Evaluation Of Aquatic Ecosystems and Fisheries Potential in The Chenab Basin of Jammu and Kashmir

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***Abstract*—The Chenab Basin in Jammu and Kashmir represents one of the most significant coldwater riverine systems of the Western Himalaya, characterized by diverse aquatic habitats and substantial fisheries potential. The present study evaluates the ecological status of aquatic ecosystems and assesses the fisheries potential across different stretches of the Chenab River and its tributaries. The results indicate that the upper and middle reaches of the basin maintain relatively good water quality, with favorable conditions for coldwater fish species, particularly indigenous taxa. However, spatial variability in habitat structure, flow regimes, and substrate composition significantly influences fish distribution and abundance. The ichthyofaunal composition is dominated by coldwater species, though localized pressures such as habitat degradation, unsustainable fishing practices, and anthropogenic disturbances are emerging concerns in certain stretches.**

The study highlights that the Chenab Basin possesses considerable potential for sustainable capture fisheries development, provided that ecological integrity is maintained. This assessment provides a baseline for future ecological monitoring and sustainable fisheries planning in the Western Himalayan river systems.

***Index Terms*—Chenab Basin, Jammu and Kashmir, aquatic ecosystems, fisheries potential, coldwater fisheries, ichthyofauna, Himalayan rivers, river ecology.**

I. INTRODUCTION

Background of the Study

Freshwater ecosystems in mountainous regions play a crucial role in sustaining biodiversity, ecological balance, and human livelihoods. The Chenab Basin, located in the Union Territory of Jammu and Kashmir, forms an important part of the Western Himalayan river system. Originating from high-altitude glaciers and snow-fed tributaries, the Chenab River exhibits a complex hydrological network that supports diverse aquatic life, particularly coldwater fish species. Despite its ecological importance, many stretches of the basin remain insufficiently studied with respect to their fisheries resources and ecosystem health.

Importance of the Chenab Basin Aquatic Ecosystem

The Chenab Basin is characterized by pristine headwaters, fast-flowing streams, and diverse microhabitats that provide suitable conditions for a range of aquatic organisms. These ecosystems are not only vital for maintaining regional biodiversity but also support fisheries-based livelihoods in rural and mountainous communities. The basin contributes significantly to ecological services such as nutrient cycling, sediment transport, and water purification. However, increasing anthropogenic pressures, including habitat modification, unregulated fishing, and climate-induced hydrological changes, are posing emerging threats to its ecological integrity.

Rationale for Fisheries Potential Assessment

An assessment of fisheries potential in the Chenab Basin is essential for sustainable resource utilization and conservation planning. Coldwater fisheries in Himalayan river systems are highly sensitive to environmental changes, making them important indicators of ecosystem health. Understanding the spatial variation in fish diversity, habitat quality, and water chemistry is necessary to identify suitable zones for conservation and sustainable fisheries development. Such evaluations also help in bridging knowledge gaps and supporting evidence-based management strategies in the region.

OBJECTIVES OF THE STUDY

The present study aims to evaluate the aquatic ecosystems and fisheries potential of the Chenab

Basin in Jammu and Kashmir. The specific objectives are:

- To assess the physico-chemical characteristics of river water in selected sites of the basin.
- To evaluate habitat conditions influencing fisheries productivity.
- To identify key threats affecting aquatic ecosystems in the study area.
- To suggest suitable conservation and management strategies for sustainable fisheries development.

II. STUDY AREA

Geographic Location of the Chenab Basin

The Chenab Basin forms an important part of the Western Himalayan river system and extends across the Union Territory of Jammu and Kashmir. Geographically, it lies between 32°53′–34°21′ N latitude and 75°01′–76°47′ E longitude. The basin encompasses a wide altitudinal gradient ranging from lower subtropical valleys to high alpine zones. Administratively, a major portion of the basin within Jammu and Kashmir includes the districts/sub-divisions of Kishtwar, Doda, Bhaderwah, and Ramban, which collectively represent diverse ecological and hydrological conditions.

Physiography and River System Characteristics

The Chenab Basin is predominantly mountainous, characterized by rugged terrain, steep slopes, deep gorges, and narrow valleys. The physiography is shaped by active tectonic processes and glacial activity, resulting in highly variable landforms. The river system is primarily snow- and glacier-fed, with the Chenab River acting as the main drainage channel. The basin exhibits high stream gradient in upper reaches, transitioning into relatively wider valleys downstream. These variations create diverse aquatic habitats that support a range of coldwater fish species and other aquatic organisms.

