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Research Paper

Restoration of Asia's largest fresh water lake using multi criteria decision making model: A case study of Wular Lake

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ABSTRACT

Multi criteria decision making (MCDM) is a framework for evaluating how well decision options perform overall in relation to various goals. The Strategy is widely adopted and there is a growing use of it in the management of water resources. In the Union territory of Jammu and Kashmir, there are a lot of lakes from different provenances. This study conducts a comprehensive examination of Wular Lake's environmental dynamics, drawing from diverse data sources. The demographic profile highlights a predominant representation of individuals aged 30-50 years, constituting 52.8% of respondents. The physiochemical analyses spanning four decades reveal distinct trends, including a consistent decline in pH, rising air and water temperatures, and significant increases in nitrate-nitrogen and phosphate levels. Dissolved oxygen levels exhibit concerning declines, particularly in Dal and Wular lakes. Regression analysis uncovers statistically significant positive relationships between various variables (LE, ID, ALC, SWD, IF, and BIO) and the lake's condition, explaining an impressive 79% of the variance. Sources of degradation identify irregular solid waste dumps (10.4%), sewage discharges (18.4%), and population expansion (7.2%) as major contributors. This multifaceted analysis underscores the imperative for holistic environmental management, encompassing waste management, sustainable practices, and community engagement. Continuous monitoring remains essential for the enduring conservation of Wular Lake.

Key words: Multi criteria decision making, over exploited, restoration, trophic status

Multiple objectives measured in various units often serve as a guide for water resource management choices (Badham 2019). Multi criteria decision making (MCDM) is a collection of methods that may be able to increase the analytical rigour, transparency, and auditability of these decisions (Rehan and Solomon 2014). The MCA framework rates or scores how well alternative decision options perform in relation to a variety of criteria that are often quantified in various units (Dodgson 2009). In the 1960s and 1970s, MCDM arose as a decision analysis technique, in part due to the rapid expansion of operations research following World War II. Military planning was one area where MCDM was first used (YILMAZ 2020). MCDM is a well-known methodology with hundreds of books, countless applications, specialised publications, software packages, and academic courses (Eloy and Fernando 2019). It has attracted particular attention in the management of water resources, in part because water policy is rarely driven by a single goal.

No one can envision a world without water because it is the most basic and one of the most important elements for survival (Margalef 1978). The most alluring quality of water is its enormous presence on earthly soil. Additionally, these bodies of water are a necessity for 80% of the valley's inhabitants (Ganaie 2018). Wular

Lake, nestled amidst the breath-taking landscape of the Union Territory of Jammu and Kashmir, stands as a true testament to the splendor of nature's creations (Gomez 2016). With its origins dating back to ancient times, Wular Lake has evolved into one of the largest freshwater lakes in Asia, spanning an impressive area of approximately 189 square kilometers (Zubair and Marc 2022). This serene water body finds its home within the verdant environs of the picturesque Kashmir Valley, encompassed by majestic mountain ranges.

The lake's significance extends beyond its sheer size and captivating beauty. Its waters serve as a vital source of sustenance for local communities, supporting not only the aquatic ecosystem but also the lives and livelihoods of those residing in its vicinity (Silvius 2000). Fishing, agriculture, and tourism have all been intricately interwoven with the lake's essence, forging a harmonious bond between humans and nature (Robert 2009). As the sun's gentle rays dance upon the lake's shimmering surface and the migratory birds grace its shores, Wular Lake remains not just a geographical wonder but a testament to the delicate balance between humanity and the environment (Sharad *et al.,* 2007). It continues to capture the hearts and minds of all who behold its tranquil beauty, echoing the enduring connection between nature and human existence.

However, Wular Lake has faced its share of challenges, including issues like water pollution, encroachment, and ecological imbalances (Wani 2020). Despite these challenges, various conservation efforts and initiatives have been undertaken to safeguard its ecological integrity and preserve its role in the region's cultural and ecological tapestry.

