, reflecting their deep understanding of the local environment and its dynamics.

This research gap is particularly significant as traditional ecological knowledge offers valuable insights into the intricate interactions between humans and their natural surroundings. Local communities possess a deep understanding of the ecological processes, species interactions, and ecosystem functions specific to their local contexts. Their knowledge often encompasses sustainable resource management practices, adaptive strategies to cope with environmental changes, and traditional values and norms that promote the harmonious coexistence with nature. However, the limited incorporation of this knowledge in lake management strategies restricts the potential benefits that can be derived from their participation and wisdom. Bridging this research gap by exploring ways to effectively integrate traditional ecological knowledge into lake management practices will not only enhance the ecological sustainability of lakes but also promote the empowerment of local communities and foster a sense of ownership and stewardship over these vital natural resources.

Lake Buyan, situated across two regencies in Bali, Indonesia, namely Tabanan and Buleleng, not only serves ecological functions but also holds socio-religious significance for the surrounding communities. In determining the management strategy for Lake Buyan preservation (LBP), it is crucial to involve local wisdom and elements of indigenous knowledge. Thus, this study aims to develop a lake management strategy for LBP by employing the ISM-DEMATEL method, utilizing the expertise of local stakeholders and incorporating the perspectives of the local community.

In the following section, we will delve into the practical implementation of ISM-DEMATEL, aiming to formulate an effective lake management strategy that takes into account the unique goals and challenges associated with the potential of Lake Buyan.

2. Methodology

The primary aim of this study is to create a structural framework that combines and utilizes the ISM and DEMATEL techniques for the exploration of causal-effect relationships and their interconnections. A visual representation of the proposed methodology can be observed in Figure 1. The ISM and DEMATEL methods possess both commonalities and distinct characteristics, enabling us to comprehend the connections between factors and offer effective solutions based on decision-making (Chauhan et al, 2018). These methods are recognized for their efficiency and robustness. By employing this approach, we can effectively identify and prioritize the goals and challenges associated with integrated lake management. Figure 1 illustrates the step-by-step procedure, beginning with the identification of goals and challenges related to lake management. Subsequently, data collection takes place, followed by an analysis that reveals the relationships between the factors. Finally, a performance ranking is conducted. The subsequent sections provide an in-depth discussion of the ISM and DEMATEL methods.

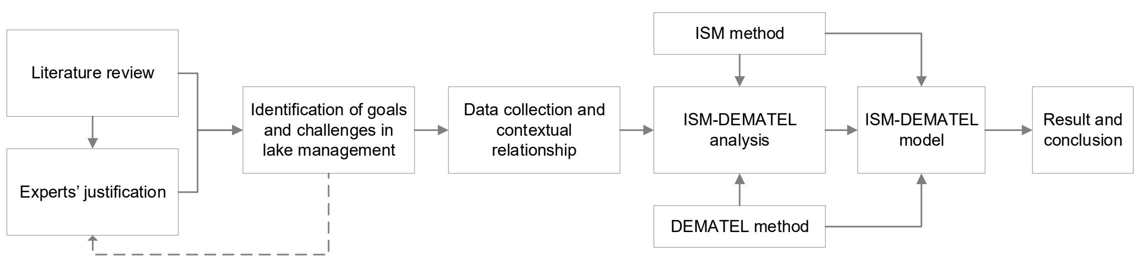

Fig. 1 The framework of lake management modeling using the ISM-DEMATEL method

ISM

The ISM method serves as a qualitative approach to simplify the comprehension and construction of a structural model based on expert judgment by transforming a complex structure into various alternatives. It finds significant application in management problems characterized by intricate structures. Through the utilization of this method, the complex structure is subdivided into subcategories, allowing for the identification and summarization of relationships among the elements (Attri et al, 2013., Manoharan et al, 2022).