Climate and Hydrological Features

The basin experiences strong climatic variability due to its complex topography and altitudinal differences. Upper reaches are characterized by a cold alpine climate with prolonged snowfall, while mid and lower reaches experience temperate to sub-tropical conditions. Temperature ranges from sub-zero conditions in higher elevations to about 40–42°C in lower valleys during summer months. The region receives an average annual rainfall of approximately 900–1000 mm (35–40 inches), with snowfall being a significant contributor to the hydrological regime. Hydrologically, the Chenab River is sustained by snowmelt, glacial melt, monsoonal rainfall, and numerous perennial and seasonal tributaries. This results in strong seasonal discharge variability, with peak flows occurring during spring and summer months due to snowmelt and rainfall.

Major Tributaries and Sampling Sites

The Chenab River system within the study area is enriched by several important tributaries, including the Marusudar, Neeru, Tawi (upper reaches), Bhaderwah streams, Kiar Nallah, and Warwan streams, among others. These tributaries contribute significantly to the ecological diversity and hydrological complexity of the basin.

For the present study, representative sampling sites were selected across upper, middle, and lower stretches of the basin to capture spatial variations in aquatic ecosystem characteristics and fisheries potential. The selected sites reflect differences in altitude, flow conditions, habitat structure, and anthropogenic influence, thereby providing a comprehensive assessment of the fisheries resources of the Chenab Basin.

III. MATERIALS AND METHODS

Field Survey and Sampling Design

The present study was conducted through systematic field surveys carried out across selected sites of the Chenab Basin representing upper, middle, and lower reaches. Sampling locations were chosen to capture spatial variation in altitude, flow regime, habitat structure, and anthropogenic influence. A stratified sampling approach was adopted to ensure representative coverage of diverse aquatic habitats, including fast-flowing streams, riffles, pools, and riverine stretches.

Field observations were recorded during different seasons to account for temporal variability in hydrological and ecological conditions. Standard field protocols were followed for habitat characterization and biological sampling.

Water Quality Analysis Methods

Water samples were collected from each selected site in pre-cleaned polyethylene bottles following standard procedures. Physico-chemical parameters such as water temperature, pH, dissolved oxygen (DO), electrical conductivity, turbidity, and total dissolved solids (TDS) were analyzed using standard methods In-situ measurements were taken using portable water quality meters, while laboratory analysis was performed for selected parameters where required. Seasonal variations in water quality were also assessed to determine their influence on aquatic biodiversity and fisheries potential.

Fish Sampling and Identification Techniques

Fish specimens were collected using traditional and standard fishing gears such as cast nets, gill nets, and drag nets, depending on site conditions. Collected specimens were preserved in 10% formalin solution and transported to the laboratory for detailed identification. Fish species were identified based on standard taxonomic keys and reference manuals. Morphological characteristics such as body shape, fin structure, scale pattern, and meristic counts were used for species-level identification. Nomenclature was verified using updated ichthyological databases and published literature.

Assessment of Aquatic Habitat Conditions

Aquatic habitat conditions were assessed through direct field observations, focusing on parameters such as channel morphology, water depth, flow velocity, substrate composition (boulder, cobble, gravel, sand), and riparian vegetation cover. Habitat quality was categorized based on suitability for fish spawning, feeding, and shelter. Anthropogenic disturbances such as sand mining, water abstraction, pollution sources, and habitat fragmentation were also recorded to evaluate their impact on fisheries resources.

IV. AQUATIC ECOSYSTEM CHARACTERISTICS

The Chenab Basin in Jammu and Kashmir represents a dynamic Himalayan riverine ecosystem shaped by steep gradients, seasonal hydrological variability, and strong geomorphological processes. Its aquatic habitat structure is highly heterogeneous, supporting a range of ecological niches that influence biodiversity distribution and fisheries potential. The characterization of habitat structure, flow regime, substrate composition, and riparian vegetation provides essential insights into ecosystem functioning and productivity.

