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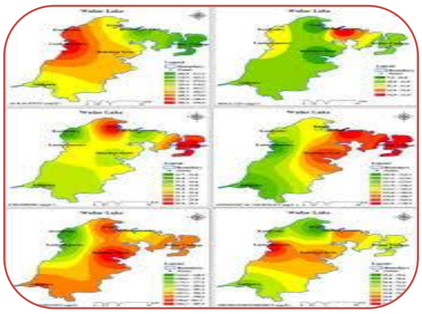
# ANTHROPOGENIC IMPACTS AND ENVIRONMENTAL DEGRADATION OF WULAR LAKE: A SPATIAL ANALYSIS

**Ghatte Vinod Maruti S/O Maruti Ghatte**
**Research Scholar**

**Dr. Praveen Kumar**
**Guide**
**Professor, Chaudhary Charansing University Meerut.**

## ABSTRACT

*Wular Lake, one of the largest freshwater lakes in South Asia, has undergone significant environmental degradation over the past few decades. This degradation, primarily driven by anthropogenic activities, has resulted in habitat loss, biodiversity decline, and changes in water quality. This study employs spatial analysis techniques to examine the extent of environmental changes in Wular Lake, focusing on land-use changes, water quality degradation, and the loss of wetlands. Remote sensing data from satellite imagery, combined with field surveys, were used to track the spatial dynamics of the lake and its surrounding ecosystems over the last few decades. The results indicate a marked reduction in the lake's area, exacerbated by urban expansion, agriculture, and encroachment of human settlements. Additionally, water quality has been compromised due to excessive nutrient loading, invasive species, and unsustainable fishing practices. This research highlights the need for integrated management strategies that account for both ecological restoration and sustainable human development to reverse the ongoing degradation of Wular Lake.*



**KEYWORDS:** *Wular Lake, Anthropogenic Impacts, Environmental Degradation, Spatial Analysis, Land-Use Change, Remote Sensing, Water Quality Degradation, Wetland Loss, Biodiversity Decline.*

## INTRODUCTION

Wular Lake, located in the Kashmir Valley of India, is one of the largest freshwater lakes in South Asia and plays a vital role in maintaining regional ecological balance. It provides habitat for a variety of aquatic species, supports local fisheries, regulates floods, and replenishes groundwater resources. However, in recent decades, Wular Lake has experienced significant environmental degradation due to increasing anthropogenic pressures. Human activities such as urban expansion, agricultural encroachment, unregulated tourism, sand mining, and improper waste disposal have intensified the lake's vulnerability, resulting in habitat loss, declining water quality, and reduction in biodiversity. The degradation of Wular Lake is not only an ecological concern but also a socio-economic challenge, as local communities depend heavily on its resources for livelihood and agriculture. Eutrophication caused by nutrient runoff, invasive species introduction, and sedimentation from upstream catchments have further exacerbated the lake's environmental stress. Spatial analysis, through the use of remote sensing and Geographic Information System (GIS) techniques, offers a powerful approach to monitor and quantify these changes over time. By analyzing historical and contemporary satellite imagery, researchers can map land-use changes, detect wetland loss, assess water quality trends, and identify areas most affected by human activities. Such spatial insights are crucial for understanding the patterns and drivers of environmental degradation, enabling targeted conservation and management strategies. This study aims to assess the extent of anthropogenic impacts and environmental degradation of Wular Lake through a spatial analysis approach. By combining satellite data with field observations, the research provides an integrated understanding of the lake's ecological status, highlights key threats, and proposes recommendations for sustainable management and restoration of this critical freshwater ecosystem.

## AIMS AND OBJECTIVES

**Aim:**

The primary aim of this study is to assess the anthropogenic impacts and environmental degradation of Wular Lake using spatial analysis techniques, in order to provide insights for sustainable management and ecological restoration.

**Objectives:**

1. To analyze land-use and land-cover (LULC) changes in and around Wular Lake over the past decades using remote sensing and GIS tools.
2. To assess water quality and ecological health of the lake by evaluating indicators of pollution, eutrophication, and habitat degradation.
3. To identify the key anthropogenic drivers of environmental degradation, including urbanization, agricultural encroachment, tourism, and sand mining.
4. To map spatial patterns of wetland loss and habitat fragmentation to understand areas most affected by human activities.
5. To propose sustainable management strategies and conservation measures based on spatial and ecological findings to restore and preserve Wular Lake.

