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A Systematic Review on Biodiversity and Ecological Integrity of Himalayan Freshwater Lakes

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ABSTRACT: The western Himalayan region, particularly the Union Territory of Jammu & Kashmir and Ladakh, was home to many freshwater lakes that represented ecologically critical systems sustaining high biodiversity and various essential ecosystem services, including nutrient cycling, climate regulation, and livelihood support. These lakes differed in size, altitude, and ecological characteristics. They contained diverse species of plankton and fish, which were key components of the aquatic food web, served as bioindicators of water quality, and played a crucial role in ecosystem functioning. This review aimed to assess the biodiversity and ecological integrity of freshwater lakes, with a focus on understanding the relationship between biological diversity, water quality, and environmental stressors. A systematic literature review was conducted in accordance with PRISMA guidelines. For data collection, Google Scholar, PubMed, ResearchGate, Scopus, and ScienceDirect databases were searched using relevant keywords. Studies published between 2010 and 2025 focusing on freshwater lakes of Jammu & Kashmir and Ladakh were included, addressing ecological integrity, including water quality, biodiversity, trophic status, and pollution. The review revealed that these lakes supported diverse and functionally important planktonic and fish communities that regulated primary productivity and acted as reliable bioindicators of water quality. However, increasing anthropogenic pressures, including pollution, urbanisation, overexploitation, and unregulated tourism, were degrading water quality and disrupting ecological balance. Climate change, particularly glacial retreat and shifting precipitation regimes, further exacerbated these impacts, accelerating ecosystem instability and biodiversity loss. Overall, the freshwater lakes of the Himalayan region were under significant stress due to anthropogenic effects and climate change, resulting in declining water quality and biodiversity loss. To prevent further biodiversity loss and maintain ecological integrity, effective conservation strategies, strict policy implementation, and community participation were required to ensure long-term ecological sustainability.

KEYWORDS: Freshwater lakes; diversity; planktons; fishes; J&K; anthropogenic effects

1. Introduction

Water was essential for life on the planet and constituted 75% of the Earth's crust [1]. It existed in three forms—solid, liquid, and gas—which continuously changed through the water cycle [2]. It acted as a source of livelihood after air [3] and was one of the natural resources used for food production (agriculture), economic activities (livestock and industries), and fish production [4,5]. A healthy economy and human well-being depended heavily on water [6,7]. Water covered approximately 70% of the Earth's surface, with 97% found in the oceans, 2% frozen in glaciers and polar ice caps, and only 1% available as freshwater in rivers, lakes, streams, reservoirs, and groundwater. Among the most profoundly altered ecosystems on Earth were surface freshwater lakes, reservoirs, and rivers [8].

Mountains, particularly the Himalayas, were well known for their highly diverse and rich ecosystems and thus formed fundamental components of the global geosphere–biosphere system. A lake was defined as a large, relatively calm body of fresh or salt water situated in a basin surrounded by land. The term "lake" originated from Old English "lacu" (pond, pool, stream) and Middle English "lake" (lake, pond, waterway) [9]. Himalayan lakes and rivers sustained a large population [10]. Approximately 20% of India's GDP came from agriculture, which consumed a significant portion of freshwater resources, largely supported by the freshwater sector. India also possessed one of the largest aquaculture sectors globally [11]. The Himalayan lakes supported the surrounding environment, wildlife, and human populations and were significant from cultural, religious, socioeconomic, biodiversity, and ecological perspectives [12]. Among these, freshwater lakes (unsalted and still water bodies) were vital to local communities' livelihoods. These lakes provided drinking water, fisheries, irrigation, and electricity generation, among other essential functions [13]. Freshwater ecosystems provided valuable economic goods and irreplaceable ecosystem services; however, aquatic biodiversity was increasingly threatened by the invasion of alien species that contaminated the food chain [14]. Lakes were projected to become one of the most valuable natural resources globally, with increasing political, social, and ecological importance. Despite housing 16% of the world's population, India had access to only 4% of global water resources and 2.5% of land area. India received more than 4,000 trillion litres of freshwater annually through precipitation in the form of rain and snowfall, much of which was returned to the oceans through major rivers. Water for human consumption was derived from two main sources: surface water and groundwater.

As the population grew, industrialisation increased, and agriculture expanded, the demand for water also increased over time [15]. Surface waters were contaminated by point-source discharges from various sectors, including mining, agriculture and aquaculture, pulp and paper production, oil and gas extraction, and urban runoff. These activities could have impacted freshwater biodiversity either directly or indirectly through habitat alteration or toxicity. As freshwater resources were increasingly exploited to meet human demands, freshwater ecosystems experienced greater stress than any other ecosystem, as reflected in rising rates of extinction, habitat degradation, and emerging environmental challenges [16]. In general, the term "eutrophication" referred to a trophic condition caused by increased inputs of nitrogen and phosphorus, particularly due to enhanced nutrient loading from urbanisation, industrialisation, and agricultural intensification. Lake eutrophication reduced water transparency and increased phytoplankton biomass [17].

Environmentalists worldwide were exploring the potential of biomonitoring tools for improved pollution management, in addition to conventional physicochemical approaches. Biomonitoring was used to assess variations in water quality and maintain the ecological balance of aquatic systems [18]. Regulations also included water quality classification systems and the establishment of protection zones within water catchment areas affected by urban, industrial, and agricultural development [19].

