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Ripples of Ecological Disarray: A Spatio Temporal Inquiry into River Ecosystem Degradation Under Pollution and Climate Stressors

Vanshri Vyas[1], Dr. Shuchita Chandorkar[2], Dr. Salil Singh[3]

[1]Research Scholar, Dept of Zoology and Biotechnology, Vikram University, Ujjain M.P.
[2]Assistant Professor in Zoology, Govt. Girls P.G. College Ujjain M.P.
[3]Assistant Professor in Zoology and Biotechnology, Vikram University, Ujjain M.P.

Abstract
Access to clean and safe drinking water is a fundamental human right, as recognized by the United Nations General Assembly in 2016. Surface water sources, especially rivers, are critical for human consumption, yet they remain vulnerable to contamination from both natural processes and human activities. Wastewater discharge, industrial pollutants, and climatic variations such as temperature and precipitation significantly impact river water quality on spatial and temporal scales. Aquatic insects serve as reliable biological indicators due to their sensitivity, diversity, and distribution, offering insight into ecosystem health and pollution levels. Traditional water quality assessment relies on comparing measured parameters with established standards, while Water Quality Indices (WQIs) provide a simplified yet comprehensive tool to evaluate and communicate water quality. The development of WQIs involves interdisciplinary methods, including mathematical modeling and artificial intelligence. Seasonal variations and pollution further stress aquatic life, influencing the reproductive success and survival of species like fish. This study emphasizes the importance of continuous water quality monitoring and the application of biological and computational tools to ensure sustainable management of freshwater resources.

Keywords: Surface water quality, River pollution, Water Quality Index (WQI), Aquatic insects, Climate variability, Ecosystem health

INTRODUCTION

Access to clean and safe water for human consumption was declared a human right by the United Nations General Assembly in July 2016 [1]. Since surface water is one of the primary sources of water supply for the population, maintaining its quality is crucial for daily household use. River water sources, in particular, are susceptible to both natural factors and human activities [2]. Pollutants from wastewater discharge and industrial emissions can significantly deteriorate river water quality. Moreover, variations in climate conditions, such as changes in temperature and precipitation across different locations and seasons, result in spatio-temporal fluctuations in river water quality [3,4].One effective method to assess water quality involves the use of aquatic insects as biological indicators. This approach is based on their diversity, abundance, and distribution across various habitats. The presence or absence of specific indicator organisms serves as an important measure to assess the extent of negative impacts on the ecosystem, as well as potential future risks to other living organisms [5].Standard techniques for evaluating water quality (WQ) typically involve comparing experimentally obtained parameter values with established standards, as described by Abbasi and Abbasi (2012b) [6]. Water Quality Indices (WQIs) are used worldwide to simplify complex water quality data. They are particularly valuable in: (a) summarizing the development of various WQIs, (b) assessing the factors that influence parameter selection, (c) identifying limitations, (d) studying the extent of WQI application globally, and (e) analyzing the comparative advantages of different WQIs for international use.The process of developing a WQI is comprehensive, involving methods such as group discussions, expert interviews, mathematical formulations, and even artificial intelligence (AI) algorithms to create robust indices [6]. Seasonal fluctuations in physicochemical parameters, combined with pollution, often exert added stress on aquatic organisms. These variations can hinder biological functions, and changes in water temperature may significantly affect the breeding and survival rates of fish and other aquatic fauna [7,8].

Seasonal and Human Impacts on Water Quality: A Spatio-Temporal Analysis of Rivers and Lakes"