Riverine Habitat Structure

The riverine habitat of the Chenab Basin is highly diverse, comprising a mosaic of riffles, runs, pools, side channels, and tributary confluences.

- Riffles and Rapids: Dominant in upper reaches, characterized by fast-flowing, highly oxygenated water and coarse substrates. These habitats support benthic macroinvertebrates and cold-water fish species.
- Pools: Occur in mid and lower reaches where channel gradient decreases. Pools provide refuge habitats, particularly during low-flow periods and winter seasons.
- Runs and Glides: Transitional habitats with moderate flow velocity, supporting feeding and migration of fish species.
- Tributary Confluences: Ecologically significant zones with enhanced nutrient mixing and habitat diversity, often serving as spawning or feeding grounds.

Overall, habitat heterogeneity in the Chenab Basin enhances ecological resilience and supports both resident and migratory fish populations.

Flow Regime and Hydrological Variability

The flow regime of the Chenab River is predominantly snowmelt- and glacier-fed, resulting in strong seasonal discharge variability.

- Snowmelt Contribution: Peak flows occur during late spring and early summer (April–June), driven by melting snow and glaciers in the upper catchment.
- Monsoonal Influence: July–September rainfall further increases discharge and sediment load, often causing short-term high turbidity events.
- Winter Low Flow: Reduced precipitation and freezing conditions lead to significantly lower discharge levels, especially in higher altitudes.
- Flow Variability: High intra-annual variability influences habitat connectivity, fish migration patterns, and spawning success.

The natural flow regime remains a key driver of ecological processes, although localized hydropower regulation in some stretches may alter downstream flow continuity.

Substrate Composition and Channel Morphology

Substrate and channel morphology in the Chenab Basin are primarily controlled by steep gradients, high-energy flow conditions, and active erosion-deposition processes.

- Upper Reaches: Dominated by boulders, cobbles, and coarse gravel due to high-energy flow and limited sediment deposition. These conditions favor benthic organisms adapted to strong currents.
- Mid Reaches: Transition zones with mixed substrates including gravel, sand, and occasional silt deposits, supporting higher habitat diversity.
- Lower Reaches: Increased deposition of fine sediments (sand and silt) leads to channel widening and reduced flow velocity.
- Channel Morphology: The river exhibits a predominantly braided to meandering transition pattern, with active lateral erosion, point bar formation, and shifting channels in lower reaches.

Substrate heterogeneity plays a crucial role in spawning habitat availability, particularly for gravel-spawning fish species such as trout.

Riparian Vegetation and Ecosystem Support

Riparian vegetation in the Chenab Basin is a vital component of ecosystem stability, providing bank protection, nutrient input, and habitat complexity.

- Vegetation Composition: Includes a mix of temperate broadleaf species, shrubs, grasses, and alpine vegetation in upper reaches. Common species include willow (Salix spp.), poplar (Populus spp.), and alder (Alnus spp.).
- Bank Stabilization: Root systems of riparian vegetation reduce soil erosion and stabilize riverbanks, particularly in flood-prone zones.
- Nutrient Cycling: Leaf litter and organic debris contribute to detrital food webs, supporting aquatic invertebrate populations.
- Shading Effect: Vegetation canopy regulates water temperature by reducing direct solar radiation, which is critical for cold-water fish habitats.
- Anthropogenic Pressure: In some lower stretches, deforestation and land-use conversion have reduced riparian buffer integrity, increasing sedimentation and habitat degradation.

V. WATER QUALITY ASSESSMENT

Water quality is a fundamental determinant of aquatic ecosystem health and directly governs the productivity, species composition, and fisheries potential of river systems. In the Chenab Basin of Jammu and Kashmir, water quality is influenced by altitude, glacial melt, seasonal precipitation, land use patterns, and anthropogenic pressures such as agriculture, settlements, and hydropower development. The assessment of physico-chemical characteristics, nutrient status, pollution indicators, and seasonal variability provides a comprehensive understanding of habitat suitability for fisheries development.

Physico-Chemical Parameters

Key physico-chemical parameters of the Chenab Basin reflect its predominantly cold-water riverine ecosystem with high oxygenation and low to moderate nutrient concentrations.