Despite the growing body of research on freshwater ecosystems, knowledge gaps remained in understanding the biological dynamics of Himalayan lakes, particularly in Jammu & Kashmir and Ladakh. Most studies focused on individual components such as fish diversity, plankton diversity, or water quality, with limited attention to their interrelationships. Additionally, the Ladakh region remained underexplored and required long-term monitoring. The impacts of anthropogenic activities and climate change on biodiversity and water quality were also insufficiently assessed. These gaps highlighted the need for integrated studies to better understand and manage lake ecosystems in the Himalayan region. Therefore, this study sought to address the following research questions: (1) what was the current ecological status of freshwater lakes in Jammu & Kashmir and Ladakh? (2) what were the primary anthropogenic pressures affecting these ecosystems? (3) how did biodiversity patterns differ among lakes in the region? and (4) what conservation or management strategies had been proposed or implemented? This review aimed to assess the status of lakes in Jammu & Kashmir and Ladakh, focusing on evaluating water quality parameters, analysing plankton and fish diversity, and examining the extent of anthropogenic impacts on lake ecosystems.

2. Materials and Methods

2.1. Systematic literature approach, search strategy and string.

A systematic literature approach was adopted to methodologically assess the ecological conditions of freshwater lakes in Jammu & Kashmir and Ladakh. This approach enabled a comprehensive and structured evaluation of existing studies related to water quality, biodiversity, and ecological integrity.

A systematic literature search was conducted across multiple electronic databases, including Scopus, Web of Science, PubMed, and Google Scholar, covering studies published between 2010 and 2025. Relevant terms were carefully selected to capture the main aspects of the study. The search strategy combined keywords such as “water quality parameters,” “freshwater lakes,” “plankton diversity,” “phytoplankton,” “zooplankton,” “native fish species,” “Jammu and Kashmir,” and “Ladakh.” Boolean operators (AND) were used to combine keywords and refine the search results. The database-wise records identified included 114 from Scopus, 66 from Web of Science, 57 from PubMed, and 253 from Google Scholar.

The search string used was (“freshwater lakes” OR “Himalayan lakes” OR “mountain lakes” OR “high-altitude lakes”) AND (“water quality” OR “physicochemical parameters” OR “limnology”) AND (“fish diversity” OR “fish assemblage” OR “plankton diversity” OR “phytoplankton” OR “zooplankton”) AND (“Jammu and Kashmir” OR “J&K” OR “Ladakh” OR “Western Himalaya”).

2.4. Screening and data extraction.

Only English-language and peer-reviewed articles were considered in this review. Duplicate records were removed, and full-text articles were carefully examined based on predefined inclusion criteria to ensure alignment with the study objectives. All relevant information was collected using a structured approach. The quality and reliability of the studies were assessed based on data presentation and methodological rigor. Data extraction included lake name, water quality parameters, phytoplankton and zooplankton diversity, fish species, and key findings, which were organised systematically. A thematic analysis was performed to categorise and synthesise the findings of the selected studies. Themes related to biodiversity, pollution levels, and ecological conditions were identified to provide a comprehensive understanding of freshwater lakes in the Jammu & Kashmir and Ladakh region. The overall process of identification, screening, eligibility, and inclusion–exclusion criteria followed the PRISMA framework and was illustrated using a flow diagram [20,21].

2.5. Inclusion and exclusion criteria.

Studies were included if they were published between 2010 and 2025, written in English, and focused on freshwater lakes in Jammu & Kashmir and Ladakh. Eligible studies addressed ecological integrity, including water quality, biodiversity, trophic status, and pollution, and provided sufficient data on both physicochemical and biological parameters. Both review articles and original research papers were considered. Studies were excluded if they fell outside the scope of freshwater lake ecosystems, did not directly address ecological integrity or ecosystem health, or lacked sufficient ecological data. Articles that were not available as full-text or accessible documents were also excluded. After applying these criteria and critically evaluating the selected studies, relevant data on study design, sample size, ecological indicators, assessment methods, and key findings were extracted, compiled, and synthesised for the systematic literature review (Figure 1).

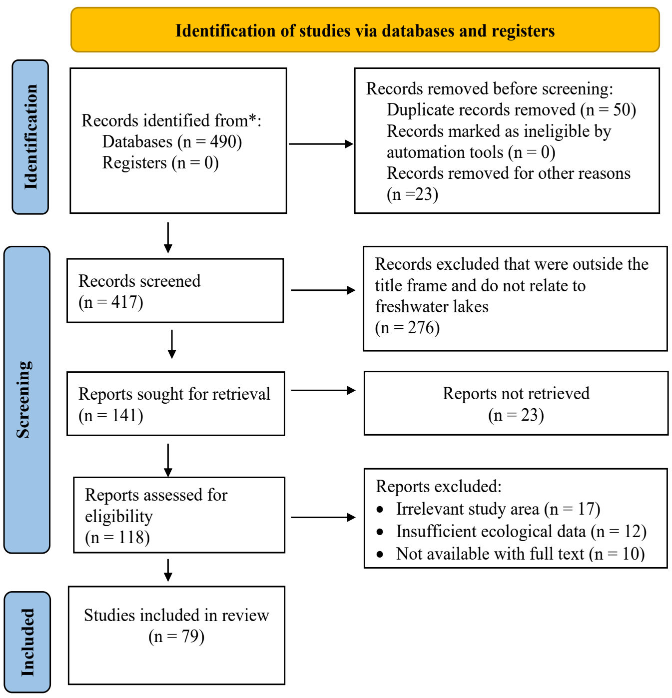

Figure 1. Systematic literature review framework using PRISMA methodology.