The ISM method follows several steps. Firstly, in Step 1, drivers and barriers are identified through a thorough review of the literature. In Step 2, a contextual relationship is established between the identified factor, encompassing goals and challenges. Step 3 involves the formulation of the Structural Self-Interaction Matrix (SSIM), represented in the form of symbols such as V, A, X, and O. These symbols are used to depict the relationship between factors "i" and "j," where V signifies that factor "i" affects factor "j," A indicates that factor "i" is affected by factor "j," X denotes mutual affect between factors "i" and "j," and O represents that factors "i" and "j" are unrelated. Step 4 involves the construction of a reachability matrix derived from the SSIM. In this process, the symbols are substituted with binary numbers, specifically 1 and 0, to convert the SSIM into the reachability matrix. The binary substitution process is illustrated in Table 1.

Table 1 The binary substitution

SSIM	(i,j)	(j,i)

V	1	0
A	0	1
X	1	1
O	0	0

Step 5: The examination of the transitivity is performed on the reachability matrix by adhering to the principle of transitivity. This matrix model was devised to derive the ultimate reachability matrix. The principle of transitivity asserts that if "Factor-1" affects "Factor-2," "Factor-2" affects "Factor-3," then it follows that "Factor-1" also affects "Factor-3". Step 6: The factors are categorized into distinct levels based on the final reachability matrix, utilizing the sets of reachability and antecedent. The reachability set comprises factors that are affected by other factors, including themselves, while the antecedent set encompasses factors that affect other factors, including themselves. Step 7: A canonical matrix is constructed by arranging the factors into different levels, considering their driving and dependence power along the row and column, which are determined by organizing the antecedent and reachability sets. Subsequently, a directed graph (digraph) is created based on the SSIM and Reachability matrix, and ranked accordingly. Finally, the structural ISM is derived from the digraph (Attri et al, 2013).

DEMATEL

The DEMATEL method was developed by the Battelle Memorial Institute of Geneva between 1972 and 1976. This method serves as a valuable tool for addressing complex and intricate problems within the realm of management, aiding in the identification of criteria that require greater attention (Manoharan et al, 2022). By employing a structural modeling technique, DEMATEL facilitates the exploration of relationships among criteria in a system through the use of a digraph. This digraph enables the study and identification of causal relationships between criteria, allowing decisions to be made based on expert judgment. The DEMATEL method follows a series of steps. In Step 1, the criteria pertaining to drivers and barriers are identified and placed within a matrix. Expert ratings are then utilized to form a pairwise matrix, employing a linguistic scale of affect as illustrated in Table 2.

Table 2 Linguistic scale and rating

Linguistic scale	Rating
No affect	0
Low affect	1
Medium affect	2
Strong affect	3

By utilizing an equation, the average score for each criterion can be computed.:

$$a_{ij} = \frac{1}{H}\sum_{k=1}^{H} x_{ij}^{k} \quad (1)$$

In step 2, we form a Normalized direct relationship matrix “D” in which the matrix obtained by multiplying matrix “A” with λ

Normalized direct relationship matrix “D” = $[A].\lambda$ (2)

where

$$\lambda = \text{Min}\left[\frac{1}{max\sum_{j=1}^{n} a_{ij}}, \frac{1}{max\sum_{i=1}^{n} a_{ij}}\right] \quad (3)$$

In step 3, we obtain the total relation matrix “T” by using the equation

$$T = D(1 - D)^{-1} \quad (4)$$

In step 4, we present the sum of rows and the sum of the column as r and c. Then the equation is used (r + c) and (r-c), where:

$$r = [\sum_{b=1}^{n} T_{ab}]_{nx1} \quad (5)$$

$$c = [\sum_{a=1}^{n} T_{ab}]_{1xn} \quad (6)$$

Then in step 5 we form the digraph using the corresponding values of the (r + c) and (r-c), which are the causal and which is affected.

In the following section, we will delve into the practical implementation of ISM-DEMATEL, aiming to formulate an effective lake management strategy that takes into account the potential goals and challenges associated with the LBP.

Model Implementation

Lake condition data consists of secondary data obtained from various sources such as research findings, reports, and documents from different institutions. Meanwhile, socio-ecosystem data comprises primary data obtained through direct interviews with local communities and stakeholders, as well as secondary data obtained from documents provided by various institutions. Furthermore, the goal and challenge factors are primary data acquired directly from questionnaires, interviews, and through Focus Group Discussions (FGD) with experts.