Study Area & Selected Respondents: In order to understand how different stakeholders feel about restoring Wular Lake-which is well-known in Kashmiri history for its enormous agricultural successes and abundant fresh water supplies that can be used for life-a proposed survey was carried out. Wular Lake is situated in the northern part of the Union Territory of Jammu and Kashmir (Raina 2002). Cradled within the heart of the mesmerizing Kashmir Valley, this picturesque freshwater lake finds itself surrounded by the grandeur of nature's wonders. Encircled by majestic mountain ranges, including the towering Himalayas, Wular Lake's precise coordinates place it at approximately 34.33’40° N latitude and 74.55’93° E longitude. The lake's strategic location positions it amidst a region renowned for its breath-taking beauty, cultural significance, and ecological diversity (Mukmin 2022). Its proximity to the Himalayan range lends an air of tranquillity and mystique, while the nearby towns and settlements add a touch of local vibrancy to the landscape. Wular Lake's location is not merely a geographical marker; it is a testament to the delicate interplay between nature's elements and human existence in this captivating corner of the world (Muhammad and Aman 2023).

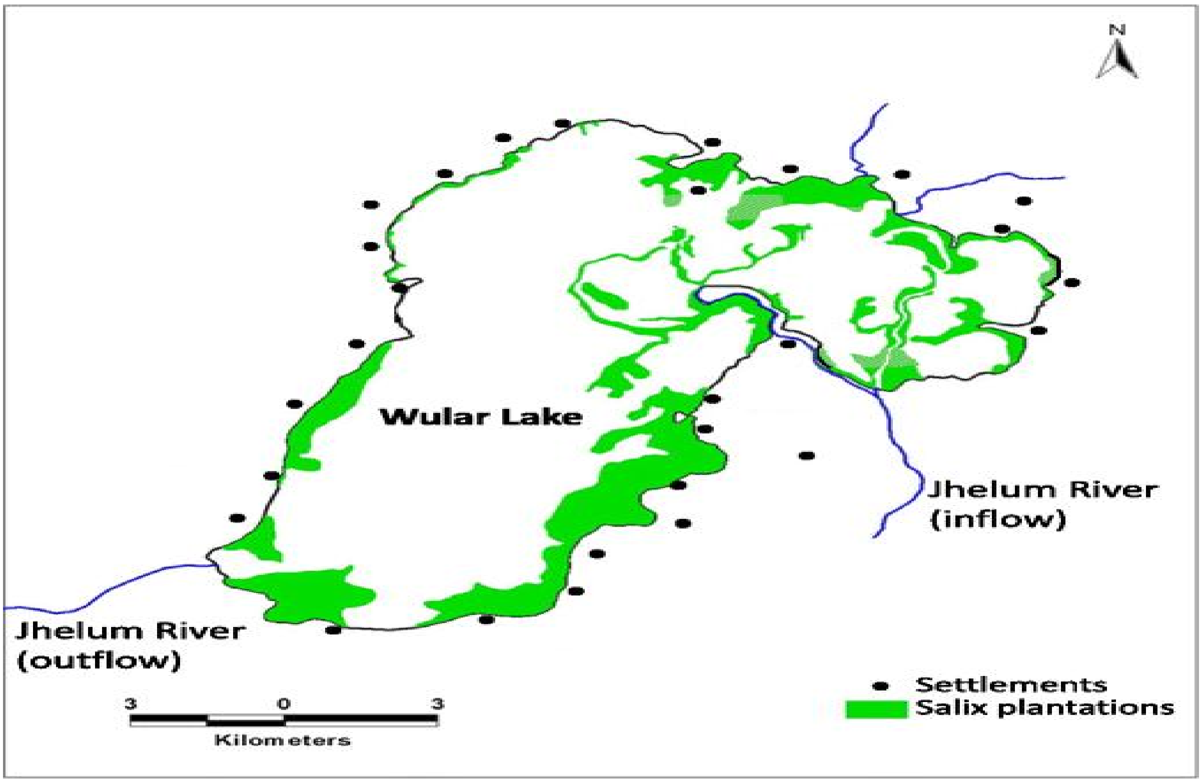


Fig. 1: Showing the description of Wular Lake

The following objectives of the present study have been set up to determine the effects of these activities on the water chemistry of Wular Lake:

- To study the perception of different stakeholders for restoration of Wular Lake.

For obtaining the present objective, a total of 125 stakeholders were surveyed within the vicinity of Wular Lake. These stakeholders mainly include Local households (60), shikara walas/fishermen (40), lotus stem cultivators & harvesters (25).

