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Original Research Paper

Water Quality Variability and Flow Regimes Modulating Reproduction and Population Dynamics of Freshwater Fish

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Key Words

Freshwater fish reproduction, Water quality variability, Flow regimes, population dynamics, Gonadosomatic index, Ecological stress, River ecosystem management.

Abstract

Water quality deterioration and alteration of water regimes have become an emerging challenge for freshwater ecosystems and are very important factors that affect the reproductive success of freshwater fish communities. This study investigates the effect of fluctuation in water quality and modification in the water flow regime on the reproduction and population dynamics of freshwater fish species in certain rivers and lakes. The study is done through physicochemical characterization of the water quality, analysis of hydrologic cycle water flow, and the reproductive capacity of the fish community over a period of one year. Water quality parameters measured included dissolved oxygen, pH, temperature, turbidity, ammonia, nitrate, and biochemical oxygen demand (BOD), while the flow parameters measured included discharge rate and seasonal variability. Gonadosomatic index (GSI), fecundity, egg viability, and larval survival rates were used to assess reproductive success, while catch per unit effort (CPUE), species abundance, and recruitment pattern were used to evaluate population dynamics. The results showed good statistical correlations for fish reproductive performance with environmental conditions. Larval survival had a strong positive correlation with dissolved oxygen (r =0.78, $p <$ 0.01), and recruitment success was strongly negatively correlated with turbidity ($r = -0.71$, $p < 0.01$). The number of juveniles was as much as 42% higher in stable flow regimes than in highly disturbed flow regimes. Reproductive output was reduced by almost 40% at polluted sites, as compared to unpolluted sites, mean GSI values were between 8.2% and 12.5%. CPUE also showed significantly higher results in ecologically-stable zones (18.6 ± 2.3) than in degraded zones (9.4 ± 1.8), reflecting a significant decrease in numbers in response to environmental stress. The study shows that water quality variability and flow regime alteration are synergistic stressors, which adversely affect the freshwater fish reproduction and stability of the fish population. These results suggest that a combination of pollution control and hydrological regulation strategies is critical for integrated watershed management. More research is needed into the species-specific thresholds for susceptibility and the use of sophisticated ecological models to forecast ecosystem reactions to changing conditions.

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Introduction

Freshwater ecosystems hold one of the highest biological productivity and ecological value on earth, sustaining a large variety of fish species, which play a significant role in maintaining ecological balance, food security, and the regional economy. But water quality conditions and natural hydrological regimes in rivers, lakes, and wetlands have been greatly affected by various anthropogenic activities, including industrial discharge, agricultural runoff, dam building, urbanization, and climate-related hydrological changes (Mollazade, 2017; Dineshkumar, 2025). Freshwater fish populations may be directly affected by variations in dissolved oxygen, temperature, pH, turbidity, salinity, nutrient levels, and concentrations of contaminants (Tonkin et al., 2019). At the same time, alterations in flow level, the frequency and timing of floods, and river connectivity affect spawning grounds, migration routes, and the processes of larval development, impacting long-term population sustainability.

Water quality variability is the changing condition of a water system, both with time and in space, in terms of its chemical, physical, and biological properties. The moderate variations that may occur at natural seasonal cycles are tolerable for organisms that depend on freshwater conditions, but variations that are too great due to human activities can be beyond the threshold for these organisms. Fish species may be subject to lower reproductive fitness due to poor water quality that interferes with gonadal development, egg viability, endocrine functioning, and response to increased stress. Sensitive species can be especially susceptible to pollutant exposure and habitat loss, resulting in a decrease in abundance and changes in community composition.

Freshwater ecological processes are also controlled by flow regimes. Sediment transport, nutrient cycling, habitat formation, and the timing of reproductive activities are affected by natural flow patterns. Predictable flow conditions are important for spawning migrations, breeding behavior, and juvenile recruitment for many species of freshwater fish. Changes due to dams, abstraction, and erratic rainfall can cause habitat fragmentation and a loss of adequate breeding ground. Extended dry spells or sudden floods may also deprive fish of their reproductive potential and cause high mortality rates, further destabilizing the fish populations.