In this study, the identification of the most promising goals and challenges is conducted by taking into account a threshold value of $\mu \geq 10\%$. Utilizing this criterion, the subsequent analysis focuses on the selected goals and challenges, which are listed in Table 3. It is noteworthy to highlight that Table 3 presents seven goals and six challenges, reflecting the feedback from 95% and 93% of the respondents, respectively.

Table 3 Goals and challenges based on the value of $\mu \geq 10\%$ threshold

Goals	Code	%	Challenges	Code	%
Eco-tourism	G1	27	Lack of public knowledge about the lake	C1	30
Eco-agrotourism	G2	24	Low community participation	C2	23
Eco-spiritualtourism	G3	19	Low community attitudes and behaviors	C3	21
Water quality meets the standards	G4	13	Lack of synchronization among relevant agencies and the community	C4	19
Reduction of environmental pollution	G5	11	Economically vulnerable communities	C5	16
Protection and preservation of sacred areas	G6	11	Weak human resources	C6	14
			Weak law enforcement	C7	13
			Lack of strict and continuous monitoring	C8	12

Following with the framework of the integrated ISM-DEMATEL approach, the initial step involves utilizing the ISM method, followed by the DEMATEL method, both utilizing the same data obtained from the Structural Self-Interaction Matrix (SSIM) derived from the ISM method (Manoharan et al, 2022). The formation of the SSIM and pairwise matrix takes into account the input and perspectives of seven stakeholders. In this particular study, a diverse group of experts consisting of two government agents, *bendesa adat*[1] and an NGO of traditional agricultural representatives of the traditional community, as well as three academics specializing in the field of environemental science, were selected. Their respective roles and work experience are presented in Table 4. The inclusion of this expert panel ensures a comprehensive and well-rounded representation, as all members possess expertise and practical knowledge in relevant areas. In cases involving multiple decision-makers, the formation of the matrix is based on the collective input obtained from each decision-maker, concerning the symbols used in the SSIM.

[1] *Bendesa adat* in Bali traditional communities serves as a vital custodian of cultural heritage, a community leader, and a guardian of customs and traditions, playing an essential role in maintaining the unique social fabric and identity of the village.

Table 4 Stakeholders and Experts' profile

Stakeholders (SH)	Designation	Field of experties	Experiences (years)
SH-1	Government officer	Forestry and land preservation	10
SH-2	Government officer	Lake and river preservation	15
SH-3	*Bendesa adat*	Local knowledge	38
SH-4	NGO	Agricultural	20
SH-5	Professor	Environmental science	35
SH-6	Professor	Social economic	30
SH-7	Professor	Socioecology	20

In the ISM method, the SIM matrix is utilized to represent goals and challenges, presented in Table 5 and Table 6 respectively. Subsequently, the SSIM is converted into binary numbers (0 and 1) using the binary substitution method described in Table 1. This transformation enables the generation of the Reachability Matrix for goals and challenges. The Transitivity Matrix is then derived by applying the transitivity rule, which allows for the determination of driving power and dependence power. These insights guide the construction of the graph, and iterations are conducted to establish different levels of partitioning for the goal factors and challenge factors (respective matrices are available in the appendix). Based on the iteration levels, the final ISM models for goals and challenges are determined and presented in Table 7 and Table 8, respectively. Lastly, Tables 9 and 10 highlight the canonical matrix for goals and challenges, respectively. The ISM models of goals and challenges, illustrated in Figures 3 and 4, respectively, serve as valuable tools for implementing lake management strategies toward LBP.

Table 5 Structural Self-Interaction Matrix (SSIM) of goal factors

	G1	G2	G3	G4	G5	G6
G1	-	V	V	V	V	V
G2		-	X	V	V	X
G3			-	V	V	X
G4				-	A	A
G5					-	A
G6						-

Table 6 Structural Self-Interaction Matrix (SSIM) of challenge factors

	C1	C2	C3	C4	C5	C6	C7	C8
C1	-	V	V	X	V	V	V	V
C2		-	X	A	V	X	A	A
C3			-	A	V	X	A	A
C4				-	V	V	V	V
C5					-	A	A	A
C6						-	A	A
C7							-	X
C8								-

