INTEGRATED ASSESSMENT OF WATER POLLUTION: LINKING PHYSICOCHEMICAL INDICATORS, AQUATIC BIOASSESSMENT, AND HUMAN HEALTH RISK

Sushma MV*, Adarsh Ramanagouda Malawade**, Baladev DR**, Dyuthi Yashavanth**, Meghana MC**

** Department of Artificial Intelligence and Machine Learning, Malnad College of Engineering, Hassan, India*

*** Department of Artificial Intelligence and Machine Learning, Malnad College of Engineering, Hassan, India*

Email: smv@mcehassan.ac.in

Abstract: Water pollution affects the physical and chemical condition of water, the structure of aquatic communities, and the health of populations that depend on contaminated resources. This paper presents a literature-based synthesis of four surveyed studies addressing water-quality parameters, macroinvertebrate bioassessment, human-health risks, and water pollution in India. The reviewed literature identifies urban sewage, industrial discharges, agricultural runoff, sediment transport, mining-related inputs, geogenic contaminants, and emerging pollutants as relevant sources. The synthesis highlights the complementary roles of physical and chemical measurements and biological indicators. Physical and chemical parameters provide information about water conditions at the time of sampling, whereas biological communities can reflect ecological stress over longer periods. Human-health interpretation requires additional consideration of contaminant concentration, exposure route, duration, and population vulnerability. Based on these findings, an integrated assessment framework is proposed to connect pollution-source identification, physicochemical monitoring, biological assessment, and human-exposure screening. The study is secondary research and does not report new field measurements or laboratory results. The proposed framework is intended to guide the design of locally relevant monitoring programmes, particularly where a single water-quality indicator would provide an incomplete assessment.

Keywords - Water pollution, water-quality assessment, physicochemical parameters, macroinvertebrates, bioassessment, human-health risk, India.

I. INTRODUCTION

Water is essential to domestic life, agriculture, industrial activity, and the maintenance of aquatic ecosystems. Its availability alone does not determine whether a resource is suitable for use; its physical, chemical, and biological condition is equally important. The entry of untreated wastewater, industrial effluents, agricultural chemicals, sediments, and other contaminants can alter water quality and restrict its beneficial uses. Pollution may also arise from natural processes, including geological interactions and climate-related events [1].

The surveyed literature approaches this issue from complementary perspectives. Misman et al. [1] review the physical, chemical, and biological parameters used to assess water quality. Xu et al. [2] investigate the use of macroinvertebrate communities as indicators of river condition. Babuji et al. [3] discuss human-health risks associated with different forms of water contamination, while Sadhu [4] provides an overview of pollution categories, sources, effects, and control measures in the Indian context. These studies collectively indicate that water pollution cannot be adequately described by one measurement or one disciplinary perspective.

II. REVIEW OF SURVEYED LITERATURE

A. Physicochemical and Biological Parameters

Misman et al. [1] classify water-quality indicators into physical, chemical, and biological groups. Physical measurements discussed in the review include turbidity, temperature, colour, electrical conductivity (EC), total suspended solids, and total dissolved solids (TDS). Chemical indicators include pH, nutrients such as ammoniacal nitrogen and phosphorus, dissolved oxygen (DO), oxygen-demand measures, and selected metals. Biological assessment considers microorganisms and their abundance or diversity. The review also describes metagenomic analysis as a culture-independent means of characterising microbial communities.

The value of this classification is that different pollution sources produce different measurable effects. Runoff and erosion may increase turbidity and suspended material, nutrient inputs may alter nitrogen and phosphorus concentrations, and organic discharges may contribute to oxygen depletion. Consequently, parameter selection should be guided by the suspected source and the intended use of the water rather than by a fixed measurement list applied without context.

B. Macroinvertebrates as Bioassessment Indicators

Xu et al. [2] studied macroinvertebrate communities at river sites with different pollution conditions and substrate characteristics. Their assessment included taxa richness, density, total and average Biological Monitoring Working Party scores, and the family biotic index. The study reports that macroinvertebrate composition differed across water-quality conditions, with some taxa associated with better conditions and others more frequently observed at heavily polluted sites.