- Temperature: River water temperature in the Chenab Basin typically ranges from 4°C to 18°C, depending on altitude and season. Upper reaches remain cold due to snow and glacial melt, supporting cold-water species such as trout. Lower reaches experience comparatively higher temperatures, influencing species diversity and metabolic activity.
- pH: The pH of river water generally remains slightly alkaline to neutral (7.2–8.2), indicating good buffering capacity and minimal acidification stress. This range is suitable for most freshwater fish species.
- Dissolved Oxygen (DO): DO levels are generally high (7–12 mg/L) in upper and mid reaches due to turbulent flow, low temperature, and high re-aeration. High DO supports sensitive cold-water fish species and indicates good ecological condition.

- Biochemical Oxygen Demand (BOD): BOD values are typically low (1–3 mg/L) in less disturbed sections, reflecting low organic pollution. Slight increases are observed near human settlements and agricultural runoff zones.
- Electrical Conductivity (EC): EC values remain low to moderate (50–250 µS/cm), indicating low ionic content and minimal industrial contamination in upper reaches.
- Total Suspended Solids (TSS): Elevated TSS levels are often recorded during monsoon and glacial melt periods due to increased sediment load, affecting light penetration and habitat quality.

Nutrient Status and Pollution Indicators

Nutrient dynamics in the Chenab Basin are generally oligotrophic in upper reaches and mesotrophic in lower reaches.

- Nitrates (NO_3^-) and Phosphates (PO_4^{3-}): Concentrations remain low in upstream regions due to limited anthropogenic activity. However, moderate increases are observed downstream due to agricultural runoff and domestic waste inputs.
- Ammonia (NH_3): Typically low, but localized spikes may occur near sewage discharge points, indicating organic pollution stress.
- Silicate and Other Nutrients: Naturally derived from weathering of Himalayan rocks, supporting primary productivity without causing eutrophication.
- Pollution Indicators:
  - Low BOD and high DO suggest relatively unpolluted conditions in upper reaches.
  - Increasing nutrient load and microbial contamination in downstream areas indicate localized anthropogenic stress.
  - Absence of heavy industrial pollution maintains overall ecological integrity of much of the basin.

Seasonal Variation in Water Quality

Water quality in the Chenab Basin exhibits strong seasonal variability driven by monsoonal rainfall, snowmelt, and winter conditions.

- Spring (Snowmelt Period): High discharge and cold temperatures lead to dilution of pollutants, high DO, and increased turbidity due to sediment influx.
- Summer (Pre-monsoon and Monsoon): Elevated temperatures and runoff from agricultural lands increase nutrient loading and suspended sediments. Turbidity peaks during monsoon rainfall events.
- Autumn: Stabilization of flow conditions results in improved clarity and balanced nutrient levels, providing optimal conditions for aquatic life.
- Winter: Low temperatures reduce biological activity, but DO remains relatively high due to reduced decomposition rates. Flow reduction may concentrate pollutants in localized areas.

Overall, seasonal fluctuations significantly influence habitat quality, spawning conditions, and fish migration patterns.

Suitability of Water for Fisheries

Based on physico-chemical and nutrient characteristics, the Chenab Basin exhibits high fisheries potential in upper and mid reaches, particularly for cold-water species.

- Upper Reaches: High DO, low temperature, and low pollution levels, Highly suitable for cold-water fisheries such as trout (rainbow trout and brown trout) and Limited nutrient availability restricts excessive primary productivity, maintaining clear-water ecosystems ideal for sensitive species
- Mid Reaches: Moderate temperature and nutrient levels, Supports both cold-water and warm-water adaptable species and Potential for diversified aquaculture and capture fisheries enhancement
- Lower Reaches: Higher nutrient load and turbidity, Suitable for hardy warm-water species (e.g., carps and minor indigenous fishes) and Increased anthropogenic pressure may reduce habitat quality if unmanaged

The Chenab Basin demonstrates good to excellent fisheries potential, especially in its upstream and midstream segments. However, sustainable management is required to prevent degradation from sedimentation, nutrient enrichment, and localized pollution. Conservation of riparian zones and regulation of wastewater discharge are critical for maintaining long-term fisheries productivity.

VI. FISH DIVERSITY AND COMPOSITION

The Chenab Basin of Jammu and Kashmir supports a diverse ichthyofaunal assemblage influenced by altitudinal gradients, hydrological variability, and habitat heterogeneity. The river system acts as a transition zone between cold-water Himalayan fauna in the upper reaches and more tolerant warm-water species in the lower stretches. Fish diversity patterns reflect ecological conditions, connectivity of tributaries, and varying degrees of anthropogenic influence.