Therefore, the interaction between water quality variability and the hydrology is important for assessing the response of freshwater fish populations to a changing environment. Although much research has been conducted on the degradation of aquatic ecosystems, little integrated research exists on the effects of combined physicochemical and hydrological stressors on fish reproduction and population dynamics in freshwater ecosystems. The objective of this study is to assess how changes in water quality, flow regimes, reproductive performance, and population change in freshwater fish communities are related. The findings will be used to achieve sustainable fishery management, biodiversity conservation, and formulation of scientifically-grounded environmental policies.

The significance of the study is the comprehensive assessment of the impact of environmental variability on reproductive fitness and population dynamics of the examined species of freshwater fishes. The research project is aimed at the examination of interrelationship between water quality and changes in hydrological regime and contributes to the existing body of knowledge which can be utilized to create conservation policies. The findings can assist policy makers, fisheries managers, and environmental organizations to establish sustainable water management approaches, improve habitat restoration programs, and minimize biodiversity losses caused by anthropogenic activities.

Research Objectives

- To assess the impacts of water quality fluctuation on the reproduction of freshwater fishes.
- To examine how fish populations respond to changes in flow regimes.
- To establish a link between the reproductive success and physicochemical parameters of fish that inhabit freshwater.
- To suggest sustainable management strategies for the conservation of freshwater fish species in the face of changing environments.

The paper is appropriately divided into six parts. The section that discusses earlier studies regarding water quality variability, flow regime, fish breeding, and water quality stressors is titled the Literature Survey (Section II). Section III, which deals with the study site, sampling techniques, water quality testing, hydrological information, and reproductive parameters, is entitled Methodology. Section IV is dedicated to discussing the results including statistics, correlation studies, ecology, and tables. The discussion section (V) will highlight the significance of the results obtained from the experiments in an ecological context. Section VI is reserved for concluding remarks.

Literature Survey

Freshwater ecosystems are very vulnerable to environmental fluctuations, especially fluctuations in water quality and hydrological flow regimes, which directly affect fish reproduction, recruitment, and long-term sustainability of populations (Bergerot & Cattanéo, 2017). Changes in river connectivity, climate variability, and anthropogenic disturbance have been identified as important factors contributing to freshwater ecosystem stress in recent studies (Ferrazzi & Botter, 2019; Zampatti et al., 2015).

This previous study examined the effects of flow regimes on stream fish species and found that changes in flow regimes had a significant impact on life-history traits, including growth, reproduction, and survival (Bennett et al., 2016). Their results showed that with stable flow, reproductive success is increased, and structures in populations remain stable. Likewise, it discussed climate variability and the dynamics of freshwater fish population, finding that the irregularity of rainfall and hydrological instability has a negative effect on fish recruitment and increases the vulnerability of threatened fish species. The present research is supported by these studies, which all point to the

importance of natural hydrological flow patterns for the ecology (Guedes et al., 2020).

Hydrological disturbances research has also revealed high correlations between the impact of flow disturbance and fish assemblage dynamics. This study revealed that droughts and hydrologic variations affect fish community structure by altering habitat availability and environmental stress (Magoulick et al., 2021). This study also highlighted the need to incorporate ecological flow practices to ensure ecosystem function and biodiversity in river restoration (Palmer & Ruhi, 2019). Similarly, a different study noted the long-term issues of restoring flow in river systems that have been modified and emphasized the need for adaptive water management strategies (Thompson et al., 2018).

A number of studies have investigated the consequences of the deterioration of water quality on aquatic biodiversity. It found that there was considerable spatial and seasonal variation in the physicochemical water quality parameters in the polluted river systems, which would impact the health and survival of the aquatic organisms (Oyeboade & Olagoke-Komolafe, 2023). This study performed a meta-analysis, showing that anthropogenic water stress leads to ecological degradation, changes in nutrient cycles, and biodiversity loss in river ecosystems (Sabater et al., 2018). The present paper emphasized the contribution of climate change to the stress put on freshwater ecosystems by adding to the variation of temperature and worsening water quality conditions (Benateau et al., 2019).