3. Lakes of Jammu & Kashmir and Ladakh

The mountainous region of Jammu & Kashmir and Ladakh was home to numerous lakes surrounded by the Himalayas [22]. With an altitude range of 220 to 8611 meters above sea level, Jammu and Kashmir (J&K) was located in the northwestern Himalayas, between latitudes 32.28° and 37.06° and longitudes 72.53° and 80.32° [23]. The Ladakh region, covering an area of 95,876 square kilometres with an average elevation exceeding 3,352 m, was situated along the western edge of the Himalayas [24]. J&K formed part of the northwestern Indian Himalayan Region (IHR) and was often referred to as the "land of mountain ranges." The Siwalik range lay to the south, while the Greater Himalaya, Zanskar Range, Pir Panjal, and Karakoram ranges were located to the north. Jammu and Kashmir was well known for its lakes and marshes and included four designated Ramsar sites: Hokersar, Wular, Tso Morari, and Surinsar–Mansar. Other prominent lakes in the region included Pangong, Manasbal, Dal, and Tso Kar. Over time, increasing sediment and silt loads in the catchments reduced their utility and contributed to a decline in the depth and size of many lakes and wetlands. Freshwater resources stored in snow and glaciers were vital for economic activities, agriculture, tourism, and hydropower generation, with most glaciers located in the Zanskar and Karakoram ranges [23].

The Jammu region experienced a subtropical climate, with an average annual rainfall of approximately 1500 mm and air temperatures ranging from about 3°C in winter to 43°C in summer. Freshwater input to Mansar Lake was provided by rainfall within the lake basin and underground springs at its base. Mansar, Surinsar, and Tsomoriri lakes were classified as eutrophic, whereas Tsokar was classified as hyper-eutrophic [25]. The twin lakes of Surinsar and Mansar were designated as Ramsar sites. Mansar Lake, located at an altitude of 666 meters above mean sea level (32°48′ N and 75°23′ E), was influenced by land use activities in its catchment, including forestry, agriculture, and encroachment, which contributed to nutrient enrichment and eutrophication. The lake supported several winter migratory bird species, including the Indian golden oriole, common sandpiper, rufous-backed shrike, white wagtail, coot, darter, night heron, grey heron, and large cormorant [26].

The high-altitude valleys contained diverse freshwater bodies rich in natural resources. Wular Lake, located in the Bandipora district of Jammu and Kashmir, was an oxbow-shaped lake and one of the largest freshwater lakes in Asia. It was situated between latitudes 34°16′ and 34°26′ N and longitudes 74°32′ and 74°42′ E. The lake played a crucial role in the hydrographic system of the Kashmir Valley by acting as a major flood absorption basin. However, rapid siltation and contamination from domestic and industrial waste, primarily transported through the Jhelum River from Srinagar, posed serious threats to its biodiversity and the livelihoods of nearby communities. Fish fauna in Wular Lake was threatened by habitat loss, overexploitation, environmental alterations, and invasive species [27]. Approximately 60% of the total fish production of Jammu and Kashmir was derived from Wular Lake, which supported both native and exotic species of commercial importance. Traditional fishing methods included gill nets, cast nets, bag nets (khurijal), dip nets, long lines (wal raz), and spears such as panzri and narchoo.

Dal Lake, covering an area of approximately 331 km² with multiple sub-basins, served as a major water body in the eastern part of Srinagar along the right bank of the Jhelum River [18]. Phytoplankton had long been used as bioindicators to monitor ecological disturbances caused by physicochemical changes, sewage pollution, and other anthropogenic activities.

Nigeen Lake experienced pollution primarily from domestic sewage and fertiliser runoff from floating gardens [28].

In the Ladakh region, particularly in the Leh district, several lakes were present, including Pangong Tso, Tso Moriri, Tsokar, Yarab Tso, Mirpal Tso, Chagar Tso, Kiagar Tso, Stat Tso, and Lang Tso. Tso Moriri, located in the Changthang region, was situated at an elevation of 4569 meters above sea level, while Pangong Tso was located at an elevation exceeding 4266 meters. During the summer months, surface temperatures in these high-altitude lakes reached approximately 19°C, while the lowest temperatures were around 8°C. These lakes typically froze between late December and early February due to declining winter temperatures [29]. The Ladakh region, characterised by a cold desert climate, received an average annual rainfall of about 100 mm and included important lakes such as Tsomoriri and Tsokar [25]. These freshwater ecosystems exhibited significant ecological, economic, and environmental importance. The key characteristics of prominent lakes in this Himalayan region were summarised in Tables 1–6.

Table 1. Major freshwater lakes of Jammu & Kashmir and Ladakh: geographical and ecological characteristics.