Table 7 Level partitioning of goals

Goals	Reachability set	Antecendent set	Interaction set	Level
G4	4	1, 2, 3, 4, 5, 6	4	I
G5	5	1,2,3,5,6	5	II
G2	2,3,6	1,2,3,6	2,3,6	III
G3	2,3,6	1,2,3,6	2,3,6	III
G6	2,3,6	1,2,3,6	2,3,6	III
G1	1	1	1	IV

Table 8 Level partitioning of challenges

Challenges	Reachability set	Antecendent set	Interaction set	Level
C5	5	1,2,3,4,5,6,7,8	5	I
C2	2,3,6	1,2,3,4,6,7,8	2,3,6	II
C3	2,3,6	1,2,3,4,6,7,8	2,3,6	II
C6	2,3,6	1,2,3,4,6,7,8	2,3,6	II
C7	7,8	1,4,7,8	7,8	III
C8	7,8	1,4,7,8	7,8	III
C1	1,4	1,4	1,4	IV
C4	1,4	1,4	1,4	IV

Table 9 Goal's canonical matrix

	G4	G5	G2	G3	G6	G1	Driver power	Level
G4	1	0	0	0	0	0	1	I
G5	1	1	0	0	0	0	2	II
G2	1	1	1	1	1	0	5	III
G3	1	1	1	1	1	0	5	III
G6	1	1	1	1	1	0	5	III
G1	1	1	1	1	1	1	6	IV
Dependence power	6	5	4	4	4	1		
Level	I	II	III	III	III	IV		

Table 10 Challenge's canonical matrix

	C5	C2	C3	C6	C7	C8	C1	C4	Driver power	Level
C5	1	0	0	0	0	0	0	0	1	I
C2	1	1	1	1	0	0	0	0	4	II
C3	1	1	1	1	0	0	0	0	4	II
C6	1	1	1	1	0	0	0	0	4	II
C7	1	1	1	1	1	1	0	0	6	III
C8	1	1	1	1	1	1	0	0	6	III
C1	1	1	1	1	1	1	1	1	8	IV
C4	1	1	1	1	1	1	1	1	8	IV
Dependence power	8	7	7	7	4	4	2	2		
Level	I	II	II	II	III	III	IV	IV		

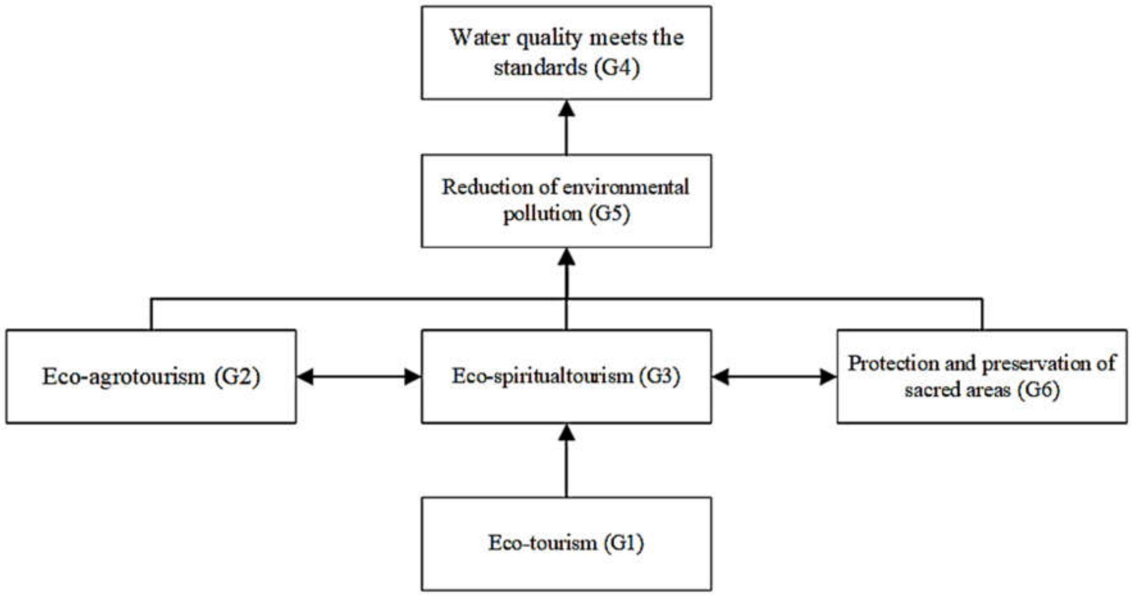

Fig. 2 ISM model for goal factors to establish the strategies of Lake Buyan management