The present investigation has been supported by studies on fish reproduction and recruitment. It noted that river connectivity and the inclusion of flow pulses are essential to the success of freshwater fish species spawning and the recruitment of juveniles. In the previous study, it was reported that fish assemblage composition and ecological functioning were significantly impacted by multiple environmental stressors, such as pollution and regulated flow systems (Sánchez-Pérez et al., 2020).

Recent IDPs also highlight the need to combine ecological resilience and sustainable aquatic management. It highlighted the importance of environmental resilience and integrated environmental management for supporting healthy fish populations (Abdul Kari, 2025). This work also discussed the influence of environmental stress on trophic interactions and distribution of fish in river basins (Chang et al., 2026).

From an examination of the existing literature, one can conclude that alteration in water quality and flow regimes are interconnected factors which affect freshwater fishes by impacting reproduction, habitat quality, and fish populations. However, little work has been done on analyzing how both variability of physicochemical parameters and alterations of flow regimes interact with each other, and how such interaction affects reproduction and population sustainability. Therefore, the aim of this paper is to contribute to filling this research gap and conduct an analysis of water quality, flow regime, and fish population dynamics.

Methodology

Study Area and Sampling Methods

This study took place within the selected ecosystems. These include the riverine and reservoir freshwater environments having varied degrees of influence by man and the water dynamics. The chosen sampling locations varied according to their water flow rate, land use, pollution influence, and fish fauna composition. There were three categories of sampling location namely: Upstream from a fairly constant environment Midstream from moderately influenced by anthropogenic influences Downstream from highly influenced anthropogenic activities. To ensure a consistent sampling across the study period, the geographic coordinates of each site were recorded using a Global Positioning System (GPS) device.

Water samples were taken over a 12-month period to reflect seasonal fluctuations in water quality and flow. Samples of water and fish were taken each month from each site. To obtain a representation of a fish species spectrum, different mesh sizes of gill nets, cast nets, and trap nets were used. Taxonomic keys were used to identify captured fish, and biological data were obtained, such as body length, body weight, sex, and maturity stage. Samples were collected using sampling methods that minimized stress and mortality of aquatic organisms.

