

Eco-chemical Health Assessment of River Basuhi and Groundwater Quality Evaluation in its Basin Jaunpur, Uttar Pradesh

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Water contamination is due to urbanization, agricultural waste, landfill leachate, urban runoff, farmland, and industrial development; have led to various environmental concerns that are impacting human health and nature globally. In recent decades, there has been growing concern about the quality of river water due to heterogeneous inputs from various human activities. The surface water bodies near industrial and urban areas are experiencing significant negative impacts on their ecological and morphological aspects. There is a need for a robust method to assess ecological integrity to address societal concerns about sustainable water resource management. Aquatic ecosystem assessment should encompass the physical, chemical, biological, and hydrological aspects.

The entire work presented in this thesis has been arranged into nine sections, the conclusion/summary of each section given below.

The water quality of the River Basuhi was analyzed to assess its suitability for drinking and agricultural purposes with reference to physicochemical characteristics. The abundance of cations in River water were found to be in order of; $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ during pre as well as post monsoon seasons. In terms of anions, the abundance was observed in the order of $\text{SO}_4^{2-} > \text{HCO}_3^- > \text{Cl}^- > \text{NO}_3^- > \text{PO}_4^{3-} > \text{F}^-$ in both the seasons. The observed ionic behaviors can be linked to the anthropogenic inputs and chemical weathering. Water Quality Index (WQI) inferred a variation in water quality and it range from 'moderate' to 'very poor' category. Irrigation suitability parameters (permeability index, Kelly ratio, soluble sodium percentage, sodium adsorption ratio, chloro-alkaline index, and magnesium adsorption ratio) revealed that the water at most of the sampling sites is suitable for irrigation. Multivariate approaches such as principal component analysis (PCA) and correlation analysis (CA) were indicated variations in water quality due to multiple sources of contamination.

The physicochemical analysis of groundwater of Basuhi River Basin (BRB) revealed significant variability among various water quality parameters. The pH of water in BRB was found to be neutral to slightly alkaline in nature. Most of the parameters were found within the acceptable limit, while fluoride in 5.82% and nitrate in 29.41% were exceeded the standard limit given by WHO (2017) and BIS (2012). Higher concentration of F^- and NO_3^- in drinking water poses the risk of fluorosis, and methemoglobinemia, respectively. Water quality index of groundwater indicated that

the water quality 76.47% of samples was acceptable for drinking, whereas, 23.52% unacceptable for drinking. Irrigation water quality parameter; SAR was found in safe zone at all the locations, while, 17.64% of samples was unsuitable for irrigation in terms of KR. SSP found in excellent to unsuitable, CAI indicated unsuitability for irrigation due to calcium and magnesium imbalances. The PCA reflected that electrical conductivity and salinity influenced the water quality with hardness, calcium, magnesium, sulfate, and chloride ions. A strong Pearson correlation was observed between EC, TDS, Na^+ , and Ca^{2+} .

The physicochemical characteristics of River sediment was also evaluated during pre and post-monsoon seasons. In pre-monsoon season pH and EC were found to be slightly acidic to moderately alkaline and moderate saline, respectively. While, in Post-monsoon season pH and EC experienced slight decrease most likely due to dilution after rainfall. Higher sand proportion and OM in River sediment highlighted decomposition and hydrodynamic conditions. PCA revealed higher loading of EC, TDS, sand, and Na^+ during pre-monsoon season, whereas in post-monsoon season it was highly loaded with EC, Na^+ , and silt. A strong correlation was observed between EC and TDS in both the seasons, confirming the impact of dissolved ions on the sediment quality of the River.