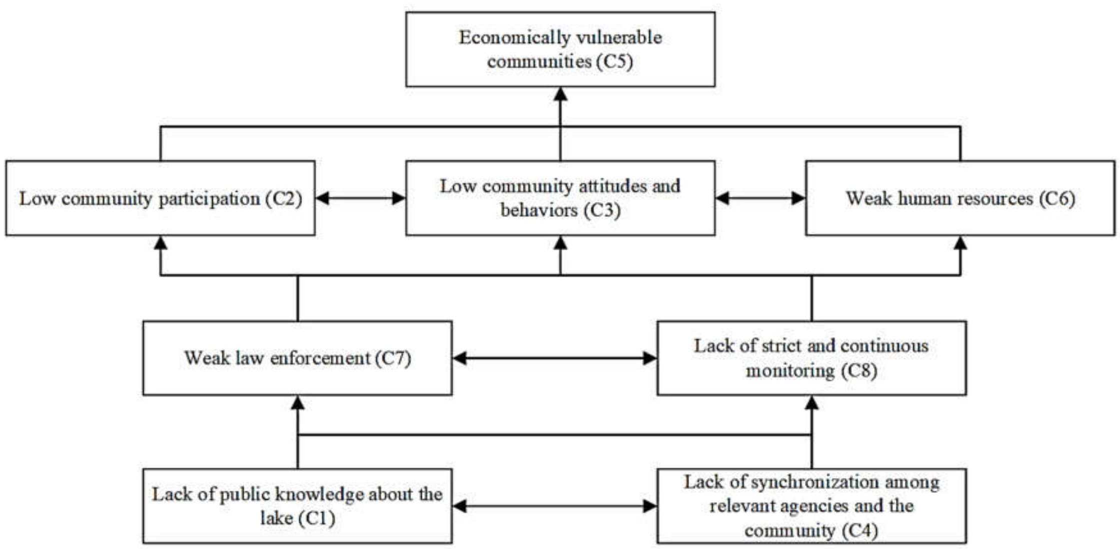

Fig. 3 ISM model for challenge factor to establish the strategy of Lake Buyan management

Utilizing the SSIM data obtained from the ISM method, we proceeded with the application of the DEMATEL method. This involved transforming the SSIM matrix into a pairwise matrix using the linguistic scale table, which assigns values to different levels of affect. This technique was applied to both goals and challenges. The pairwise matrices for goals and challenges can be found in Table 11 and Table 12, respectively. Subsequently, the Normalized Direct Relationship matrix "D", the (I-D)−1 matrices for goals and challenges, presented in the appendix respectively. Furthermore, with the formulation of the "T" matrix, the sums of individual rows and columns were considered to determine (R+C) and (R-C), which were instrumental in plotting the digraph. These values also reveal the causal and affected relationships between each factor, highlighted in Table 13 for goals and Table 14 for challenges. Figures 4 and 5 illustrate the digraphs representing the relationships among goal factors and challenge factors, respectively.

Table 11 Combine decision matrix of goals based on the poll

	G1	G2	G3	G4	G5	G6

G1	0	3	3	3	3	3
G2	0	0	2	3	3	2
G3	1	2	0	3	3	2
G4	1	1	1	0	1	1
G5	1	1	1	3	0	1
G6	1	2	2	3	3	0

Table 12 Combine decision matrix of challenges based on the poll

	C1	C2	C3	C4	C5	C6	C7	C8
C1	0	3	3	2	3	3	3	3
C2	1	0	2	1	3	2	1	1
C3	1	2	0	1	3	2	1	1
C4	2	3	3	0	3	3	3	3
C5	1	1	1	1	0	1	1	1
C6	1	2	2	1	3	0	1	1
C7	1	3	3	1	3	3	0	2
C8	1	3	3	1	3	3	2	0