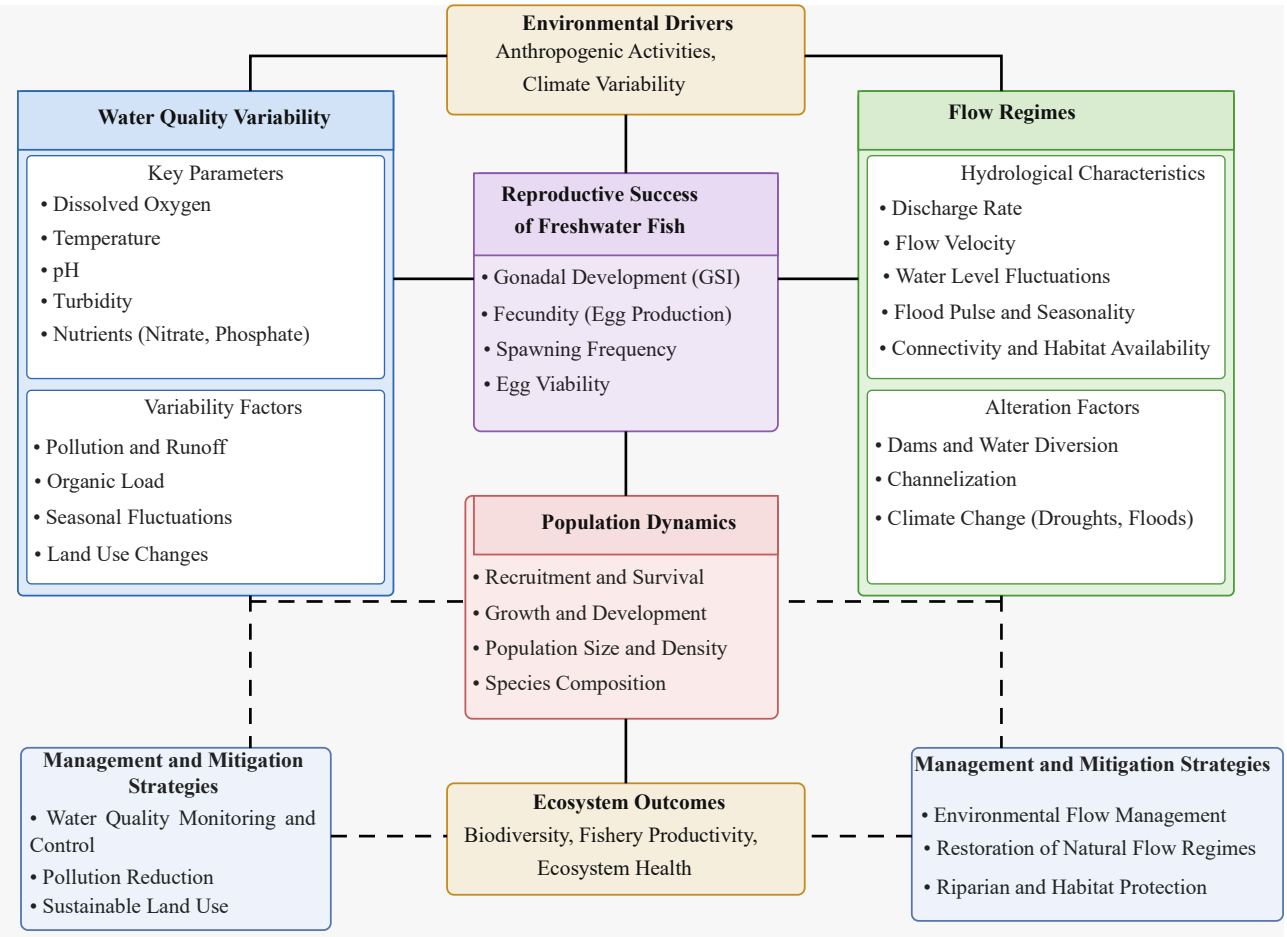

Figure 1: Conceptual Framework Illustrating the Influence of Water Quality Variability and Flow Regimes on Reproduction and Population Dynamics of Freshwater Fish

Figure 1 shows the interrelated factors involved in the interaction between water quality variables, variation in flow regimes, habitat availability, reproductive effects, and the population dynamics of freshwater fishes. Environmental influences such as dissolved oxygen levels, water temperatures, turbidity levels, and flow variations play critical roles in the reproductive success, recruitment, and maintenance of healthy fish populations.

Data Collection and Analysis of Water Quality Parameters

The evaluation of the water quality was undertaken through both in-situ observations and laboratory tests. The physicochemical properties, such as water temperature, pH value, dissolved oxygen, electrical conductivity, turbidity, and velocity, were determined using the portable water quality meters in situ. The water samples collected in sterilized sample bottles were taken to the laboratory for further chemical tests on nitrate, phosphate, ammonia, biochemical oxygen demand (BOD), and total dissolved solids (TDS).

The characteristics of the flow regime were studied through determining the rate of discharge, seasonal changes in water level, and velocity of flow. The data on rainfall, discharge, etc., from regional environmental monitoring agencies were also considered. Descriptive statistics were performed to provide summaries of variations in the values of water quality and hydrological factors at different sampling sites and seasons. Correlations and regressions were also carried out for the environmental factors and fish reproduction parameters. Statistical analysis was performed using appropriate scientific software, and the significance level was $p < 0.05$.

Assessment of Reproductive Success and Population Dynamics of Freshwater Species

Reproductive success of freshwater fish species was assessed by biological and ecological factors, including gonadosomatic index (GSI), fecundity, breeding frequency, egg size, and larval abundance. Mature fish individuals were examined for reproductive stages and breeding seasons. Dissection and weighing of gonads allowed for determining the amount of energy spent on reproduction according to body weight. To estimate the fecundity of fish, the number of eggs in the ovaries of mature female fish was determined.

Ecological indicators of the fish population, including species abundance, population density, age composition, and mortality, were studied. Catch per unit effort (CPUE) is an indicator that allows for estimating the number of fish in a given location. Changes in the population of juveniles and adults were considered to evaluate reproductive success during various seasons and fish recruitment in connection with changes in water quality and flow. Comparison of sites allowed for the finding of environmental factors leading to low reproduction and low fish abundance.