The study supports combining biological and chemical approaches. Chemical measurements can indicate the concentration of selected substances at the time of sampling, whereas biological communities can reflect the combined effects of environmental pressures. However, indicator taxa and index thresholds are sensitive to geography, habitat, substrate, and local ecological conditions. The taxa reported for Chinese rivers in [2] should therefore not be assumed to represent validated indicators for Indian rivers without local study.

C. Human-Health Implications

Babuji et al. [3] review health concerns related to anthropogenic and geogenic contamination, heavy metals, microplastics, and pharmaceutical residues. The review emphasises that risk interpretation depends on the hazard as well

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as the degree and route of exposure. Relevant assessment steps include identifying the hazard, estimating exposure, determining contaminant concentration, and applying an appropriate dose-response model.

The review discusses metals including arsenic, cadmium, chromium, lead, mercury, nickel, copper, and zinc, alongside emerging contaminants such as microplastics and pharmaceutical compounds. The presence of a contaminant alone does not establish a particular health outcome. Concentration, exposure frequency, duration, route, and the characteristics of the exposed population are needed for a defensible risk assessment [3].

D. Water Pollution in India

Sadhu [4] describes surface-water, marine, groundwater, microbiological, and macroscopic pollution. The dissertation also distinguishes point sources, such as identifiable discharge outlets, from non-point sources that contribute contaminants through diffuse runoff. Sewage, industrial waste, agricultural inputs, solid waste, and geogenic groundwater contaminants are discussed as relevant concerns in India. Since the dissertation dates from 2021 and includes historical statistics, those figures are not treated here as current national estimates. Its contribution is used primarily for source classification and the India-focused context.

III. RESEARCH METHODOLOGY

A. Research Design

A qualitative literature-synthesis design was adopted. The four supplied documents were treated as the source set and examined under five themes: pollution sources, physicochemical parameters, biological response, human health implications, and management measures. The work is not presented as a systematic review because a comprehensive database search, formal screening protocol, and risk-of-bias assessment were not performed.

B. Thematic Extraction and Synthesis

Information was extracted from each document according to its main contribution. The parameter review [1] provided the monitoring categories; the macroinvertebrate study [2] contributed ecological assessment concepts; the health-risk review [3] informed the exposure perspective; and the India-focused dissertation [4] provided local source and control themes. The themes were then compared to identify complementary roles and limitations.

C. Methodological Limitations

The source set contains documents with different research designs, publication dates, and geographical contexts. The studies do not provide a common dataset suitable for statistical pooling. The biological indicator findings in [2] are specific to the investigated rivers, and the older statistics in [4] require verification before being used to describe present-day conditions. The conclusions are therefore analytical and conceptual rather than site-specific.

IV. PROPOSED INTEGRATED ASSESSMENT FRAMEWORK

The synthesis leads to a framework that connects four assessment dimensions: pollution source, water-quality condition, ecological response, and human exposure. The framework is intended to guide the organisation of a local monitoring programme rather than function as a new regulatory index.

A. Source Identification

The first step is to identify likely pollution sources and the pathways by which contaminants enter the water body. Point sources may include sewage-treatment outlets and industrial discharge pipes. Non-point sources may include agricultural runoff, urban stormwater, and sediment transport. Natural and geogenic contributions should also be considered, particularly in groundwater investigations [1], [3], [4].

B. Physicochemical Monitoring

The second step is to select physical and chemical measurements according to the suspected pressure. Turbidity, temperature, EC, and TDS can help describe physical conditions, while pH, DO, nutrients, oxygen demand, and selected metals can provide chemical information. Microbiological testing is relevant where sewage or faecal contamination is suspected. Results should be interpreted against applicable standards and the intended use of the water [1].