S.No	Authors Name	Year	Findings
1	Arafat Rahman et.al	2021	The study aimed to assess seasonal changes in Turag River water quality, identify pollution sources, and group months by similarity. Results showed only 40% of parameters were within safe limits, with EC, Cl^-, TA, turbidity, DO, BOD_5, and COD consistently high. Industrial discharge and toxic substances were major pollution sources, explaining 94.29% of the variance. Cluster analysis showed the highest pollution occurred in winter. A self-purification trend was observed, with water quality improving from winter to rainy season.[9]
2	Nguyen Tuan Anh et.al	2023	The review aimed to analyze natural and human-induced factors affecting river water quality, focusing on temporal and spatial variations, land use, seasonal changes, and emerging pollutants. It found that both natural processes (e.g., rock weathering, climate events) and human activities (e.g., industrial waste, agriculture) influence water quality. Seasonal changes and land use patterns play a major role, while emerging pollutants like OCPs, PAHs, PCBs, PFASs, and PhACs are rising threats. The study also highlighted differences between urban and rural river systems, offering insights for sustainable water management.[10]
3	Tanushree Chakravarty&Susmita Gupta	2024	The study aimed to examine seasonal distribution and diversity of aquatic insects in the Jatinga River for water quality assessment across five sites over a year. A total of 72 species from 58 genera and 38 families were recorded, with species like Micronecta sp.1, Ptilomera assamensis, and Hydropsyche sparna being

			eudominant. Biotic indices indicated good to clean water at upstream sites (S1, S2), with a decline downstream. Most environmental parameters met BIS and WHO standards, except EC and TDS. PCA and CCA analyses revealed that insect distribution was strongly influenced by riverbed structure and water chemistry.[11]
4	Dheeraj Kumar et.al	2024	The review aimed to evaluate the methodologies and limitations of various regional and global Water Quality Indices (WQIs) and their role in sustainable water resource management. It found that WQIs, in use since the 1960s, effectively simplify complex data for communication and monitoring. However, regional differences in environmental conditions call for tailored WQIs. The study also identified methodological weaknesses in existing approaches and emphasized the need for more structured evaluations. It offers valuable guidance for improving WQIs to better support local and global water quality goals and sustainable development.[12]
5	Nighojkar Abhineet and ER.D. Dohare	2014	The study aimed to assess the water quality of the Khan River in Indore, focusing on the effects of untreated industrial and domestic waste, particularly during monsoon flow into the Kshipra River. Results showed the river is severely polluted (E quality) from source to confluence, mainly due to sewage and industrial effluents. Key parameters like pH, EC, TDS, turbidity, DO, BOD, and COD exceeded safe limits. The pollution poses serious risks to public health and agriculture, especially downstream. The findings highlight the urgent need for effective waste treatment and river management.[13]
6	Shazia Husain & Ram Kumar	2022	The study aimed to monitor the water quality of the Ram Ganga River by analyzing seasonal variations in physicochemical parameters and their impact on aquatic life, particularly fish reproduction and survival. Results showed that seasonal changes in temperature and pH significantly influence biological activity in the river. Pollution from urban and industrial waste has led to a decline in water quality, adversely affecting aquatic biodiversity and fish populations. Variations in water parameters directly impact fish survival and reproduction, threatening overall faunal diversity. This highlights the urgent need for regular water quality monitoring and conservation efforts.[14]
7	S. Sohani et.al	2014	The study aimed to assess the seasonal physico-chemical variability of water in Sirpur Talab near Indore to evaluate its suitability for drinking and domestic use. Results showed significant seasonal changes in key parameters like dissolved oxygen, total hardness, calcium, and magnesium. Several

			samples exceeded WHO permissible limits, indicating the water is not safe for direct consumption without treatment. The findings emphasize the need for regular monitoring and better management to ensure water safety.[15]
8	Anima Upadhyay & Chandrakala M	2017	The study aimed to assess the water quality of the River Ganga at Rishikesh by analyzing key physicochemical parameters and calculating the Water Quality Index (WQI). Parameters like pH, alkalinity, hardness, conductivity, calcium, magnesium, and TDS were measured and compared with WHO and ISI standards. The WQI provided a single, comprehensive value reflecting overall water quality, offering a clear and simplified assessment to support effective monitoring and management decisions.[16]
9	Hassan Shaheed et.al	2024	The study aimed to develop machine learning models for classifying and predicting Water Quality Index (WQI) using data from rivers in India, Iraq, and Malaysia. Using 32 water quality variables, classifiers like XGBoost, Naive Bayes, SVM, and AdaBoost were applied, with XGBoost achieving the highest classification accuracy (93%), precision (92%), and recall (97%). For prediction, the M5 Model Tree outperformed other regression models. The results highlight the potential of advanced ML techniques as reliable tools for accurate water quality assessment and effective resource management.[17]
10	Shraddha Vaishnav et.al	2017	The study aimed to assess the water quality of the Shivnath River in Durg District by analyzing physicochemical and biological parameters to evaluate pollution from industrial and human activities. Results showed high levels of temperature, turbidity, color, BOD, COD, total hardness, pH, TDS, and TSS, indicating significant pollution. Biological analysis also confirmed water quality deterioration. The findings underscore the major impact of industrial discharge and development on river health, emphasizing the urgent need for effective pollution control and sustainable management strategies.[18]
11	D. N. Gatlewar et.al	2024	The study aimed to evaluate the water quality of Khudawadi Dam using the National Sanitation Foundation's Water Quality Index (WQI) to determine its suitability for drinking and irrigation. Based on key parameters like pH, the WQI provided a clear, 100-point scale assessment of water health. The results effectively classified the water's condition and demonstrated that WQI is a valuable tool for simplifying complex data and supporting informed water management decisions.[19]
12	Arief Dhany Sutadian et.al	2016	This paper aimed to review global Water Quality Indices (WQIs), analyze their development methods, and suggest improvements for creating accurate, region-specific WQIs. Reviewing 30