Table 13 Total relation matrix for goals

	G1	G2	G3	G4	G5	G6	R	R-C	R+C
G1	0.126	0.405	0.405	0.569	0.506	0.405	2.415	1.661	3.169
G2	0.088	0.139	0.257	0.424	0.376	0.257	1.541	0.113	2.969
G3	0.154	0.281	0.163	0.457	0.406	0.281	1.742	0.314	3.170
G4	0.110	0.152	0.152	0.151	0.190	0.152	0.906	-1.509	3.320
G5	0.123	0.171	0.171	0.357	0.151	0.171	1.144	-0.892	3.179
G6	0.154	0.281	0.281	0.457	0.406	0.163	1.742	0.314	3.170
C	0.754	1.428	1.428	2.415	2.035	1.428			

Table 14 Total relation matrix for challenges

	C1	C2	C3	C4	C5	C6	C7	C8	*R*	*R-C*	*R+C*
C1	0.119	0.361	0.361	0.206	0.426	0.361	0.289	0.289	2.410	1.390	3.430
C2	0.110	0.123	0.210	0.110	0.289	0.210	0.131	0.131	1.314	-0.692	3.320
C3	0.110	0.210	0.123	0.110	0.289	0.210	0.131	0.131	1.314	-0.692	3.320
C4	0.206	0.361	0.361	0.119	0.426	0.361	0.289	0.289	2.410	1.390	3.430
C5	0.092	0.137	0.137	0.092	0.116	0.137	0.109	0.109	0.928	-1.624	3.481
C6	0.110	0.210	0.210	0.110	0.289	0.123	0.131	0.131	1.314	-0.692	3.320
C7	0.136	0.303	0.303	0.136	0.358	0.303	0.119	0.206	1.865	0.460	3.269
C8	0.136	0.303	0.303	0.136	0.358	0.303	0.206	0.119	1.865	0.460	3.269
C	1.020	2.006	2.006	1.020	2.552	2.006	1.405	1.405			