Lake Name	Coordinates (Lat–Long)	Type	Elevation (m)	Area (km²)	Key Features	References
Dal Lake	34°05′–34°09′N, 74°49′–74°53′E	Urban freshwater	1583	24.0	Major tourist destination; provides water supply, fisheries, and vegetables	[30]
Wular Lake	34°16′–34°20′N, 74°33′–74°44′E	Oxbow	1580	31.4	Ramsar site; floodwater sink of Jhelum River; supports rich fish diversity	[27,31]
Manasbal Lake	34°14′–34°16′N, 74°40′–74°43′E	Semi-drainage	1585	22.0	Deepest lake in Kashmir Valley; supports irrigation, fisheries, and tourism	[13]
Gadsar Lake	34°25′18.76″N, 75°03′27.05″E	Oligotrophic	3584	0.398	Also known as Yemsar Lake; drains into Neelum River; used for grazing	[32]
Tarsar Lake	34°08′19″N, 75°08′50″E	Glacial	3620	2.0	Popular trekking destination (Tarsar–Marsar trek)	[33]
Marsar Lake	34°08′39″N, 75°06′37″E	Glacial	3833	NA	Twin lake with Tarsar; located near Pahalgam in Anantnag district	[33]
Gangabal Lake	34°25′55.49″N, 74°55′27.12″E	Glacial	3576	1.65	One of the largest glacial lakes in Ganderbal district	[34]
Nundkol Lake	34°25′25″N, 74°56′19″E	Glacial	3575	0.37	Habitat for cold-water fish species	[33]
Kishansar Lake	34°23′47.87″N, 75°06′10.26″E	NA	3815	1.62*	Limited ecological data available	[32]
Vishansar Lake	34°23′15.46″N, 75°07′05.28″E	NA	3683	NA	Limited ecological data available	[32]
Gilsar Lake	34°07′–34°09′N, 74°48′–74°50′E	Freshwater	1582	1.8	Urban lake with limited ecological data	[35]
Nigeen Lake	34°06′–34°07′N, 74°49′–74°50′E	Freshwater	1584	1.38	Deep basin of Dal Lake; major water supply source	[36, 37]
Anchar Lake	34°20′–34°26′N, 74°82′–74°85′E	Freshwater	1584	5.8	Nutrient enrichment from runoff, sewage, and agricultural activities	[38]
Ahansar Lake	34°18′N, 74°39′E	Semi-drainage, oxbow	1583	0.17	Supports paddy cultivation; drains into Jhelum River	[39]
Brari Nambal	34°05′13″N, 74°48′50″E	Lagoon	1580	0.437	Lagoon of Dal Lake located near old Srinagar city	[40]
Nilnag Lake	33°51′23″N, 74°41′42″E	Freshwater	2110	0.0816	Located in Pir Panjal foothills; surrounded by forest and agriculture	[41]
Hokersar Lake	34°06′N, 74°05′E	Wetland	1584	13.75	Ramsar site; habitat for migratory waterfowl	[42]

Table 2. Ecological overview of prominent freshwater lakes in Ladakh.

Lake Name	Geo co-ordinates	Type	Elevation	Area	Features	References
Tso Moriri	32° 45′-33° 00′ N, 78° 15′-78° 22′ E	NA	4650 m	15 km²	The lake is fed by snowmelt and glaciers in Ladakh, a Ramsar Site located in the harsh and rugged landscapes of the Himalayas.	[43]
Tso Kar	32° 10′–33° 30′ N, 77° 55′-78° 20′ E	NA	4545 m	19.5 km²	It is a brackish water lake in the Rupshu plains of the Changthang region, enriched with borax and salt deposits.	[44]
Kyagar Tso	33°06′26.14″N, 78°18′4.66″E	Alkaline	4700m	NA	It is situated within the Puga gneiss complex, south of Sumdo town covered by rocks of the Puga formation, forming the lower unit of tso moriri basin.	[45]

Table 3. Physico-chemical characteristics of selected freshwater lakes in Jammu & Kashmir and Ladakh.

Lake Name	Water Temp	pH	TDS	Conductivity	DO	BOD	Hardness	Nitrates	Nitrites	Phosphates	Alkalinity	Ref
Dal Lake	25	7.83	230.1	328.7	3.73	2	126.5	Nil	0.07	2	101.8	[40]
Gadsar Lake	9.5	7.6	15.5	24	7.9	NA	119	200	75	NA	52.5	[32]
Manasbal Lake	15.45	8.05	136.9	271.3	8.95	NA	175.4	133	18.05	NA	133.4	[13]
Gangabal Lake	12	7.41	0.5	21	7.8	NA	121	147	57.5	NA	69	[32]
Nundkol Lake	12.9	7.55	12	20	8.4	NA	121	117	40	NA	42	[32]
Vishansar Lake	13.4	7.56	24	37	7.9	NA	115	151	62	NA	52	[32]
Kishansar Lake	13.3	7.46	18.5	29	7.8	NA	114	174	48	NA	55	[32]
Anchar Lake	16.3	7.5	207.4	250.7	7.6	5.8	199	NA	NA	0.1	85.3	[38]
Wular Lake	13.42	7.82	145.4	199.4	9.4	NA	1213.2	0.73	NA	NA	92.5	[46]
Gilsar Lake	20	7.15	135	0.6	2.1	37.2	166.6	NA	NA	0.2	NA	[35]
Brari Nambal	4.23	7.57	310.3	528.3	3.73	20.4	NA	NA	NA	NA	333.3	[47]
Nilnag Lake	NA	7.51	NA	206.4	9.92	NA	NA	NA	NA	515.7	NA	[41]
Hokersar Lake	16.65	8.15	NA	0.31	6.9	NA	NA	NA	NA	NA	235.97	[48]
Nigeen Lake	25.2	7.9	185.5	265	4	2.03	106	NA	0.02	NA	84.5	[40]

Water Temp: °C; TDS: mg/L; Conductivity: µS/cm; DO, BOD: mg/L; Hardness, Nitrates, Nitrites, Phosphates, Alkalinity: mg/L

Table 4. Distribution of phytoplankton species in selected freshwater Lakes of Jammu & Kashmir and Ladakh.