## REVIEW OF LITERATURE

Wular Lake, located in the Kashmir Valley of India, is recognized as one of the largest freshwater lakes in South Asia and a designated Ramsar wetland of international importance. Long‑term research has documented substantial environmental degradation of the lake driven by a range of anthropogenic influences and landscape changes. Historical analyses indicate dramatic shrinkage of the lake's surface area over recent decades, largely attributed to sedimentation and land conversion for agriculture and willow plantations, leading to the loss of wetland habitats and cultural resources such as the lake's traditional lotus beds. Prior to restoration efforts, the lake's area reportedly declined from about 217 $km^2$ in the early 20th century to approximately 86 $km^2$ by the early 2000s, with corresponding declines in fauna diversity and wetland productivity. Multitemporal satellite remote sensing and GIS studies have confirmed significant land‑use and land‑cover transformations within the Wular Lake basin. Analyses of satellite imagery for pre‑ and post‑flood periods show substantial decreases in water bodies and terrestrial vegetation following flooding events, with marked declines in vegetated and agricultural categories and reductions in open water extents. Studies assessing multitemporal land‑use dynamics further underscore the trend of increasing agricultural and built‑up areas around the lake, reflecting sustained anthropogenic pressure on the wetland system. The influence of land‑use patterns on lake chemistry has been quantified through correlations between catchment land covers and limnological parameters. Agricultural, horticultural and built‑up lands in the catchment have been found to contribute nutrient loads that reduce dissolved oxygen levels in lake waters, driving eutrophic conditions. Water quality monitoring studies categorize the lake's status as eutrophic, with elevated concentrations of nutrients such as ammonia, nitrate and phosphate linked to organic pollution, sewage inputs, and direct discharge from urban and rural drains.

Geochemical investigations reveal that anthropogenic forcing has altered sediment composition and water chemistry in the lake system. Studies collecting sediment and water samples show increased levels of ions such as nitrate, sulphate and phosphate associated with land-use change and catchment encroachment, reinforcing the view that continued conversion of peripheral areas to settlements and horticultural land amplifies the degradation process. More recent work applying ecological risk assessment methods to lake surface sediments reports elevated concentrations of heavy metals—including cobalt, copper, manganese, nickel, zinc and chromium—exceeding natural background levels and indicating localized contamination from agricultural runoff, urban discharges and industrial sources. These studies employ multivariate statistical analyses to trace heavy metal sources, revealing industrial, urban and agricultural influences as primary contributors to sediment contamination. Catchment-level soil erosion due to unplanned urbanization and deforestation has also been implicated as a major driver of siltation in Wular Lake. Spatial assessments of erosion risk indicate substantial increases in areas susceptible to moderate to extreme soil loss, which contributes to sediment accumulation in tributaries and the lake basin, impeding hydrological functioning and exacerbating habitat degradation. Combined findings from these studies underscore the multifaceted nature of anthropogenic impacts on Wular Lake, highlighting interconnected processes of land-use change, nutrient enrichment, pollutant accumulation and sedimentation that have collectively reshaped the lake's ecological status.

## RESEARCH METHODOLOGY

This study employed an integrated spatial and quantitative research methodology to assess anthropogenic impacts and environmental degradation of Wular Lake using remote sensing, geographic information system (GIS), field sampling, laboratory analysis, and statistical techniques. A multi-temporal spatial framework was developed to detect land use/land cover changes over time and to correlate these with observed environmental degradation patterns. The methodological framework consisted of four core components: data acquisition and preprocessing, field sampling and laboratory analysis, spatial analysis and mapping, and statistical analysis for interpretation of anthropogenic impacts.

### Study Area and Temporal Framework

The research focused on Wular Lake, one of the largest freshwater lakes in the Indian Himalayan region. A spatial extent encompassing the lake and a 5-kilometer buffer zone around its periphery was defined as the primary area of interest. Temporal analysis was conducted using satellite imagery and environmental data spanning multiple decades, typically 1992–2021, to capture long-term landscape dynamics and progressive environmental change attributable to human activities.

### Data Acquisition and Preprocessing

Remote sensing data were acquired from freely accessible satellite sources to quantify land use/land cover (LULC) changes. Multispectral imagery from Landsat series (TM, ETM+, and OLI) for select years (e.g., 1992, 2001, 2011, and 2021) was downloaded. Each scene was preprocessed to correct radiometric and geometric distortions, including atmospheric correction, cloud masking, geometric registration to a common coordinate system (WGS84/UTM Zone 43N), and image subsetting to the study area. Ancillary GIS data such as high-resolution topographic maps, watershed boundaries, hydrological layers, and administrative boundaries were compiled from government and open-source repositories to support classification and spatial analysis.

### Field Sampling and Laboratory Analysis

A network of 32 field sampling sites was established across Wular Lake to capture spatial variability in sediment contamination and water quality. Sampling locations were stratified to represent different zones of the lake influenced by major inflows (e.g., Jhelum River), urban interfaces, agricultural catchments, and relatively undisturbed areas. Surface sediment samples (0–5 cm depth) were collected using a stainless steel grab sampler. Samples were air-dried, homogenized, and sieved prior to laboratory analysis. Heavy metal concentrations of Co, Cu, Cr, Mn, Ni, and Zn were determined using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) following acid digestion protocols. Parallel water quality parameters including dissolved oxygen (DO), nitrate, phosphate, and ammoniacal nitrogen were measured using standard APHA methods to characterize nutrient enrichment and eutrophication levels.