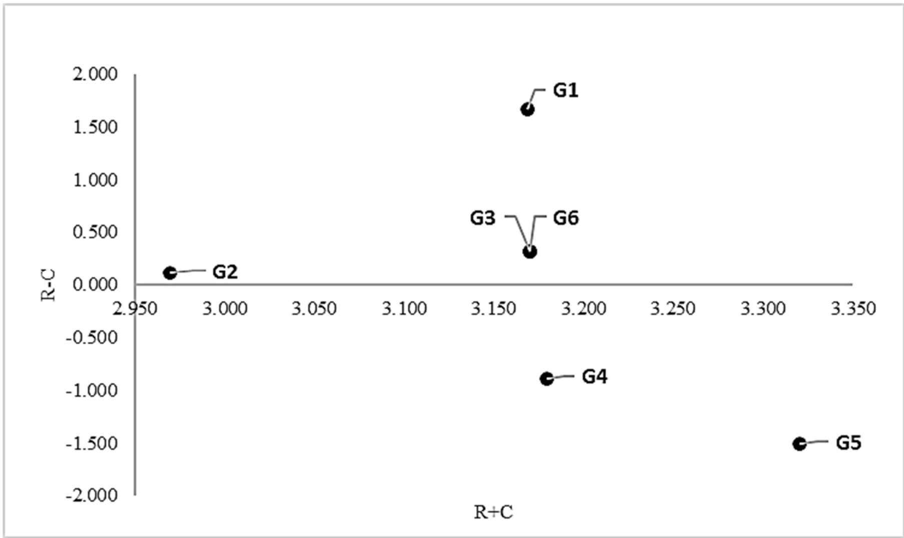

Fig. 4 Relationship digraph of goal's factors

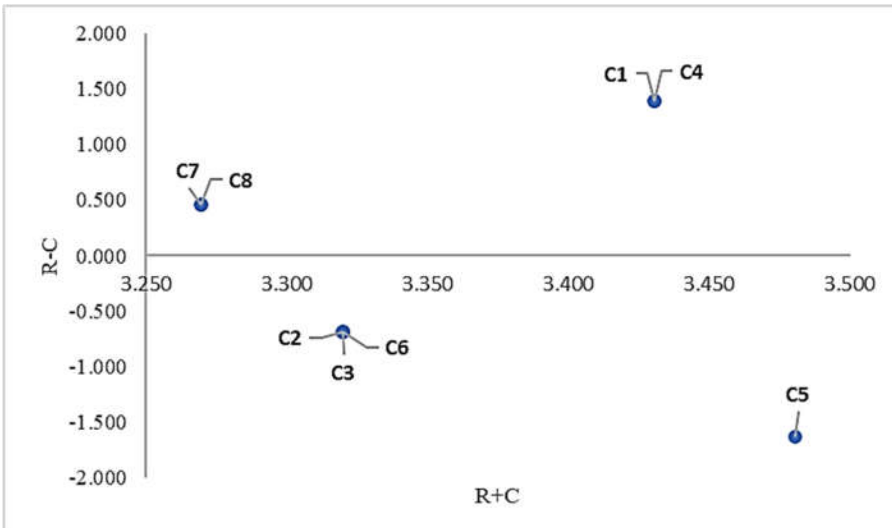

Fig. 5 Realtionship digraph of challenge's factors

3. Result and discussion

This study utilizes integrated ISM-DEMATEL models to identify potential goals and challenges in Lake Buyan management and establish cause-effect relationships among them based on expert opinions. The proposed DEMATEL model effectively highlights the importance of these goals and challenges, providing a visual representation of the complex causal relationships through matrices or digraphs. Moreover, it reveals the interdependence among the various goals and challenges.

Figure 2 depicts the influential factor of 'Eco-tourism' (G1), which demonstrates high driving power and weak dependence power. This finding suggests that prioritizing eco-tourism initiatives can make a significant contribution to the LBP and offer substantial potential benefits. Conversely, Figure 3 illustrates that the challenges of 'Lack of public knowledge about the lake' (C1) and Lack of synchronization among relevant agencies and the community (C4) hold the highest levels of affect and exhibit considerable driving power. Addressing these challenges is crucial to overcoming obstacles and maximizing the overall benefits of LBP.

Table 15 Ranking of goal and challenge factors

Goals			Challenges		
	Degree of importance	Rank		Degree of importance	Rank
G1	3.169	4	C1	3.430	2

G2	2.969	5	C2	3.320	3
G3	3.170	3	C3	3.320	3
G4	3.320	1	C4	3.430	2
G5	3.179	2	C5	3.481	1
G6	3.170	3	C6	3.320	3
			C7	3.269	4
			C8	3.269	4

Goals and challenges with high importance and net effect are considered critical for implementing the LBP. The (R+C) score indicates the relative importance of each goal and challenge, allowing for a prioritized ranking. Based on Table 15, goal G4 has the highest degree of importance, followed by G5. Similarly, challenge C5 stands out as the most influential. Figures 5 and 6 provide causal relationship diagrams that identify the most significant goals and challenges for LBP and their levels of affect. These diagrams visually represent the feedback from seven experts, categorizing the goals and challenges into causes and effected groups. Figure 5 reveals that goals G1, G2, G3, and G6 are causal factors, while G4 and G5 belong to the effected group. Similarly, based on Figure 5, challenge C1, C4, C7, and C8 are causal factors, while C2, C3, C6, and C5 challenges belong to the effected group. By focusing on these potential goals and challenges, the development of lake management strategies can be more targeted, effectively working towards achieving the LBP.

The results of this study indicates that eco-tourism (G1) has the highest level of driving power for the LBP, with the ultimate indicators being the compliance of water quality with the established standards (G4) and the decrease of environment pollution (G5). This finding is in line with a study conducted by (Santari et al, 2021) that Lake Buyan possesses natural resources such as diverse flora and fauna, scenic landscapes, and the socio-cultural potential of the local community, which can be developed and packaged as an eco-tourism.