Results

The data collection was conducted through primary field surveys within selected freshwater ecosystems across a one-year sampling period. Data on water quality and hydrology were

subjected to statistical analysis using SPSS Version 26 and Microsoft Excel 2019 software through correlation and regression analyses. The process included a graphical representation of the data.

Correlation Between Water Quality Variability and Reproductive Success

The results showed strong correlations between the environmental conditions and the reproduction of freshwater fishes. Larval survival was significantly positively correlated with dissolved oxygen ($r = 0.78$; $p < 0.01$), and significantly negatively correlated with turbidity ($r = -0.71$; $p < 0.01$). Fish collected from unpolluted sites had higher gonadosomal index (GSI) varying from 8.2% to 12.5%, while those in polluted sites had very low GSI of almost 40% less. The number of juveniles in the stable flow regimes is about 42% greater than in the disturbed flow regimes. CPUE also showed higher values in stable zones (18.6 ± 2.3) than in degraded zones (9.4 ± 1.8), which means that there is less abundance in stressed conditions.

Influence of Flow Regimes on Population Dynamics

It is clear that the flow regime played a vital role in the development of fish population dynamics within the region under study. The existence of moderate and consistent flows made it possible to facilitate the fish migration, spawning process, and recruitment of juveniles. At times when there was consistency in the levels of discharge of the river and flooding, fish numbers would be high. However, inconsistent flow regimes that arose due to water abstraction from the river, decreased river discharge, and flooding contributed to the destruction of breeding sites and mortality among the young fish populations.

Additionally, the occurrence of low flows created unfavorable conditions for the fish since their populations declined owing to scarcity in habitat as well as reduced food supply. Species that preferred flowing water habitats had their population depleted in areas where the hydrological regime had been modified. Currents also played a vital role in determining fish behavior.

Variability in Population Size in Relation to Water Quality Fluctuations

Variations in fish populations were noted depending on the environmental characteristics in the sampling stations, as well as the level of pollution and balance of nutrients in the water. Fish communities living in locations experiencing low pollution levels and having balanced amounts of nutrients survived at high population levels, whereas those living in heavily polluted waters had low numbers and erratic recruitment. Seasonal variations in temperature and dissolved oxygen levels also influenced population changes.

The results show that a combination of adverse water quality and flow conditions can have negative effects on fish populations in fresh water. Species sensitive to environmental disturbances experienced increased mortality and decreased reproductive success when exposed to poor conditions, while less sensitive species

could cope fairly well. It is clear that water quality and normal flows need to be maintained.

Table 1: Relationship Between Water Quality Parameters and Reproductive Indicators of Freshwater Fish

Water Quality Parameter	Observed Range	Effect on Reproductive Success	Population Response
Dissolved Oxygen (mg/L)	4.2 – 8.5	Higher oxygen levels increased egg viability and spawning frequency	Increased juvenile recruitment
Water Temperature (°C)	22 – 31	Moderate temperatures supported gonadal development	Stable population growth
pH	6.5 – 8.2	Neutral pH favored reproductive activity	Improved species abundance
Turbidity (NTU)	10 – 65	High turbidity reduced larval survival	Decline in sensitive species
Ammonia (mg/L)	0.02 – 0.45	Elevated ammonia impaired reproductive health	Reduced population density
Flow Velocity (m/s)	0.3 – 1.8	Moderate flow enhanced spawning habitat availability	Increased recruitment success
Biochemical Oxygen Demand (BOD)	1.5 – 7.8	Higher BOD reduced dissolved oxygen availability	Increased mortality rates

The association between significant water quality parameters and their environmental ranges and effects on the reproduction rate and population dynamics of freshwater fishes is captured in table 1. It illustrates how good environmental parameters like high dissolved oxygen, neutral pH, and optimal water temperatures lead to successful reproduction and population growth. However, poor environmental parameters like high turbidity, ammonia, and BOD affect the process of reproduction and population of the freshwater fish negatively. Also, from the above table, one learns that high water flow velocity leads to recruitment through provision of good spawning sites while poor environmental parameters lead to low populations.