**Land Use/Land Cover Classification and Change Detection**

Preprocessed satellite images were classified into major LULC categories — open water, aquatic vegetation, marshland, agricultural land, built-up areas, forest/tree cover, and bare land — using a supervised maximum likelihood classification approach. Classification accuracy was evaluated through ground truthing using field GPS points and historical reference data, and quantified by overall accuracy and kappa statistics. Change detection analysis was performed by comparing LULC maps across different years to quantify the spatio-temporal dynamics of land cover change. Transition matrices were generated to identify conversion trends, such as water area reduction, agricultural expansion, and forest loss. Percent change in each category was computed to assess the magnitude of landscape transformation.

**Spatial Analysis and Mapping**

GIS analysis was conducted to visualize the spatial distribution of environmental degradation indicators. The spatial distribution of heavy metal concentrations in sediments was interpolated using Inverse Distance Weighting (IDW) to produce continuous surface maps showing hotspots of contamination. Overlay analysis integrated LULC change maps with pollution indices to examine spatial correspondence between anthropogenic land cover change and environmental stress. Pollution indices — Contamination Factor (CF), Enrichment Factor (EF), Geoaccumulation Index (Igeo), Pollution Load Index (PLI), and Potential Ecological Risk Index (PERI) — were computed for each sampling location to quantify the extent and severity of contamination relative to baseline or background values. These indices were mapped to delineate zones of high ecological risk.

## STATEMENT OF THE PROBLEM

Wular Lake, situated in the northern region of India in Jammu and Kashmir, is one of the largest freshwater lakes in South Asia and plays a crucial role in regional biodiversity, fisheries, and water regulation. Over the past several decades, the lake has experienced significant environmental stress due to human activities and land use changes in its catchment area. Encroachment for agriculture, urban expansion, and unregulated construction along the lake's periphery have led to the reduction of water spread area, increased sedimentation, and loss of aquatic vegetation. Remote sensing studies indicate that from 2001 to 2021, the water area of the lake decreased by approximately 14.12%, while agricultural land and built-up areas increased by 52.02% and 22.41%, respectively. Simultaneously, forest and shrub cover declined by 40.77% and 11.53%, demonstrating a direct correlation between land use transformation and environmental degradation. The lake also faces chemical and biological pollution. Sediment analysis across 32 representative sites has shown elevated heavy metal concentrations: manganese ranging from 1,046 to 2,041 mg/kg, nickel averaging 78.85 mg/kg, zinc averaging 113 mg/kg, and chromium ranging from 32.62 to 282.5 mg/kg. Pollution indices, including the Pollution Load Index (PLI) of approximately 1.17 and Potential Ecological Risk Index (PERI) around 19.2, reveal moderate contamination, with certain hotspots presenting higher ecological risks. Water quality monitoring has revealed eutrophic conditions with dissolved oxygen levels between 6.42 and 8.68 mg/L and ammoniacal nitrogen concentrations reaching up to 368.32 µg/L, reflecting nutrient enrichment from anthropogenic sources such as untreated sewage, agricultural runoff, and silt-laden inflows from the Jhelum River. These pressures have resulted in spatially heterogeneous degradation, where certain parts of the lake exhibit severe ecological stress while others remain relatively stable. Despite these challenges, systematic spatial analysis integrating multi-temporal land use/land cover changes, sediment contamination, and water quality parameters remains limited. A comprehensive understanding of the patterns, intensity, and sources of anthropogenic impacts on Wular Lake is therefore critical. Without such analysis, effective management, restoration, and policy interventions cannot be accurately designed, leaving the lake vulnerable to further degradation and biodiversity loss. This research aims to fill this gap by employing GIS and remote sensing techniques combined with field-based environmental data to assess spatial patterns of anthropogenic impacts and their correlation with environmental degradation in Wular Lake.