Heavy metals (Al, Fe, Cr, Mn, Cd, Ba, and Pb) concentration of river Basuhi in water and sediments have exceeded the permissible limits recommended by WHO (2017) and BIS (2012). Various heavy metals indices such as Heavy Metal Pollution Index (HPI), Degree of Contamination (C_{deg}), Heavy Metal Evaluation Index (HEI), Pollution Load Index (PLI), Geo-accumulation Index (I_{geo}), and Potential Ecological Risk Index (PERI) were evaluated in water and sediments. HPI, HEI, and C_{deg} in 40, 80, and 90% of water samples fell in the high-risk category which confirms that the river water quality is highly contaminated by the HMs and needs serious attention for its protection. In sediment PERI, and I_{geo} , revealed that the cadmium and Cobalt are prime causes. PLI at all locations were found greater than 1 which reflects the high risk category. The PCA and correlation studies reflected that the Basuhi River is affected by various anthropogenic activities particularly agricultural, industrial, and municipal waste.

The dissolved heavy metals in Basuhi River water at 18 locations and are locations of River Varuna revealed variability in their concentrations. The average concentrations of heavy metals in water of River Basuhi were found to be in the order of Al (409.27) > Sr (374.33) > Fe (139.61) > Ba (63.59) > Zn (49.63) > Mn (14.15) > Cr (5.79) > As (4.56) > Ni (4.08) > Pb (3.73) > Cu (1.98) > Se (0.39) > Ag (0.23) > Co (0.19) > Cd (0.17). HPI, HEI, and C_{deg} were also evaluated in River water with reference to dissolved metals. HPI at all locations, while HEI in 76.47 and C_{deg} in 77.7% of samples was found to be in 'risk' category. Five extracted principal components were found responsible for 99% of the total variance. PC1 influenced by Al, Fe, and Sr, PC2 by Sr and Zn and negative loading with Al, while other PCs were dominated by Fe, Zn, and Ba, reflecting distinct sources of metals. Positive correlations were found between Mn with Fe, Fe with Co, Co with As, Se with Zn, Sr with Zn, suggesting similar sources, and negative correlations reflects between Cr with Mn, Se and Ba, indicated competitive interactions with multiple sources.

The concentration of studied metals in groundwater at Basuhi River basin was found to be within the permissible limits prescribed by the WHO (2017) and BIS (2012), except for Al (409.27), Mn (14.15), and Pb (3.73). The PCA and correlation studies confirmed the geogenic origin of heavy metals. Regular heavy metal monitoring is recommended to ensure the safe drinking water and to minimize associated health risks. Further, outcomes may be referred to assess the probable ecological, economic, and health implications of future development around the river basins sharing similar geographical and climatic conditions.

The diversity and heavy metal accumulation of submerged macrophytes was also analyzed in River Basuhi. *Potamogeton pectinatus* was widely distributed species at all surveyed locations except one, indicate its adaptability and potential resilience in varying conditions, whereas *Crassula helmsii* was least dominant indicating specific habitat requirement and can be considered as sensitivity species. The heavy metal accumulation among different macrophytes indicates notable variations in between the species. *Carex atherodes* and *Eichhornia crassipes* showed high accumulation of Cr and Mn respectively, while *Lemna minor* accumulated the highest concentration of Pb and *Hydrilla verticellata* recorded the lowest levels of Co and Cd, suggesting a lower affinity for these metals. The average heavy metal concentrations across all the species underscore diverse uptake mechanisms and varying metal

accumulation capacities, reflecting the species' ecological niches and environmental interactions. Findings are crucial in identification of bioremediation potential, management of riverine ecosystem, and targeted conservation strategies to address metal pollution.

The FTIR spectra revealed a complex mineralogical composition in river sediments, dominated by quartz and kaolinite, with the presence of calcite and magnesium oxalate suggesting diverse sediment sources and depositional processes. Minerals; chlorite, sepiolite, quartz, orthoclase, gibbsite, kaolinite, albite, magnesium oxalate, and calcite were found present in the River Basuhi. Functional groups; Si-O-Si, C-O, H-O-H, and C=O were identified in the sediments representing presence of organic and inorganic materials. Findings shall be helpful in understanding the geological formations, pollutant transport, and environmental dynamics within the riverine ecosystem.

Microplastic contamination in the River poses significant risks to both environment and human health. FTIR analysis identified five polymers; Polyvinyl chloride (PVC), Vinyl chloride (VC), High Density Polyethylene (HDPE), Polystyrene (PS), Nylon, and Cellulose acetate (CA) in river water and sediments. SEM-EDS analysis was applied to confirm morphology and elemental compositions (carbon, phosphorus, and chlorine) of encountered microplastic polymers. Microplastics adversely affect the various ecological processes taking place in the river. Further, they not only adversely affect aquatic life but also act as excellent substrate for a number of chemical reactions.