			indices, the study identified 7 commonly used ones and noted that government support plays a key role in their adoption. It highlighted the importance of expert input in parameter selection and weighting to reduce subjectivity. The paper also found that uncertainty and sensitivity analyses are often lacking but essential for improving WQI reliability, recommending their inclusion—along with expert consensus methods like the Delphi technique—in future WQI development.[20]
13	Ashwini D. Toraskar et.al	2022	The study aimed to evaluate seasonal variations in water quality and microbial pollution in the Mandovi and Zuari estuaries in Goa, focusing on Water Quality Index (WQI) and antibiotic resistance in bacteria. Results showed 'poor' water quality in pre- and post-monsoon seasons, and 'good' quality during the monsoon due to rainfall-induced dilution. Microbial pollution was highest pre-monsoon but declined afterward. Notably, bacteria isolated during the monsoon exhibited the highest antibiotic resistance, indicating potential health risks despite improved water quality. The study underscores the need for continuous monitoring and effective management of estuarine health.[21]
14	Atul Kumar Sinha et.al	2021	The study aimed to analyze seasonal variations in the water quality of the River Gandak in Bihar during the monsoon by examining key physicochemical parameters. Results showed significant changes in turbidity, electrical conductivity, sulphate, phosphate, free CO_2, and total iron, largely due to increased surface runoff and catchment influences. These findings highlight the role of both natural and human-induced factors in shaping the river's water quality during the monsoon season.[22]
15	Trupti Kamble et.al	2016	The study aimed to evaluate spatial and short-term seasonal variations in groundwater quality in Jaipur district, Rajasthan, during pre- and post-monsoon periods, assessing its suitability for drinking and irrigation. Using WHO standards, USSL diagrams, and statistical tools, the study found significant seasonal and spatial differences, with most parameters showing non-normal distributions influenced by rainfall recharge. Strong correlations were noted among EC, TDS, sodium, and chloride. T-tests revealed significant changes in six parameters pre-monsoon and in nitrate post-monsoon. Overall, the groundwater was deemed unsuitable for drinking and irrigation, highlighting the need for urgent water quality management.[23]
16	Sayanti Kar et.al	2022	The study aimed to assess the seasonal and tidal effects on pollutant distribution in the River Ganga (Hooghly) near five major outfalls, using GIS and statistical tools to model pollutant