MATERIALS AND METHODS

The multi criteria decision making tool is used to evaluate the best criterion available in order to restore Wular Lake. MCDM is a decision analysis technique by which steps shall be taken as follows:

- Identification of the problem related to particular natural resource
- Analyzing different criteria for accurate solution of the problem
- Ranking those criteria on the basis of responses recorded from the respondents
- Selecting the highest ranked criteria

The responses recorded from respondents were of different age groups including both men and women. These responses were recorded on well framed interview schedules.

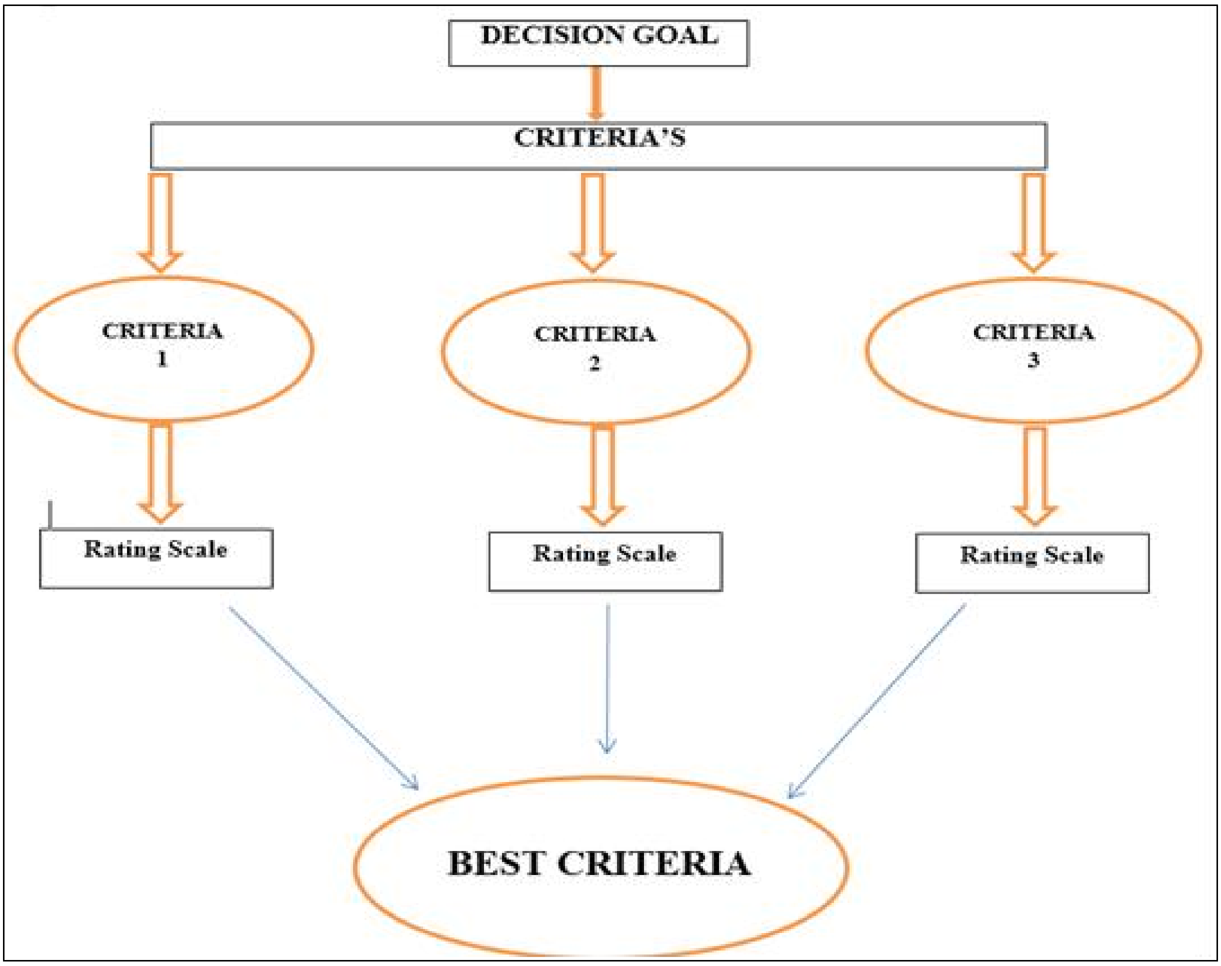


Fig 2: Multi criteria dimension analysis

Lake Degradation Function: To capture the determinants of lake degradation following function was fitted and estimated;