Fisheries Status in the Chenab Valley

The Chenab Valley, characterized by rugged mountainous topography, primarily supports hill-stream fisheries. According to Hora (1922), hill-stream fishes have evolved specific adaptations to survive in fast-flowing torrential waters. The aquatic ecosystem of the Chenab Valley comprises rivers, tributaries, nallahs, and natural and seasonal ponds. The region is also marked by extensive forest cover and snow-fed mountain catchments, resulting in cold, clear, and oxygen-rich waters that are highly suitable for cold-water fish species.

In recent years, the construction of hydropower projects on the Chenab River has introduced new opportunities for reservoir fisheries development. The Baglihar Hydroelectric Project, with a reservoir extending approximately 17 km, offers significant potential for fisheries enhancement. Additionally, several other sanctioned and proposed hydropower projects across the Chenab River and its tributaries further expand the scope for reservoir-based fisheries and aquaculture development in the region.

The ichthyofaunal diversity of the Chenab basin is predominantly composed of hill-stream and cold-water fish species. Key genera reported from the region include Schizothorax, Glyptothorax, Nemacheilus, Barilius, Tor tor, Cirrhinus, Puntius, and Labeo. These species exhibit specialized morphological adaptations such as adhesive structures and modified body forms that enable survival in high-velocity streams (e.g., Glyptothorax spp.).

Despite its rich aquatic biodiversity and favorable ecological conditions, fisheries development in the Chenab Valley remains in its early stages. Limited exploitation of resources is largely attributed to difficult terrain, poor accessibility, and inadequate infrastructural development. However, recent developmental initiatives have improved connectivity and accessibility, creating new prospects for sustainable fisheries development.

With proper planning, scientific management, and institutional support, the fisheries sector in the Chenab Valley has strong potential to contribute to rural livelihoods, generate employment, and enhance nutritional security through protein-rich fish production. Future emphasis on systematic exploration and sustainable utilization of aquatic resources is essential for realizing the full fisheries potential of the Chenab basin.

VII. FISHERIES POTENTIAL EVALUATION

The fisheries potential of the Chenab Basin in Jammu and Kashmir is governed by its Himalayan riverine characteristics, including cold-water regimes in upper reaches, mixed transitional habitats in mid-reaches, and comparatively warmer, nutrient-enriched conditions downstream. The basin exhibits significant spatial variation in fish production potential, influenced by hydrology, habitat quality, water temperature, substrate availability, and anthropogenic pressures. A comprehensive evaluation of capture fisheries, aquaculture suitability, spawning habitats, and productivity status highlights both existing strengths and future development opportunities.

Assessment of Capture Fisheries Potential

Capture fisheries in the Chenab Basin are primarily riverine and subsistence-oriented, with localized commercial value in accessible stretches.

- Upper Reaches: Capture fisheries potential is limited in terms of quantity but high in ecological and economic value due to the presence of high-value cold-water species such as trout (Salmo trutta fario, Oncorhynchus mykiss). These zones are highly suitable for sport fisheries and regulated angling activities.
- Mid Reaches: Represent the most productive capture fisheries zones due to habitat diversity and moderate flow conditions. Indigenous species such as Schizothorax spp. contribute significantly to fish biomass.

- Lower Reaches: Higher fish abundance and diversity, including cyprinids and catfishes, support small-scale artisanal fisheries. However, habitat degradation and pollution in some sections reduce overall catch quality.
- Overall Assessment: The basin has moderate capture fisheries potential, with high-value niche fisheries (trout-based) in upper reaches and broader species-based fisheries downstream.

Aquaculture Suitability in the Basin

Aquaculture development in the Chenab Basin is highly feasible in selected zones, particularly where clean water and stable flow conditions are available.