			dispersion and zones of influence. Results showed higher concentrations of DO, BOD, nitrate nitrogen, and chloride in the pre-monsoon season. GIS mapping and t-tests confirmed significant seasonal differences, while regression analysis revealed strong correlations between fecal coliform and heavy metals. Acoustic Doppler profiling and the Plug Flow Model enabled accurate discharge and water quality estimates. The study provided a predictive model to aid future water quality management and policymaking.[24]
17	Sanal Kumar Adityaa	2024	The study aimed to systematically investigate the geochemical processes and hydrochemical characteristics of the Periyar River Basin (PRB), assessing water suitability for drinking, irrigation, and industrial use across different seasons. Results showed calcium and magnesium dominated the cationic composition, while chloride and bicarbonate were the main anions. Water was mostly transitional in type, with rock-water interaction identified as the primary factor influencing water chemistry. Elevated pCO_2 levels indicated anthropogenic impacts. The Water Quality Index (WQI) ranged from excellent to unsuitable, with significant seasonal and spatial variation. Most water samples were suitable for irrigation, except in some lowland areas.[25]
18	H. V. Vyas and V. A. Sawant	2008	The study aimed to examine seasonal variations in borewell drinking water quality in Kolhapur city during 2005–2006, assessing compliance with WHO and BIS standards across summer, rainy, and winter seasons. Analysis of parameters such as pH, EC, DO, alkalinity, chloride, TDS, hardness, calcium, magnesium, and sulphate revealed that some exceeded permissible limits, indicating potential health concerns. Significant seasonal fluctuations in water quality were observed, highlighting the influence of climate on groundwater composition[26].
19	Rachna Bhateria & Disha Jain	2016	The study reviewed how population growth, urbanization, and land use changes impact lake water quality, focusing on issues like nutrient enrichment, pollution, and eutrophication. It found that nutrient runoff, heavy metals, plastic waste, and algal blooms are major threats to lake ecosystems. Assessment tools such as the Water Quality Index, Hyperion imaging, and Hazard Quotient were identified as effective. The study recommends pollution control, water reuse, and nutrient recycling in urban agriculture to safeguard freshwater resources.[27]
20	Edovia Dufatanye Umwali et.al	2021	The study assessed spatio-seasonal variations in water quality of Lake Muhazi, Rwanda, in relation to land use/land cover (LULC) using NSF-WQI, PCA, Cluster Analysis, and PLS-PM. Poor

			water quality was found at sites like Mugorore, Butimba, and Bwimiyange, varying by season. PCA highlighted seasonal water quality changes, while Cluster Analysis grouped samples by LULC. PLS-PM revealed a strong positive correlation between LULC and water quality during the rainy season (+0.831) and a negative correlation in the dry season (−0.542), with cropland having a major impact. The study emphasizes that human land use significantly affects lake water quality and recommends sustainable land management and protective buffer zones around the lake.[28]
21	Narasimman Manickam et.al	2018	The study investigated the impact of seasonal changes on zooplankton biodiversity in Ukkadam Lake, Coimbatore, from December 2011 to November 2012, using zooplankton as an ecological indicator of lake health. A total of 28 species were recorded, with Rotifera being the most dominant group (35%), followed by Cladocera and Copepoda (29% each), and Ostracoda (7%). Zooplankton density peaked in summer and was lowest during early monsoon. The study concluded that rising temperatures in summer enhance zooplankton productivity, suggesting climate change may affect lake biodiversity. Zooplankton diversity was affirmed as a valuable bioindicator of water quality and fishery potential.[29]
22	Xiaotong Wen et.al	2020	The study evaluated the effectiveness of current microbial indicators, such as E. coli and total coliforms, for assessing drinking water quality, with a focus on China. It found that waterborne diseases like diarrhea continue despite water testing, suggesting current indicators may lack sensitivity and reliability. Many countries are adopting alternative indicators, including enteric viruses and protozoa, for improved accuracy. In China, the testing is limited mostly to pathogenic E. coli and protozoa, highlighting a need to expand and enhance microbial monitoring systems to better protect public health.[30]
23	Kadarshahib Roshinebegam et.al	2014	The study assessed seasonal variations in the physico-chemical parameters of the Periyar River, Tamil Nadu, from February 2012 to January 2013, to understand their impact on aquatic productivity and plankton distribution. Water samples from six stations during dry and wet seasons showed that most parameters like temperature, pH, EC, TDS, DO, and nutrients met IS 10500:2004 standards, though some exceeded IS:2296 limits. The findings provide an important baseline for river remediation and management, emphasizing the influence of seasonal changes on water quality.[31]
24	R.EUGENE	2016	The study examined the Lukha River's seasonal water quality in

	LAMARE and O. P. SINGH		Meghalaya, focusing on the unusual deep blue color seen in winters. Results showed that mining, cement production, and deforestation in the catchment have led to water quality deterioration. Some sites were classified as having 'poor' water quality according to the CCME-WQI, indicating significant human impact on the river's health and appearance.[32]

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