In the dimension of challenges, this study reveals the lack of peoples' knowledge of the lake (C1) and the lack of synchronization among stakeholders (C4) as the affect factors. The public's knowledge of lake protection is restricted to understanding the importance of not directly disposing domestic waste in the lake. However, they tend to overlook the substantial impact of pollutants resulting from runoff. Traditional knowledge of lake and forest preservation is known among the older generation but not effectively transmitted to the younger generation. This knowledge gap can be addressed by revitalizing traditional and fundamental knowledge on pollution, its hazards, and preventive measures. In the context of the Buyan Lake and special tourism area, there is a lack of integration between sectors and the regional government, resulting in overlapping policies, wasted budgets, and suboptimal ecosystem management. Improved communication, agreement on integrated management goals, and collaboration between central and local governments are essential for restoring the lake and its ecosystem. However, commitment to conservation activities and weak institutional structures pose challenges to effective water resource management.

Based on interviews with traditional community leaders and NGOs, it is found that Lake Buyan is an area primarily used for seasonal agriculture, such as flowers, vegetables, and fruits, with a significant reliance on chemical fertilizers and pesticides. The utilization of these substances can result in environmental pollution, while the presence of *regosol*[2] soil in the vicinity of Lake Buyan renders it susceptible to erosion and surface runoff during the rainfall (Rousmini, 2020). Furthermore, traditional community leader state that the introduction of ecotourism would encourage some farmers to convert their agricultural land into tourist attractions by rearranging their plots with the planting of shade trees and grass. This approach strengthens the land and improves its ability to absorb rainwater compared to seasonal agriculture. In addition to indirectly supporting the local economy, this shift can also reduce pollution entering the lake's water bodies. The findings of this study align with the current situation, where ecotourism is recognized as a favorable option for maximizing the tourism potential of Lake

[2] *Regosol*, classified as one of the soil groups in the Food and Agriculture Organization (FAO) classification system, is distinguished by its shallow depth, medium to fine texture, and unconsolidated parent material, often of alluvial origin. It is further characterized by the absence of a well-defined soil horizon formation, primarily due to arid or cold climatic conditions [46].

Buyan. It offers the dual advantage of generating economic benefits while prioritizing the conservation of the lake's environment.

4. Conclusion

This study demonstrates the successful application of the ISM-DEMATEL approach in identifying influential and affected factors related to the goals and challenges for developing lake management strategies. In the case of Lake Buyan, this approach identifies influential factors in the goal aspect, such as ecotourism, agrotourism, spiritual tourism, and the protection of sacred areas, with the effect being a reduction in lake pollution and compliance with water quality standards. Regarding the challenges aspect, the study finds that the most influential challenges are the lack of public knowledge about the lake, lack of synchronization among relevant agencies and the community, weak law enforcement, and inconsistent monitoring. The affected challenges include low community participation, low community behavior, weak human resources, and vulnerability in the local economy.

Despite the valuable insights gained from the application of the ISM-DEMATEL approach in this study, it is important to acknowledge certain limitations. Firstly, the results obtained from this approach heavily rely on expert opinions and subjective judgments, which may introduce a level of uncertainty. The selection of experts and their biases could potentially influence the outcomes of the analysis. Secondly, the ISM-DEMATEL approach simplifies the complex lake management system by breaking it down into a set of variables, potentially overlooking intricate dynamics and interactions within the system. Furthermore, the findings of this study are specific to the context of Lake Buyan and may not be readily generalizable to other lakes or regions. These limitations highlight the need for a cautious interpretation of the results and the recognition of the specific context in which the study was conducted.

This study opens up avenues for further research in the field of lake management strategies. Future studies can explore the integration of quantitative data and statistical analysis to complement the qualitative findings of the ISM-DEMATEL approach. Incorporating data-driven modeling techniques, such as machine learning algorithms or simulation models, could enhance the accuracy and robustness of the analysis. Additionally, expanding the scope of the study to include a comparative analysis of multiple lakes or regions would provide a broader understanding of the factors influencing lake management strategies. Further, investigating the long-term effects and outcomes of implementing different lake management strategies would be valuable in evaluating their effectiveness and identifying areas for improvement. These research directions have the potential to contribute to the development of more comprehensive and evidence-based lake management strategies.

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Data availability

The corresponding author can provide the datasets used or analyzed during the study upon request.

Conflict of interest

The authors affirm that there are no conflicts of interest associated with the publication of this manuscript. Furthermore, the authors have adhered to ethical considerations encompassing aspects such as plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

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