LWD= f (LL, LE, AL, IDW, SW, IW, IFP, BIO, EHG, IT…… U)

Where;

LWD = Lake Water Degradation (%)

LL = Land on Lease for lotus stem cultivation (in kanals)

LE = Land encroachment by local households (in kanals)

IDW = Improper damping of solid and plastic waste (binary 1 for yes and 0 otherwise)

AL = Agricultural land conversion by local households (in kanals)

SW = Sewage water discharge by local households (binary 1 for yes and 0 otherwise)

IW = Industrial wastewater (binary 1 for yes and 0 otherwise)

IFP = Intensive use of fertilizers and pesticides by local farmers (binary 1 for yes and 0 otherwise)

BIO = Blockage of various inlet and outlets (binary 1 for yes and 0 otherwise)

EHG = Extensive harvesting of goods from lakes (binary 1 for yes and 0 otherwise)

IT = Irresponsible Tourism (binary 1 for yes and 0 otherwise)

A number of variables were attempted in the estimation of this function; however, the final model retained only those variables which gave best fit to its estimates.

RESULTS AND DISCUSSION

The Table 1 illustrates the demographic composition of 125 respondents categorized into four age groups: 10-30, 30-50, 50-70, and above 70 years. Bhargavi *et al.,* (2020) also reported that 61.6% of the respondents belonged to the age group of 31-56 years. Notably, the largest portion of respondents falls within the 30-50 age bracket, comprising 52.8% of the total sample. This indicates a predominant representation of individuals in their middle age. The 10-30 age groups constitute 15.2% of respondents, highlighting a smaller yet significant presence of younger participants. The distribution is relatively balanced among the older age groups, with 16.8% for 50-70 years and 15.2% for above 70 years. This suggests a deliberate effort to capture insights from a diverse age range. In summary, the breakdown offers valuable insights into the distribution of respondents across different life stages, providing a foundation for understanding potential variations in responses based on age.

Table1: Selection of respondents **(n=125)**

S. No	Age Group (in Years)	No. of Respondents	Percentage
01	10-30	19	15.2
02	30-50	66	52.8
03	50-70	21	16.8
04	Above 70	19	15.2
	Total	**125**	**100**

Source: Field Survey 2022

The provided table (Table 2) delineates the water levels of Wular Lake during the years 1980, 1990, 2000, 2010, and 2022, offering a historical perspective on the lake's hydrological dynamics. The data reveals a consistent decrease in water levels over the observed decades. In 1980, the lake registered a water level of 189 units, followed by a gradual decline to 185 units in 1990, 181 units in 2000, 177 units in 2010, and further diminishing to 173 units in 2022. This prolonged trend prompts concerns about the environmental implications for Wular Lake and its surrounding ecosystem. Understanding the historical context is essential for a comprehensive analysis, as factors like climate change, human interventions, or alterations in precipitation patterns may contribute to this decline. Delving into the historical background and causative factors is imperative for devising effective conservation measures and ensuring the sustainable management of Wular Lake (Alam 2020). This information is vital not only for ecological preservation but also for informed decision-making to mitigate potential challenges associated with the diminishing water levels of this significant water body

Table 2: Change in the area of wular lake (in sq. kms)