Sr. no	Name of the Species	Name of the Lakes							
		Manasabal [49]	Pangong Tso [49]	Tso moriri [29]	Wular [29]	Nigeen [28]	Dal [50]	Mansar [51]	Anchar [52]
1.	Bacillariophyceae								
	Amphora sp	+	+	+	+	+	+	+	+
	Achnanthes sp.	+	+	+	-	+	+	+	+
	Amphipleura sp.	-	-	-	-	+	-	-	-
	Anabaena sp.	-	-	-	-	-	+	-	-
	Asterionella sp.	+	-	-	-	+	-	-	-
	Cymbella sp.	+	+	+	+	+	+	+	+
	Ceratoneis sp.	+	-	-	-	-	-	-	-
	Cocconeis sp.	-	-	-	-	+	-	+	+
	Chroococcus sp.	-	-	-	-	-	-	+	-
	Cyclotella sp.	-	-	-	-	+	+	-	+
	Diatoma sp.	+	+	+	+	+	-	+	+
	Diatomella sp.	+	-	-	-	-	-	-	-
	Denticulla sp.	+s	-	-	-	-	-	-	-
	Didymosphenia sp.	-	-	-	-	+	-	-	-
	Epithemia sp.	+	+	+	+	+	-	-	+
	Eunotia sp.	+	+	+	+	-	-	-	+
	Fragilaria sp.	+	+	+	+	+	-	+	+

Sr. no	Name of the Species	Name of the Lakes							
		Manasabal [49]	Pangong Tso [49]	Tso moriri [29]	Wular [29]	Nigeen [28]	Dal [50]	Mansar [51]	Anchar [52]
	Gomphonema sp.	+	+	+	+	+	-	+	+
	Gyrosigma sp.	+	-	-	-	-	-	+	-
	Gymnodium sp.	-	-	-	-	-	-	-	+
	Hantzchia sp.	-	-	-	-	-	+	-	+
	Liomophora sp.	-	+	+	-	-	-	-	-
	Lyngbya sp.	-	-	-	-	-	-	+	-
	Melosira sp.	+	-	-	-	-	+	-	+
	Meridion sp.	+	+	+	-	+	-	-	-
	Merismopedia sp.	-	-	-	-	-	-	+	-
	Microcystis sp.	-	-	-	-	-	-	+	-
	Navicula sp.	+	+	+	+	+	+	+	+
	Nitzschia sp.	+	+	-	+	+	-	-	+
	Nostoc sp.	-	-	-	-	-	+	+	-
	Oscillatoria sp.	-	-	-	-	-	+	+	-
	Phopalodia sp.	-	-	-	-	-	-	-	+
	Pinnularia sp.	+	-	-	-	-	-	-	+
	Rhizoselenic sp.	-	-	-	-	-	-	-	+
	Spirulina sp.	-	-	-	-	-	+	+	-
	Stauronies sp.	+	+	+	-	-	-	-	+
	Surinella sp.	+	-	-	-	+	-	-	+
	Synedra sp.	+	+	-	+	+	-	-	+
	Synecocystis sp.	-	-	-	-	-	-	-	-
	Tabellaria sp.	-	-	-	-	+	-	-	-
2.	Chlorophyceae								
	Actinastrum sp.	-	-	-	-	-	-	-	+
	Anacystis sp.	-	-	-	-	-	+	-	-
	Ankistrodesmum sp.	-	-	-	-	-	+	+	-
	Anthrodesmus sp.	-	-	-	-	-	+	-	-
	Bulbochaete sp.	-	-	-	-	-	-	+	-
	Chlorella sp.	+	+	+	-	+	+	+	+
	Chlorococcum sp.	+	-	-	-	+	-	-	-
	Chlorodella sp.	-	-	-	-	-	-	-	+
	Cladophora sp.	+	-	-	-	-	+	+	-
	Closteriopsis sp.	-	+	+	-	-	-	-	-
	Closterium sp.	-	-	-	-	-	-	+	+
	Coelastrum sp.	-	-	-	-	-	-	+	+
	Coleochaete sp.	-	-	-	-	-	-	+	-
	Cosmarium sp.	+	-	-	-	+	-	+	+
	Crucigenia sp.	-	-	-	-	-	-	+	+
	Cyclotella sp.	-	-	-	-	-	-	+	-
	Desmidium sp.	-	+	+	-	-	-	-	-
	Diadesmis sp.	-	-	-	-	-	-	-	-
	Dictyosphaerium sp.	-	-	-	-	-	-	+	+
	Euastrum sp.	-	-	-	-	-	-	-	+
	Golenkinia sp.	-	-	-	-	-	-	+	-
	Gonatozygon sp.	-	-	-	-	-	-	-	+
	Gonium sp.	-	-	-	-	-	-	-	+
	Hormidium sp.	-	+	+	-	-	-	-	-
	Hydrodictiyon sp.	-	-	-	-	-	-	+	-
	Melosira sp.	-	-	-	-	-	-	+	-
	Microastrias s.	-	-	-	-	-	-	-	+
	Mougeotia sp.	+	-	-	-	-	-	+	-
	Nitzschia sp.	-	-	-	-	-	-	+	-
	Nochneriella sp.	-	-	-	-	-	-	-	+
	Oedogonium sp.	+	-	-	-	-	-	+	+
	Oocystis sp.	+	-	-	-	-	-	+	-
	Pandorina sp.	-	-	-	-	-	-	+	+
	Pediastrum sp.	-	-	-	-	+	-	+	+
	Penium sp.	-	-	-	-	-	-	+	-
	Pinnularia sp.	-	-	-	-	-	-	+	-
	Planktosphaeria sp.	-	-	-	-	-	-	-	-
	Pleuroateria sp.	-	-	-	-	-	-	-	+
	Plueraotacnium sp.	-	-	-	-	-	-	+	-
	Scenedesmus sp.	-	-	-	-	-	-	+	+
	Schaeroplea sp.	-	+	+	-	-	-	-	-
	Schroederia sp.	-	-	-	-	-	-	+	-
	Sirogonium sp.	-	-	-	-	-	-	-	-
	Sirocladium sp.	-	-	-	-	-	-	+	-