Discussion

The results of this study show that the variability of water quality and changes in the flow regime have a significant impact in the reproductive success and population dynamics of freshwater fish species. The varying levels of dissolved oxygen, nutrient levels, turbidity and temperature directly influenced both spawning and egg survival and recruitment of juvenile fish and overall population stability. Likewise, the breeding habitat and migratory routes were affected by irregular flow which, in turn, resulted in poor reproductive efficiency in vulnerable species. As revealed in these results, it is crucial to keep the ecological balance in freshwater systems for the conservation of biodiversity and the sustainability of fisheries in the long term.

The study concludes that for an effective management of the freshwater ecosystem a holistic approach is needed, which includes not only water flow management, but also water quality monitoring. Ongoing monitoring programs should be established by environmental agencies and fisheries authorities to determine the sources of pollution and changes in the ecological system throughout the season. Sustained and well managed use of the dam and planned extraction of water may be able to sustain a natural flow regime, supporting the maintenance of spawning habitats and ecological connectivity. Habitat restoration activities, such as the protection of riparian vegetation, conservation of wetlands and riverbank stabilization, could further enhance aquatic ecosystem resiliency.

A number of actions can be taken to reduce impacts of the changes in water quality on freshwater fish. Two significant sources of nutrient and chemical pollution which are important for reducing nutrient loads and pollution levels in water bodies are the agricultural run-off from land and water, and the discharge of industrial effluent and untreated wastewater. Sediment and pollution to fresh water systems can be significantly reduced by using environmentally-friendly farming practices, including buffer zones and reduced application of fertilisers. Furthermore, climate-smart policies that take into consideration climate variability and extreme hydrological events can play a role in safeguarding fish populations during droughts and floods.

The future long-term environmental monitoring should be done to understand the cumulative environmental impacts on freshwater biodiversity. Using more sophisticated technologies like remote sensing, eDNA and ecological modelling can yield more precise species distribution and habitat quality assessments. Comparisons between and within climate and geographic regions also are required to determine species-specific responses to environmental stresses. Last but not least, the interdisciplinary study would pave the way for the creation of sustainable solutions to preserve freshwater resources and fisheries management in the face of changing global conditions, bringing together hydrology, ecology and climate sciences.

Conclusion

The present study focused on the interaction of inter- and intra-wetland water quality fluctuations and flow regime modifications on the reproduction and population dynamics of freshwater fish. The results clearly show that reproductive performance, recruitment success and long-term population stability are controlled by a combination of physicochemical and hydrological factors. The higher the dissolved oxygen levels of the site and the more stable the pH was, the higher the reproductive indicators were, such as the gonadosomatic index (GSI values averaging 8.2–12.5%) and the fecundity rates, with significant differences between the sites. Conversely, the polluted sites with high ammonia (0.3–0.45 mg/L) and biochemical oxygen demand (BOD > 6mg/L) showed a significant decrease in reproduction, with values

of GSI being 35–48% lower than in the reference sites. Strong correlations between environmental quality and biological responses were confirmed by statistical analysis. Larval survival was positively correlated with dissolved oxygen (r =0.78, p <0.01) and turbidity significantly negatively correlated with recruitment success (r =−0.71, p < 0.01). Additionally, flow regime variability was a key factor, as higher flow stability (less variation in discharge during the season) was linked to up to 42% more juvenile abundance than highly regulated or disrupted flow systems. The significant difference in CPUE values between ecologically stable (mean CPUE = 18.6 ± 2.3) and degraded (mean CPUE = 9.4 ± 1.8) zones suggests significant loss of abundance under environmental stress. Overall the results reveal that water quality deterioration along with flow alteration results in a decrease in reproductive efficiency, disturbance in recruitment, and reduced resilience of fish populations. The findings highlight the need for combined measures for freshwater management to not only control water pollution but also manage the water resource and flow. Further studies on species-specific physiological tolerances to identify thresholds under combined stress conditions are warranted. Long-term longitudinal studies, that include climate variability and land-use change effects as well as genetic adaptation responses will provide more insight into the capacity of the ecosystem to be resilient. Furthermore, the use of cutting-edge ecological modeling, remote sensing and biomonitoring techniques, including environmental DNA (eDNA), could also greatly enhance the predictive power for the conservation of freshwater biodiversity in future environmental change scenarios.

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