- Cold-Water Aquaculture: Upper reaches are highly suitable for trout farming due to: Low water temperatures (optimal for salmonids), High dissolved oxygen levels, Clean, unpolluted streams and springs This supports both cage culture and raceway systems.
- Warm-Water Aquaculture: Lower and some mid-reach floodplain areas are suitable for carp-based aquaculture: Cyprinus carpio (common carp) and Indian major carps in pond systems (where feasible)
- Constraints: Steep topography limits pond construction in upper regions, seasonal flow variability affects water retention and infrastructure stability and risk of disease transmission between cultured and wild populations
- Overall Suitability: The basin has high potential for diversified aquaculture, particularly integrated cold-water trout farming and low-intensity carp culture in valley bottoms.

Spawning and Nursery Grounds

The Chenab Basin contains several ecologically important spawning and nursery habitats essential for sustaining fish populations.

Spawning Grounds

- Gravel-bed riffles and runs in upper and mid reaches provide ideal spawning sites for salmonids and Schizothorax spp.
- Clean, well-oxygenated, and fast-flowing water supports successful egg incubation.
- Tributary junctions serve as important spawning aggregation zones due to improved habitat diversity.

Nursery Areas

- Shallow marginal zones, backwaters, and floodplain edges serve as nursery habitats for juvenile fish.
- Mid-reach slower-flowing segments provide refuge from strong currents and predators.
- Seasonal inundation of floodplains enhances food availability for larval and juvenile stages.

Productivity Status of Riverine Fisheries

The productivity of riverine fisheries in the Chenab Basin varies significantly along its longitudinal profile.

- Upper Reaches (Low Productivity–High Value): Low primary productivity due to cold temperatures and oligotrophic conditions and high ecological quality supports high-value species rather than high biomass
- Mid Reaches (Moderate Productivity): Increased nutrient availability and habitat complexity, highest balance between species diversity and biomass production and considered the most productive zone for sustainable fisheries
- Lower Reaches (Moderate to High Productivity): Higher nutrient inputs from agriculture and settlements , greater fish biomass but reduced water quality in some sections and productivity often dominated by tolerant and fast-growing species

Overall Productivity Pattern

- The basin exhibits a moderate overall fisheries productivity, with a shift from low-biomass high-value fisheries upstream to higher-biomass mixed fisheries downstream.
- Productivity is strongly influenced by seasonal flow regimes, sediment load, and anthropogenic disturbances.

VIII. THREATS AND CONSTRAINTS

The Chenab Basin in Jammu and Kashmir, despite its relatively high ecological integrity in upper reaches, is increasingly subjected to multiple anthropogenic

and climatic stressors. These pressures are altering habitat structure, water quality, and biological communities, thereby constraining fisheries productivity and long-term sustainability. The major threats include habitat degradation, unsustainable fishing practices, climate change impacts, and pollution from expanding human activities.

Habitat Degradation and River Alteration

Habitat degradation is one of the most significant constraints affecting aquatic ecosystem health in the Chenab Basin.

- Hydropower Development: Construction of dams, diversion structures, and tunnels has altered natural flow regimes, reduced sediment continuity, and fragmented fish habitats. This particularly affects migratory pathways and spawning movements.
- River Channel Modification: Activities such as bank cutting, channelization, and embankment construction have reduced natural habitat complexity, especially in mid and lower reaches.
- Sand and Gravel Mining: Unregulated extraction of riverbed materials disturbs spawning grounds, increases turbidity, and destabilizes channel morphology.
- Flow Regulation Impacts: Altered environmental flows reduce habitat availability during critical breeding and juvenile development periods.

Overall, habitat degradation leads to reduced ecological connectivity and loss of habitat heterogeneity essential for sustaining diverse fish communities.

Overfishing and Unsustainable Practices

Fishing pressure in the Chenab Basin is generally localized but can be unsustainable in accessible stretches.

- Indiscriminate Fishing Methods: Use of fine-mesh nets, traps, and occasionally destructive methods reduces recruitment by capturing juveniles and broodstock.
- Lack of Regulation Enforcement: Weak monitoring in remote areas leads to unregulated harvesting, particularly during spawning seasons.
- Targeting of High-Value Species: Selective fishing of trout and Schizothorax species reduces reproductive potential of populations.
- Recreational Pressure: In some upper reaches, unregulated angling may contribute to localized depletion of cold-water fish populations.

These practices collectively contribute to declining fish stocks and altered community structure.

Climate Change Impacts on Aquatic Systems

Climate change is emerging as a major long-term threat to the Chenab Basin's aquatic ecosystems.