Lake	1980	1990	2000	2010	2022
Wular	189	185	181	177	173

Source: *WUCMA 2021*

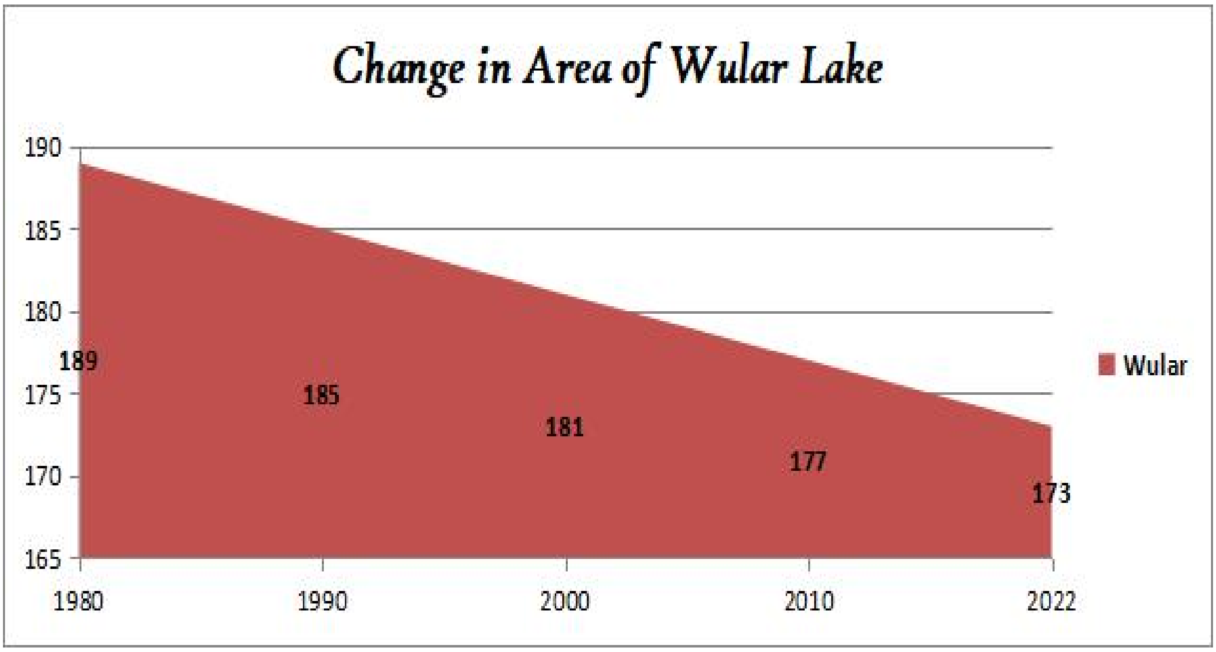


Fig. 3: Change in Area of wular lake (1980-2022)

The table 3 delineates the physiochemical characteristics of Wular Lake across five different years (1980 to 2022), providing crucial insights into the lake's environmental dynamics. The recorded pH levels indicate a marginal decrease over the observed period, with a change of -0.46 units, suggesting a potential shift in the lake's acidity. Air temperatures exhibit a consistent upward trend, with an increase of 1.23˚C, indicating a warming trend in the surrounding atmosphere. Conversely, water temperatures display a more modest increase of 0.40˚C, suggesting a comparatively slower response of the lake's water to climatic changes. The concentrations of nitrate-nitrogen demonstrate a notable rise over the years, with a considerable change of 77.12 mg/L. This increase could be indicative of heightened nutrient inputs, potentially from agricultural runoff or other anthropogenic sources.

Dissolved oxygen levels show a concerning decline of -5.41 mg/L, suggesting a possible deterioration in water quality and the lake's capacity to support aquatic life *(*Bhateria 2016). Phosphate levels have also increased significantly, with a change of 141 mg/L, pointing to a potential increase in nutrient loading, which can have adverse effects on the lake's ecosystem. Overall, the observed changes in physiochemical parameters underscore the dynamic nature of Wular Lake and the potential impacts of various environmental stressors. The findings emphasize the importance of continued monitoring and targeted interventions to address the identified challenges, particularly concerning nutrient levels and dissolved oxygen concentrations. Such efforts are crucial for maintaining the ecological balance and overall health of Wular Lake, a significant water body in the region.

The presented table 4 outlines the perceived sources of degradation for Wular Lake, as indicated by respondents, with a total of 125 participants contributing to the assessment. The primary source identified is irregular solid waste dumps, accounting for 10.4% of responses (Kadafa 2017). This underscores the impact of improper waste disposal practices on the lake's well-being, emphasizing the necessity for robust waste management strategies. The second significant source is sewage and septic discharges, representing 18.4% of responses, underscoring the crucial role of wastewater management in mitigating environmental degradation. Urbanization and population expansion are recognized contributors, comprising 5.6% and 7.2% of responses, respectively, indicating the perceived impact of human development on the lake's surroundings.