Sr. no	Name of the Species	Name of the Lakes Manasabal [49]	Pangong Tso [49]	Tso moriri [29]	Wular [29]	Nigeen [28]	Dal [50]	Mansar [51]	Anchar [52]
	Sphaerozosma sp.	-	-	-	-	-	-	-	+
	Spirogyra sp.	-	-	-	-	-	-	+	-
	Spondylosium sp.	-	-	-	-	-	-	+	+
	Staurastrum sp.	-	-	-	-	-	-	+	+
	Staurodesmus sp.	-	-	-	-	-	-	-	+
	Stigeoclonium sp.	-	-	-	-	-	-	+	-
	Surirella sp.	-	-	-	-	-	-	+	-
	Synedra sp.	-	-	-	-	-	-	+	-
	Tetraedon sp.	-	+	+	-	+	-	+	+
	Tetrastrum sp.	-	-	-	-	-	-	-	+
	Tracubaria sp.	-	-	-	-	-	-	-	+
	Triploceras sp.	-	-	-	-	-	-	-	+
	Ulothrix sp.	+	-	-	-	-	-	-	-
	Volvox sp.	-	-	-	-	-	-	+	+
	Xanthidium sp.	-	-	-	-	-	-	-	+
	Zygnema sp.	-	+	+	-	+	-	+	-
3.	Chrysopyceae								
	Synura sp.	+	-	-	-	-	-	-	-
4.	Cyanophyceae								
	Anabaena sp.	+	-	-	-	+	+	+	+
	Anabaenbopsis sp.	-	-	-	-	-	-	-	+
	Anacystis sp.	+	-	-	-	-	+	-	-
	Aphanocapsa sp.	-	-	-	-	-	+	-	+
	Aphanopusa sp.	-	-	-	-	-	-	-	+
	Aphanothece sp.	+	-	-	-	-	-	-	-
	Arthrospira sp.	-	-	-	-	-	-	-	+
	Calothrix sp.	-	-	-	-	-	-	+	-
	Chroococcus sp.	-	-	-	-	-	-	+	-
	Coccochloris sp.	+	-	-	-	-	-	-	+
	Coelosphaerium sp.	-	-	-	-	-	-	-	+
	Crococcus sp.	+	-	-	-	-	-	-	-
	Gloeocapsa sp.	+	-	-	-	-	-	-	-
	Gomphosphaera sp.	+	-	-	-	-	-	-	-
	Lyngbia sp.	+	+	+	-	-	-	+	-
	Merismopedia sp.	+	-	-	-	-	-	+	+
	Microcystis sp.	+	-	-	-	+	-	+	+
	Nostoc sp.	+	-	-	-	+	-	+	+
	Oscillatoria sp.	+	-	-	-	+	-	+	+
	Phormidium sp.	+	-	-	-	-	-	-	-
	Rivularia sp.	-	-	-	-	-	-	-	+
	Spirulina sp.	+	+	+	+	+	-	+	+
5.	Dinophyceae								
	Ceratium sp.	-	-	-	-	-	-	-	+
	Glenodinium sp.	-	-	-	-	-	-	+	-
	Peridium sp.	-	-	-	-	-	-	-	+
6.	Euglenophyceae								
	Astasia sp.	-	-	-	-	-	-	-	+
	Chlorogonium sp.	-	-	-	-	-	-	-	+
	Colacium sp.	-	-	-	-	+	-	-	-
	Euglena sp.	+	-	-	-	-	+	+	+
	Lepocinclis sp.	-	-	-	-	+	-	-	-
	Phacus sp.	-	-	-	-	+	+	+	+
	Synura sp.	+	-	-	-	-	-	-	-
	Trachelosmonas sp.	-	-	-	-	+	-	-	-
7.	Pheophyceae								
	Batrachospermum sp.	-	+	+	-	-	-	-	-
	Horea sp.	-	+	+	-	-	-	-	-
8.	Xanthopyceae								
	Arachnochloris	-	+	+	-	-	-	-	-
	Vacheria sp.	-	+	+	+	-	-	-	-

Note: The species Abundance is represented using a simplified semi-quantitative scale, where "+" indicates presence (low to moderate abundance) and "–" indicates absence of the species.

Table 5. Zooplankton species recorded in selected freshwater lakes of Jammu & Kashmir and Ladakh.