- Glacial Retreat and Snowmelt Variability: Reduced glacier mass and altered melt timing affect seasonal flow regimes, leading to irregular discharge patterns.
- Rising Water Temperatures: Gradual warming of river waters may shift cold-water habitats upstream, reducing suitable habitat for trout and other stenothermal species.
- Increased Extreme Events: Higher frequency of floods and drought-like low-flow conditions disrupt fish breeding cycles and habitat stability.
- Phenological Shifts:Changes in spawning timing and migration patterns affect recruitment success and ecosystem balance.

Climate-induced stress is expected to disproportionately impact cold-water fisheries in the upper basin.

Pollution and Anthropogenic Pressure

Although the Chenab Basin remains relatively less industrialized, pollution and human activities are increasing in localized zones.

- Domestic Sewage Discharge: Untreated or partially treated wastewater from settlements increases nutrient loading and microbial contamination.
- Agricultural Runoff: Fertilizers and pesticides contribute to eutrophication risk in downstream stretches, altering nutrient balance.
- Solid Waste Disposal: Riverbanks near inhabited areas are often impacted by plastic and solid waste accumulation.
- Sedimentation and Turbidity: Land use changes, deforestation, and construction activities increase sediment load, reducing light penetration and affecting aquatic productivity.
- Cumulative Impact: Although pollution levels remain moderate compared to heavily industrialized basins, the cumulative effect of

multiple stressors is gradually degrading water quality and habitat integrity.

IX. CONSERVATION AND MANAGEMENT STRATEGIES

The long-term sustainability of fisheries in the Chenab Basin requires an integrated management framework that combines ecological conservation, regulated resource use, and active participation of local communities. Given the basin's ecological sensitivity and increasing anthropogenic pressures, conservation strategies must focus on maintaining habitat integrity, ensuring sustainable harvest, and restoring degraded aquatic ecosystems.

Sustainable Fisheries Management Approaches

Sustainable fisheries management in the Chenab Basin should be based on ecosystem-based and precautionary principles, ensuring that exploitation does not exceed natural regenerative capacity.

- Regulation of Fishing Effort: Implementation of licensing systems, seasonal fishing bans during spawning periods, and restriction of fishing effort in ecologically sensitive zones can help maintain fish populations.
- Mesh Size Regulation: Enforcement of minimum mesh size standards is essential to prevent harvesting of juvenile fish and ensure successful recruitment.
- Species-Specific Management: High-value cold-water species such as trout require stricter conservation measures, including catch limits and protected stretches.
- Monitoring and Stock Assessment: Regular assessment of fish population dynamics, catch per unit effort (CPUE), and habitat condition is necessary for adaptive management.
- Environmental Flow Maintenance: Ensuring minimum ecological flows, particularly in hydropower-affected stretches, is critical for sustaining aquatic life cycles.

Habitat Restoration Measures

Restoration of degraded habitats is essential for improving ecological integrity and enhancing fisheries productivity in the basin.

- Riparian Zone Restoration: Reforestation of riverbanks using native species (e.g., Salix, Populus, Alnus) helps stabilize banks, reduce erosion, and improve habitat quality.
- Spawning Habitat Enhancement: Artificial creation and protection of gravel beds in riffle zones can improve spawning success for cold-water fish species.
- Sediment Management: Control of sand and gravel mining is necessary to prevent destruction of benthic habitats and spawning grounds.
- Removal of Physical Barriers: Construction of fish passes or ladders at hydropower structures can restore connectivity for migratory species.
- Water Quality Improvement: Reduction of untreated sewage discharge and agricultural runoff is essential to restore ecological balance.

Community-Based Fisheries Management

Active participation of local communities is critical for the success of conservation initiatives in the Chenab Basin.

- Fisher Cooperatives: Formation of community-based organizations can help regulate fishing practices and ensure equitable resource use.
- Awareness and Capacity Building: Educational programs on sustainable fishing techniques, biodiversity conservation, and pollution control can enhance community stewardship.
- Co-Management Systems: Shared governance between local communities and fisheries departments can improve compliance and enforcement.
- Alternative Livelihoods: Promotion of ecotourism, sport fishing, and aquaculture reduces dependence on wild fish stocks and alleviates fishing pressure.
- Citizen Monitoring: Involving local stakeholders in monitoring fish populations and reporting illegal activities strengthens conservation outcomes.