Table 3: Physiochemical characteristics of wular lake

Year	Physiochemical Characteristics	Wular
1980	PH	7.87
Air Temperature (˚C)		16.12
Water Temperature (˚C)		15.82
Nitrate-Nitrogen (mg/L)		325
D. Oxygen (mg/L)		8.23
Phosphates (mg/L)		252
1990	PH	7.57
Air Temperature (˚C)		16.67
Water Temperature (˚C)		15.98
Nitrate-Nitrogen (mg/L)		345.21
D. Oxygen (mg/L)		8.42
Phosphates (mg/L)		268
2000	PH	7.57
Air Temperature (˚C)		16.98
Water Temperature (˚C)		16.23
Nitrate-Nitrogen (mg/L)		384.22
D. Oxygen (mg/L)		8.16
Phosphates (mg/L)		321
2010	PH	7.41
Air Temperature (˚C)		17.12
Water Temperature (˚C)		16.54
Nitrate-Nitrogen (mg/L)		387.21
D. Oxygen (mg/L)		7.93
Phosphates (mg/L)		365
2022	PH	7.41
Air Temperature (˚C)		17.35
Water Temperature (˚C)		16.22
Nitrate-Nitrogen (mg/L)		402.12
D. Oxygen (mg/L)		2.82
Phosphates (mg/L)		393
Change	PH	-0.46
Air Temperature (˚C)		1.23
Water Temperature (˚C)		0.40
Nitrate-Nitrogen (mg/L)		77.12
D. Oxygen (mg/L)		-5.41
Phosphates (mg/L)		141

Source: **Dal lake**: Wani (2005), **Wular lake:** Dar (2021), **Anchar lake:** B. Gulzar (2019)

Other notable sources include land fill sites/encroachment, developmental practices (residential/recreational), unwanted weed growth, and Lake Inlet and outlet blockade, each contributing to varying degrees. Irresponsible tourism is acknowledged as a concern, with 7.2% of respondents attributing degradation to this factor. The lack of government-sponsored cleanliness drives is identified by 8% of respondents, emphasizing the potential impact of insufficient government initiatives on environmental conservation. Additionally, 5.6% of respondents attribute degradation to other factors not explicitly listed in the table.

In summary, the table provides a comprehensive insight into the diverse perspectives on the sources of degradation for Wular Lake, as perceived by the respondents. The multifaceted nature of these sources highlights the complexity of the environmental challenges facing the lake, necessitating a holistic approach that includes effective waste management, sewage control, sustainable urban planning, and government-led initiatives to promote cleanliness and responsible tourism (Daniel *et al.* 2017).

Table 4: Source of degradation of wular lake (%)

Source of Degradation	Wular
Irregular Solid Waste Dumps	13(10.4)
Pesticide & Fertilizer	6(4.8)
Urbanization	7(5.6)
Sewage/Septic Discharges	23(18.4)
Population Expansion	9(7.2)
Land Fill Site/Encroachment	12(9.6)
Developmental Practices (Residential/ Recreational)	9(7.2)
Unwanted Weed Growth	12(9.6)
Lake Inlet and Outlet Blockade	8(6.4)
Irresponsible Tourism	9(7.2)
Lack of Govt. Sponsored Cleanliness Drives	10(8)
Others	7(5.6)
Total	**125(100)**

Note: Figures in parenthesis determine numbers in percentage of total

The provided table 5 presents the results of a regression analysis using primary data for Wular Lake. Each row corresponds to a variable, and the associated coefficients with their respective standard errors are reported. The dependent variable is not explicitly mentioned, but it appears to be Wular, given the table's heading. The coefficients associated with each variable provide insights into their impact on the dependent variable. For instance, the variable LL (land on lease) has a coefficient of -0.163, indicating a negative relationship with the dependent variable. This suggests that an increase in LL (land on lease) is associated with a decrease in the dependent variable, holding other factors constant. Variables LE, ID, ALC, SWD, IF, BIO, and IR all have positive coefficients, suggesting a positive relationship with the dependent variable. Among these, LE, ID, ALC, SWD, IF, and BIO have statistically significant coefficients at the 0.05 significance level, denoted by the double asterisks (**) and the reported p-values in parentheses. Conversely, the variables EGS has a negative coefficient, suggesting a negative relationship with the dependent variable, but it is not statistically significant as its p-value is greater than 0.05.