C. Biological Assessment

Where ecological condition is part of the study objective, macroinvertebrate sampling can complement water chemistry. Suitable local taxa, sampling methods, habitat conditions, and seasonal factors should be documented. Metrics such as taxa richness, abundance, and an appropriately calibrated biotic index may be used to compare sites. The approach is supported by [2], but local reference data are required before applying a biological classification in a different river system.

D. Human-Exposure Screening

The fourth step considers how people may contact the water, including drinking, cooking, bathing, irrigation, or consumption of aquatic food. Any health-risk assessment should use measured contaminant concentrations and documented exposure assumptions. Hazard identification must be distinguished from a quantified estimate of risk, as emphasised in [3].

E. Management Response

Management priorities should address the identified source. Possible measures include sewage collection and treatment, industrial effluent control, improved agricultural nutrient and pesticide management, erosion control, safe waste disposal, and protection of groundwater sources. Follow-up monitoring is necessary to determine whether the intervention improves chemical condition and biological response [1], [3], [4].

V. DISCUSSION

The four sources demonstrate why water-quality evaluation benefits from more than one evidence stream. Physicochemical monitoring is necessary for identifying changes in selected parameters, but a sample represents a particular location and time. Pollution may vary with rainfall, flow, season, or discharge activity. Biological observations can provide evidence of ecological response over a longer period, although they are also influenced by habitat and natural variability. Interpreting both types of evidence can provide a more complete understanding than either alone [1], [2].

Biological indicators also require chemical and habitat context. A change in taxa richness or community composition may reflect pollution, but it may also be influenced by substrate alteration, flow changes, or other environmental pressures. Chemical testing helps investigate possible causes, while habitat observations help interpret the ecological signal. The findings of Xu et al. [2]

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support this combined approach, but their specific taxa associations should not be transferred directly to other regions.

Ecological impairment and human-health risk are related but distinct. A pollutant may affect aquatic organisms without necessarily producing a high human exposure through drinking, while a groundwater contaminant may create a human-health concern even where surface-water indicators are not informative. As discussed by Babuji et al. [3], exposure pathway, concentration, and duration must be considered before drawing conclusions about health risk.

For Indian water-quality studies, source identification should account for local land use, sewage infrastructure, industrial activity, agricultural practices, and geology. The categories in [4] provide a useful starting point, but current claims about pollution levels should be based on contemporary, location-specific monitoring data. The framework proposed here is therefore best viewed as a structure for designing field studies and organising evidence, not as a substitute for current regulatory monitoring.

VI. RECOMMENDATIONS AND FUTURE SCOPE

Monitoring programmes should select parameters based on likely pollution sources and intended water use, repeat sampling across relevant seasons, and interpret biological indicators using locally appropriate reference conditions. Sewage and industrial discharges should be controlled at source, while agricultural runoff and erosion require catchment-level management. Where groundwater contamination is suspected, both geogenic and human-related pathways should be examined. Health-risk communication should distinguish the detection of a hazard from evidence of actual exposure and quantified risk.

Future work can apply the framework to a selected river or groundwater system in India. A field investigation could compare upstream, discharge-adjacent, and downstream sites; measure a consistent set of physicochemical parameters; record land use and habitat; and conduct macroinvertebrate sampling where suitable. If contaminants of health concern are detected, a separate exposure assessment should be undertaken using current standards and accepted risk-assessment methods. Such a study would provide primary evidence that is not available in the four surveyed documents.

VII. CONCLUSION

This paper synthesises four surveyed documents to develop an integrated view of water-pollution assessment. The literature identifies natural and human-related sources of contamination and demonstrates the importance of physical, chemical, and biological measurements. Macroinvertebrate bioassessment adds ecological evidence, while human-health interpretation requires concentration and exposure information. The proposed framework links source identification, physicochemical monitoring, biological assessment, and human-exposure screening to support more complete local investigations. Since this work is based on secondary sources and contains no new field measurements, its framework requires validation through site-specific monitoring before operational use.

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