An eco-friendly, efficient, and cost-effective biochar obtained from Radish leaves (raw and chemically modified) was applied for the removal of fluoride from an aqueous medium. Fluoride removal efficiency of Chemically Modified Biochar (CMB) was found to be more than double as compared to Raw Biochar (RB). The batch adsorption study showed that the maximum adsorption was 30 and 79 % using 0.6 g/L dose of RB and CMB, respectively. FTIR spectra experienced the variations in peaks obtained before and after adsorption confirming fluoride adsorption. Elemental composition exhibited successful impregnation of $MgCl_2$ in CMB prepared from radish leaves powder. Hydrogen bonding, fluoride complexation and electrostatic attraction were found to be major mechanisms involved in fluoride

removal. Thermodynamic studies and kinetic isotherms also validated the obtained data. Findings provide a low-cost alternative to address the problem of fluoride pollution and may also be helpful in handling the wet bio-waste.

De-fluoridation using combination of bio-waste and geo-materials (Sphagnum Peat Moss & Clay Cup) revealed good adsorption properties/efficiency. Scanning Electron Microscope (SEM) analysis demonstrated the increased surface roughness and expansion after fluoride adsorption. Energy Dispersive X-rays (EDX) analysis showed the reduction in the atomic weight (%) due to binding of fluoride with elements like Al, K, and Pt. The particle size of adsorbent was found in the range of 100 to 680 nm, providing sufficient surface area for adsorption. XRD patterns confirmed the crystalline nature of CCSPM, with consistent peak values before and after adsorption. FTIR spectra indicated shifts in functional group peaks, further confirming fluoride adsorption. Noticeably, fluoride removal was significantly affected by the factors like pH, time, dose, concentration, and temperature. The adsorbent obtained from the SPMCC demonstrated the effective fluoride adsorption with potential applications in water treatment processes.

Challenges and Future Direction

- ✓ Advance monitoring technologies are required for the collection of comprehensive and real-time data to bridge the gaps existing in river health assessment.
- ✓ Most of the findings done by researchers across regions lack standardized methods. Data conflict to compare one finding to another at a similar place.
- ✓ Human interference (Construction, Land use changes, and Industrialization) creates dynamic conditions that make it difficult to monitor the quality of the River and its management.
- ✓ Coordination among government agencies, local communities, industries, and environmental organizations is required for successful River rejuvenation programs.

- ✓ Advanced treatment technologies are expensive and difficult to implement in rural or low-income areas. Efforts are needed to explore eco-friendly and economic options.
- ✓ Development of water treatment methods that effectively address multiple contaminants simultaneously without causing secondary challenges.
- ✓ Sustainable methods for safe disposal or recycling of adsorbent materials are a critical challenge in the water treatment process, which need to be addressed judiciously

Recommendation

- ✓ Coordinated efforts are needed to maintain river water and groundwater systems to ensure sustainable water use, groundwater recharge, restoration of natural water flow patterns, and presence ecological balance.
- ✓ Strengthening pollution control network is required to ensure that the effluents are properly treated before being discharged into the river.
- ✓ Designing and Implementation of stringent regulations to reduce plastic waste discharge into aquatic environments, coupled with public education campaigns to minimize the use of single-use plastics and promote proper disposal methods.
- ✓ Develop and install community-scale fluoride removal systems that utilize locally available bio-geo-waste materials, ensuring accessibility of safe drinking water at affordable rates to the rural and low-income areas.
- ✓ Urgent need to promote active collaboration between stakeholders, policymakers, leaders, researchers, and residents for effective implementation of better data collection and specific decision-making for holistic solutions to address water quality.
- ✓ Raise public awareness campaigns about the importance of river health and groundwater quality and highlight mitigate adverse impacts on human health, agriculture, and ecosystems to foster responsible water usage.