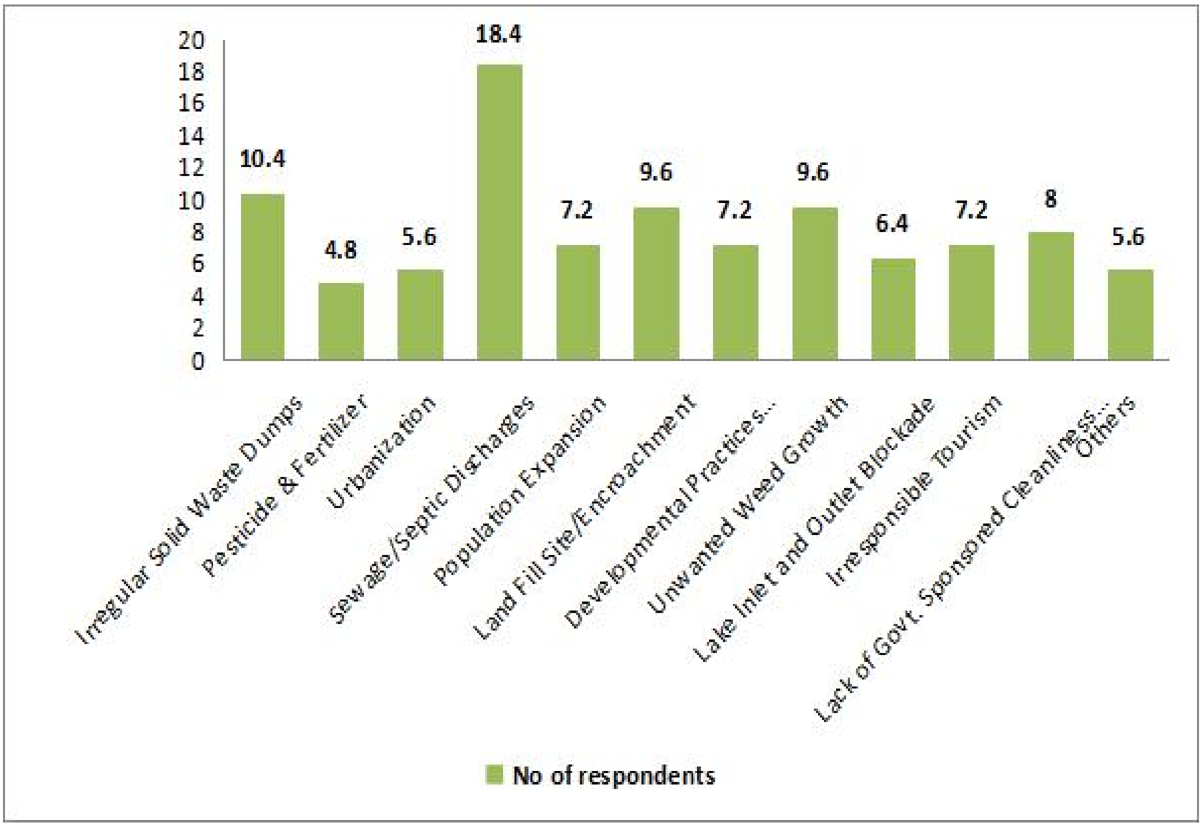
Table 5: Regression Analysis using primary data

Variables	Wular
LL	-0.163 (0.017)
LE	0.061** (0.045)
ID	0.471** (0.026)
ALC	0.512** (0.031)
SWD	0.894** (0.014)
ID	-0.134** (0.62)
IF	0.074** (0.82)
BIO	0.307** (0.28)
EGS	-0.682 (0.39)
IR	0.023** (0.087)
R^2	**0.79**
Adjusted R^2	**0.73**

Note: N= 125, **Significant at 1 per cent level, *Significant at 1 and 5 per cent level, NS = Non-significant

The R^2 value of 0.79 indicates that the model explains approximately 79% of the variance in the dependent variable. The Adjusted R^2, accounting for the number of predictors in the model, is 0.73, suggesting a reasonable fit of the model to the data. In summary, this regression analysis suggests that several variables (LE, ID, ALC, SWD, IF, and BIO) have statistically significant positive relationships with the dependent variable, while EGS has a non-significant negative relationship. The model overall exhibits a good fit, explaining a substantial portion of the variance in the dependent variable.