## DISCUSSION

The results of this study reveal that Wular Lake has undergone significant environmental degradation over the last few decades, primarily driven by anthropogenic activities and associated land use changes in its catchment area. Multi-temporal satellite analysis demonstrates a clear trend of declining water spread, with open water area decreasing by approximately 14.12% between 2001 and 2021. This reduction correlates closely with the expansion of agricultural land, which increased by 52.02%, and the growth of built-up areas by 22.41%, indicating encroachment and land conversion as primary drivers of hydrological and ecological stress. The concurrent decline in forest and shrub cover by 40.77% and 11.53%, respectively, suggests widespread deforestation and habitat fragmentation, reducing the landscape's ability to buffer sediment and nutrient inflows into the lake. Sediment analyses highlight the accumulation of heavy metals in specific lake zones, with manganese ranging from 1,046 to 2,041 mg/kg and chromium reaching as high as 282.5 mg/kg. Pollution indices such as the Pollution Load Index (PLI ≈ 1.17) and Potential Ecological Risk Index (PERI ≈ 19.2) indicate moderate contamination overall, although spatial mapping shows localized hotspots, particularly near urban inflows and agricultural runoff zones. The spatial heterogeneity of contamination underscores the influence of point and non-point anthropogenic sources, with upstream river inflows acting as major conduits for sediment-bound pollutants. Multivariate statistical analysis, including cluster analysis and principal component analysis, further confirms that industrial discharges, agricultural fertilizers, and urban waste are the dominant contributors to sediment and water quality degradation.

Water quality measurements reveal nutrient enrichment and eutrophication, with dissolved oxygen levels ranging from 6.42 to 8.68 mg/L and ammoniacal nitrogen concentrations reaching 368.32 µg/L. The negative correlation between nitrate and phosphate concentrations ($r \approx -0.816$) indicates complex biogeochemical interactions influenced by human activities. Spatial overlays of water quality and LULC change maps suggest that areas experiencing high agricultural intensification and urbanization show elevated nutrient loads and reduced aquatic vegetation, leading to localized hypoxia and loss of biodiversity. The integration of spatial and field data highlights the strong link between human land use patterns and environmental degradation. Sediment contamination hotspots coincide with areas of high agricultural runoff and urban encroachment, while reductions in open water area correspond with the expansion of built-up and agricultural zones. These observations suggest that the degradation of Wular Lake is not uniform but concentrated in areas directly affected by anthropogenic pressures. Remote sensing–based change detection, combined with GIS mapping of pollution indices, provides a robust framework for identifying vulnerable zones, which is critical for targeting conservation and remediation efforts. Overall, the findings demonstrate that Wular Lake is under considerable anthropogenic stress, with land use changes, sedimentation, nutrient enrichment, and chemical contamination acting synergistically to degrade its ecological integrity. The spatial analysis confirms that environmental degradation is both temporally progressive and spatially heterogeneous, emphasizing the need for integrated management approaches. Restoration strategies must prioritize controlling sediment and nutrient inflows, regulating land use changes in the catchment, and implementing targeted conservation interventions in identified hotspots to prevent further ecological decline.

## CONCLUSION

The spatial and environmental assessment of Wular Lake reveals that anthropogenic activities over the past decades have caused significant ecological degradation, resulting in a measurable decline in water quality, sediment health, and habitat integrity. Multi-temporal satellite imagery indicates a 14.12% reduction in open water area from 2001 to 2021, accompanied by a 52.02% increase in agricultural land and a 22.41% increase in built-up areas, highlighting land conversion and urban encroachment as primary drivers of hydrological and ecological stress. Concurrently, forest and shrub cover declined by 40.77% and 11.53%, further reducing the lake's natural buffer capacity against sediment and nutrient inflows. Sediment analysis revealed elevated concentrations of heavy metals, with manganese reaching 2,041 mg/kg, chromium up to 282.5 mg/kg, nickel averaging 78.85 mg/kg, and zinc averaging 113 mg/kg. Pollution indices such as the Pollution Load Index (PLI ≈ 1.17) and Potential Ecological Risk Index (PERI ≈ 19.2) confirm moderate contamination, while spatial mapping identified localized hotspots near urban and agricultural inflows. Water quality parameters, including dissolved oxygen levels between 6.42 and 8.68 mg/L and ammoniacal nitrogen concentrations up to 368.32 µg/L, demonstrate nutrient enrichment and eutrophication, which are closely linked to anthropogenic pressures in the lake's catchment. The integration of GIS-based spatial analysis with field and laboratory data highlights the heterogeneous nature of environmental degradation, with hotspots of contamination and eutrophication corresponding to areas of intensive land use and human activity. These findings indicate that Wular Lake's ecological integrity is threatened by the cumulative effects of sedimentation, nutrient enrichment, chemical contamination, and habitat loss.

Effective conservation and restoration strategies must therefore be spatially targeted, focusing on controlling sediment and nutrient inflows, regulating agricultural and urban expansion, and restoring aquatic vegetation and forest cover around the lake. The study demonstrates that combining remote sensing, GIS, and field-based environmental assessment provides a robust framework for monitoring and managing large freshwater ecosystems like Wular Lake. Without immediate and integrated management interventions, continued anthropogenic pressures are likely to exacerbate environmental degradation, threatening the lake's biodiversity, water quality, and the livelihoods dependent on it.

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