Sr. No	Zooplankton Class	Species	Mansar [53]	Surinsar [53]	Dal Lake [54]	Wular [55]	Manasbal [56]	Pangong [29]	Tso Moriri [29]
1	Protozoa	*Vorticella* sp.	+	–	–	–	–	–	–
		Centropyxis sp.	+	–	–	–	–	–	–
		Difflugia sp.	+	–	–	–	–	–	–
		Pareuglypha sp.	+	–	–	–	–	–	–
2	Rotifera	*Brachionus* sp.	+	+	+	+	+	–	–
		Keratella sp.	+	+	+	+	+	–	–
		Bdelloids sp.	–	–	+	+	–	–	–
		Cephalodella sp.	–	–	+	+	–	–	–
		Colurella sp.	–	–	+	+	–	–	–
		Anuraeopsis sp.	–	+	–	+	+	–	–
		Euchlanis sp.	+	+	+	+	–	–	–
		Trichocerca sp.	–	+	+	+	+	–	–
		Asplanchna sp.	+	+	+	+	–	–	–
		Polyarthra sp.	–	+	+	+	–	–	–
		Gastropus sp.	–	–	–	+	–	+	+
3	Cladocera	*Chydorus* sp.	+	+	+	+	+	–	–
		Pleuroxus sp.	–	–	+	+	–	–	–
		Alona sp.	–	+	+	+	+	–	–
		Bosmina sp.	–	–	+	+	–	–	–
		Macrothrix sp.	+	+	–	+	–	–	–
		Daphnia sp.	+	+	+	+	–	–	–
		Graptolebris sp.	–	–	+	+	+	–	–
4	Copepoda	*Cyclops* nanus	+	+	+	+	+	+	+
		Mesocyclops sp.	+	+	–	–	+	–	–
		Tropocyclops sp.	+	+	–	–	–	–	–
		Nauplius larvae	+	+	–	+	–	+	+
		Diaptomus sp.	+	–	+	+	–	+	+
5	Ostracoda	*Cypris* sp.	+	–	–	–	–	–	–
		Stenocypris sp.	–	+	–	–	–	–	–
		Eucypris sp.	–	+	–	–	–	–	–
		Onchocypris sp.	–	+	–	–	–	–	–

Note*:* Presence of species is indicated by "+" (low to moderate abundance) and absence by "–".

Table 6. Fish species distribution in selected freshwater Lakes of Jammu & Kashmir and Ladakh.

Sr. No	Fish Species	Wular Lake [27]	Dal Lake [57]	Manasbal Lake [13]	Anchar Lake [38]
1	*Bangana diplostoma*	–	–	–	+
2	*Botia birdi*	–	+	–	–
3	*Carassius* sp.	+	+	+	+
4	*Crossocheilus diplochilus*	+	+	+	+
5	*Cyprinus carpio communis*	+	+	+	+
6	*Cyprinus carpio specularis*	+	+	+	+
7	*Gambusia affinis*	–	–	–	+
8	*Gambusia holbrooki*	–	+	+	–
9	*Pethia conchonius*	+	+	+	–
10	*Salmo trutta fario*	–	–	–	+
11	*Schizothorax esocinus*	+	–	–	+
12	*Schizothorax curvifrons*	+	+	+	+
13	*Schizothorax niger*	+	+	+	+
14	*Schizothorax labiatus*	–	–	–	+
15	*Schizothorax plagiostomus*	–	–	–	+
16	*Schizothorax richardsoni*	–	–	–	+
17	*Triplophysa* sp.	+	–	–	–

Note*:* Presence of species is indicated by "+" (low to moderate abundance) and absence by "–".

4. Anthropogenic Effects on the Lakes

Lake ecosystems were equally important for the survival and well-being of all living organisms, including humans. Anthropogenic discharges were a continuous source of pollution, whereas surface runoff occurred seasonally and was strongly influenced by the climatic conditions of the basin. The discharge of municipal sewage and agricultural waste was identified as a primary cause of lake degradation. Activities such as fishing and boating also contributed significantly to the deterioration of water quality [40]. Many lakes in the region exhibited common characteristics, including low dissolved oxygen (DO) concentrations, high pH, and elevated nutrient levels. These conditions resulted in anoxia, algal blooms, and the transition of several lakes from eutrophic to hypereutrophic states. Climate change and the increasing influx of tourists further exacerbated these impacts [10].

Eutrophic stagnant water bodies, such as Dal and Wular lakes, supported a higher number of invasive species compared to flowing water systems such as rivers. Increased anthropogenic disturbances in freshwater habitats facilitated the spread of alien species at the expense of native biodiversity [14]. Freshwater lakes in the Western Himalayan region were subjected to multiple stressors arising from human activities, climate change, and natural processes. This included pollution, intensified human interference, and land use changes, all of which threatened the ecological balance of these fragile aquatic ecosystems [58].

The growing human population not only degraded but also polluted these vital water resources [59]. Anthropogenic activities accelerated the natural ageing process of lakes by reducing water quality and adversely affecting aquatic life. Agricultural runoff and sewage discharge from nearby settlements further contributed to declining water quality. Elevated levels of nitrogen, phosphate, chloride, alkalinity, hardness, conductivity, and free CO_2, along with reduced dissolved oxygen levels, indicated increasing trophic status, particularly in littoral zones [60]. Rapid population growth led to the expansion of human settlements around lakes, negatively impacting aquatic ecosystems. In many cases, untreated sewage and industrial waste were discharged into water bodies despite their ecological and economic importance. Consequently, water quality deteriorated due to unsustainable use, poor management, and negligence [61]. Dal Lake, for instance, exhibited rapid eutrophication driven by increasing anthropogenic pressures within its catchment. The lake showed clear signs of ecological degradation, including shrinking surface area, declining water quality, and intensified mineral extraction activities [62]. Despite the growing dependence of local populations on these ecosystems, there remained limited understanding of the processes driving lake degradation [10].

Pollution exerted severe impacts on freshwater biodiversity, either through direct toxicity or disruption of ecosystem functions [63]. In Manasbal Lake, both fauna (e.g., *Schizothorax* species) and flora (e.g., *Euryale ferox*) declined due to increasing anthropogenic pressures, which altered the lake’s trophic status. Limestone extraction within the catchment area was identified as a major contributing factor, as it increased siltation and reduced water quality [64]. Studies conducted at multiple sites in Anchar Lake evaluated several physicochemical parameters and revealed substantial pollution linked to human activities. Significant variations in water depth (0.71–1.73 m) and transparency (0.27–0.93 m) indicated nutrient enrichment and eutrophication [43]. Biodiversity assessments of Anchar Lake showed a decline in fish diversity, with *Schizothorax esocinus* dominating at approximately 35.2%, reflecting deteriorating ecological conditions [38].