Fig. 4: Source of degradation of wular lake



The presented table (Table 6) assesses various criteria for environmental conservation initiatives, assigning degrees of effectiveness through a weighted mean score and corresponding ranks. Notably, the most impactful measure is identified as the "Reduction in Sewage Discharges," achieving a perfect score with a weighted mean of 1.75 and securing the top rank.

Table 6: Selection of effective criteria using MCDM for restoration **(n=125)**

S. No	Criteria	Degree of Effectiveness			Weighted Mean Score	Rank
		Most Effective (2)	Effective (1)	Least Effective (0)		
01	Reduction in disposal of solid Waste	80	30	15	1.60	**2nd**
02	Eradication of weeds	70	40	15	1.40	**4th**
03	Reduction in use of fertilizers	35	70	20	1.10	**6th**
04	Afforestation in Adjoining Areas.	30	35	60	0.90	**9th**
05	Responsible Tourism	00	00	125	0.00	**12th**
06	Avoiding Land Filling Process	25	75	35	1.05	**7th**
07	Restoration of Lake inlets and outlets	55	55	15	1.35	**5th**
08	Reduction in Sewage Discharges	100	25	00	1.75	**1st**
09	Government Sponsored Cleanliness Drives	35	45	45	0.95	**8th**
10	Restriction in construction in & around the Lake	35	25	65	0.85	**10th**
11	Sustainable harvesting of goods from the Lake	25	30	70	0.70	**11th**
12	Lake Deepening/Dredging	45	75	10	1.45	**3rd**

This underscores the critical importance of managing and minimizing sewage discharges for overall environmental conservation around the lake. Following closely, the "Reduction in Disposal of Solid Waste" is positioned as the second most effective criterion, earning a weighted mean of 1.60 and securing the second rank. "Eradication of Weeds" and "Lake Deepening/Dredging" emerge as the third and fourth most effective measures, boasting weighted mean scores of 1.45 and 1.40, respectively, leading to their third and fourth ranks. In contrast, "Responsible Tourism" is identified as the least effective criterion with a score of 0.00, ranking twelfth. This comprehensive evaluation provides valuable insights for prioritizing and implementing conservation strategies, emphasizing the significance of addressing sewage discharges and solid waste reduction in the lake's environmental management (Sahoo 2024). The results suggest that focusing on these high-ranking measures could yield more impactful outcomes in sustaining the ecological balance of the lake.

CONCLUSION

In summation, the examination of the tables points to clear priorities for effective environmental conservation strategies around the lake. Foremost among these is the imperative to address the reduction of sewage discharges, identified as the most critical and impactful criterion with a top-ranking perfect weighted mean score of 1.75. This underscores the urgency of implementing measures to control and minimize sewage discharges to preserve the ecological well-being of the lake. Additionally, the reduction in the disposal of solid waste emerges as the second most effective measure, emphasizing the pivotal role of waste management practices in conservation efforts. Noteworthy contributions to environmental preservation are also associated with the eradication of weeds and lake deepening/dredging, securing the third and fourth ranks, respectively. Conversely, responsible tourism is deemed the least effective criterion, receiving a score of 0.00 and ranking twelfth. This highlights the necessity for a reassessment of strategies, ensuring that tourism activities align with environmental preservation goals.

In conclusion, the prioritization of conservation measures should center on controlling sewage discharges and managing solid waste, as evidenced by their high effectiveness rankings in the provided tables. These findings underscore the significance of targeted and comprehensive strategies to address specific environmental challenges around the lake. On-going monitoring and adaptive management approaches will be imperative to ensure the sustained health of the lake's ecosystem amidst evolving environmental conditions and human activities (Brunckhorst 2013).

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