Policy Recommendations for Basin Conservation

Effective policy interventions are required to ensure long-term conservation of aquatic ecosystems in the Chenab Basin.

- Integrated River Basin Management (IRBM): Adoption of basin-wide planning that integrates hydrology, fisheries, forestry, and land-use management.

- Strengthening Environmental Regulations: Strict enforcement of laws regulating pollution discharge, sand mining, and hydropower environmental compliance.
- Protected Aquatic Zones: Identification and designation of fish conservation zones, especially in spawning and nursery habitats.
- Climate Adaptation Strategies: Incorporation of climate-resilient fisheries planning, including protection of cold-water refugia and flow regulation adjustments.
- Research and Monitoring Framework: Establishment of long-term ecological monitoring stations for tracking water quality, fish diversity, and habitat changes.
- Institutional Coordination:Strengthening coordination between fisheries departments, hydropower agencies, and environmental authorities for unified basin management.

X. FUTURE RESEARCH NEEDS

Despite existing knowledge, several gaps remain that require further scientific attention for effective fisheries management in the Chenab Basin:

- Long-Term Ecological Monitoring: Establishment of continuous monitoring programs for water quality, fish diversity, and flow regimes to detect long-term environmental changes.
- Comprehensive Stock Assessment: Detailed studies on fish population dynamics, recruitment patterns, and catch per unit effort (CPUE) across different basin zones.
- Impact of Hydropower Projects: In-depth evaluation of ecological flow requirements and fish migration barriers caused by dams and diversion structures.
- Climate Change Impact Studies: Modeling of temperature rise, glacial retreat, and hydrological shifts on cold-water fisheries and habitat suitability.
- Genetic Diversity of Native Fish: Assessment of genetic variability in indigenous species such as Schizothorax spp. to support conservation planning.
- Aquaculture Integration Studies: Evaluation of sustainable aquaculture practices compatible with natural ecosystem dynamics, particularly trout farming systems.
- Socio-Economic Assessments: Understanding the dependency of local communities on fisheries and evaluating livelihood diversification options.

XI. CONCLUSION

The present study evaluated the aquatic ecosystems and fisheries potential of the Chenab Basin in Jammu and Kashmir, revealing strong ecological gradients and diverse habitat characteristics that govern fish diversity and fisheries productivity. The river exhibits a clear longitudinal pattern, with cold, oxygen-rich, low-nutrient waters in the upper reaches gradually transitioning to warmer and more productive conditions downstream.

Overall, water quality remains good across the basin, particularly in the upper and middle reaches, as indicated by high dissolved oxygen, low biochemical oxygen demand, and low to moderate nutrient concentrations. However, localized deterioration is evident near settlements and agricultural areas. Habitat complexity also varies considerably, ranging from fast-flowing riffle–rapid systems upstream to pool–run habitats downstream, providing a wide range of ecological niches.

Fish assemblages closely reflect these environmental gradients. Cold-water species, including trout and snow trouts, dominate the upper reaches, whereas cyprinids and catfishes are more abundant in the middle and lower reaches. Although exotic species occur in limited areas, they may influence native fish communities. Critical spawning and nursery habitats are primarily associated with gravel-bed riffles, tributary confluences, and marginal floodplain zones, highlighting their importance for sustaining fish populations.

The basin demonstrates moderate to high fisheries potential with distinct spatial variation. The upper reaches support high-value cold-water fisheries, particularly trout fisheries and recreational angling, making them ecologically significant and economically valuable. The middle reaches provide the greatest scope for fisheries development due to their balanced productivity, habitat diversity, and mixed fish assemblages, offering opportunities for both capture fisheries enhancement and small-scale

aquaculture. The lower reaches possess higher fish biomass and species richness, supporting productive warm-water fisheries; however, increasing anthropogenic pressures and habitat degradation may limit their long-term sustainability. Overall, the Chenab Basin supports a dual fisheries system, comprising high-value, low-biomass cold-water fisheries in the upper reaches and higher-biomass mixed fisheries downstream. Realizing its full fisheries potential will require integrated watershed management, habitat conservation, protection of critical spawning grounds, and sustainable fisheries practices to maintain ecological integrity while supporting long-term livelihoods.

CONFLICT OF INTEREST

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