Nigeen Lake exhibited clear signs of eutrophication due to nutrient enrichment, particularly from diffuse nitrogen and phosphorus inputs [65]. Anthropogenic disturbances disrupted the hydrochemical balance of the lake, adversely affecting aquatic organisms, especially sensitive fish and invertebrate species [66]. Similarly, Wular Lake experienced significant water quality deterioration due to untreated wastewater discharge and agricultural runoff containing pesticides, leading to increased micropollutant levels [67]. Although natural processes influenced its geochemical characteristics, human activities such as land use change and pollution had become the dominant drivers affecting water and sediment composition [68].

Ahansar Lake showed progressive eutrophication since the 1930s, with peak biological productivity observed between 1970 and 2016, as indicated by proxy measures such as total organic carbon (TOC), total nitrogen (TN), and nitrogen isotope ratios ($\delta^{15}N$) [69]. Waskursar Lake also exhibited eutrophic conditions, primarily driven by sewage inputs and elevated nutrient concentrations, which altered plankton composition and reduced overall water quality. Gilsar Lake, once an important freshwater resource in Srinagar, experienced significant ecological degradation due to rapid urbanisation and increasing pollution levels [70]. Restoration activities, including dredging, altered the physicochemical properties of sediments in Brari Nambal Lake [71].

High-altitude lakes such as Vishansar required continuous monitoring to assess the impacts of anthropogenic pressures on biodiversity and water quality [32]. Although limited studies were available for Tulian Lake, findings from nearby systems suggested that agricultural runoff containing fertilisers and pesticides contributed to water quality deterioration [72]. Similarly, the ecological integrity of Tarsar Lake was threatened by unregulated tourism, which led to pollution, inadequate sanitation, and increased sedimentation [73].

5. Research and Monitoring Program

The development of monitoring techniques capable of revealing the ecological status of these ecosystems in response to biotic and natural events was urgently needed, as such approaches directly supported effective conservation planning [74]. By incorporating biological components, biomonitoring evaluated the structural and functional characteristics of aquatic ecosystems [18]. Several important groups of organisms, including fish, higher plants, fungi, algae, protozoa, bacteria, and macroinvertebrates, were used as indicators of environmental contamination [51]. The presence or absence of these indicator species reflected the condition of the aquatic environment. Algae were considered among the most effective bioindicators due to their short life cycles and rapid response to environmental changes [75]. Phytoplankton, in particular, responded quickly to environmental stressors such as nutrient depletion or enrichment, making them reliable indicators of ecological status and water quality [76].

Zooplankton, including rotifers, primarily fed on phytoplankton and showed seasonal variations, with higher abundance during summer months. However, some rotifer species maintained relatively stable populations even during winter, indicating their adaptability to cold conditions. The distribution and density of zooplankton populations were strongly influenced by temperature and food availability [77]. Fish diversity and population health were also key indicators of the ecological condition of aquatic systems. Over recent decades, fish biodiversity in India has declined significantly due to environmental degradation and anthropogenic activities such as pollution, water abstraction, and dam construction [78]. In addition, long-term monitoring of nutrient cycling and microbial processes, particularly those mediated by bacteria, provided valuable insights into ecosystem functioning and biogeochemical dynamics [79].

5. Conclusion

This review identified a wide range of freshwater lakes in Jammu & Kashmir and Ladakh, encompassing diverse hydrological types, including natural, glacial, tectonic, and high-altitude systems. These lakes exhibited varying water quality patterns; remote high-altitude lakes generally maintained good water quality, whereas lakes subjected to significant human interference showed increasing signs of pollution, eutrophication, and nutrient enrichment. Moderate to high biodiversity of plankton and fish was observed across many lakes; however, declining biodiversity trends were evident in ecologically stressed systems. Major anthropogenic pressures included agricultural runoff, sewage discharge, untreated wastewater, pollution, fishing, boating, unregulated tourism, and resource exploitation. These impacts were further intensified by climate-related factors such as glacial retreat and changing precipitation patterns. Despite these findings, variability in research methodologies, spatial coverage, and data availability across studies introduced uncertainties and limited direct comparability, highlighting the need for standardised assessment frameworks. This review emphasised the need for lake-specific management strategies, effective control of pollution sources, promotion of sustainable and eco-friendly tourism, and active community participation for conservation. The development and implementation of robust monitoring techniques remained essential for accurately assessing ecological conditions. The use of biological indicators, including fish, higher plants, fungi, algae, protozoa, bacteria, and macroinvertebrates, was strongly recommended for evaluating environmental contamination. Future research should focus on addressing data gaps, strengthening interdisciplinary approaches, and improving methodological consistency to support evidence-based lake management practices.

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Author Contribution

All listed authors contributed significantly to the manuscript and met the criteria for authorship. Parul Sharma, Chander Shekhar, and Akshay Kumar collected the literature and drafted the manuscript. Arvind Kumar Sharma Rakesh Kumar Dorach proposed the systematic methodology, Rakesh Kumar performed data curation. Amit Kumar Sharma revised and formatted the manuscript, conceptualised the study, and contributed to its design. Amit Kumar Sharma and Sunil Kumar supervised the work, conducted the final editing, and approved the final version of the manuscript.

Competing Interest

All authors declared that they had no financial, personal, or professional relationships that could influence or be perceived to influence the outcomes of this research.

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