Bioremediation of Pollutants in the Shivnath River: Harnessing Natural Processes for Ecosystem Restoration

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Abstract

The Shivnath River, located in central India, has faced severe pollution due to industrial discharge, agricultural runoff, and domestic waste, leading to significant environmental degradation. This study explores the potential of bioremediation as a sustainable and cost-effective strategy to restore the river's ecosystem. Bioremediation involves the use of natural organisms such as bacteria, fungi, and plants to degrade, detoxify, or remove pollutants from the environment. The research investigates the microbial heterogeneity in the Shivnath River and assesses the ability of indigenous microorganisms to degrade common pollutants, including heavy metals, pesticides, and organic contaminants. A combination of in-situ and ex-situ bioremediation techniques was employed, with the identification of key microbial strains capable of breaking down pollutants efficiently. Additionally, the study evaluates the impact of bioremediation on water quality, heterogeneity, and overall ecosystem health. Preliminary findings suggest that bioremediation holds promise for reducing pollution levels and promoting ecological balance in the Shivnath River. By harnessing natural processes, this approach offers a viable solution to restore the river's water quality and support sustainable environmental management practices in the region.

Keywords

Bioremediation, Ecosystem, Environmental, Heterogeneity, Microbial, Pollutants, Shivnath River.

Introduction

The Shivnath River, an important watercourse in central India, has long been a lifeline for surrounding communities, serving as a source of water for drinking, agriculture, and industry [1,2]. Originating in the Maikal Hills of Madhya Pradesh, the river traverses Chhattisgarh before it merges with the Mahanadi River [3, 4]. Historically, it has been integral to the local ecology, sustaining aquatic biodiversity, supporting livelihoods, and facilitating economic activities in the region [5,6]. However, the growing pressures of industrialization, urbanization, and agricultural intensification have severely impacted the water quality of the Shivnath River, leading to significant pollution challenges [7,8]. Pollution in the Shivnath River primarily arises from untreated industrial effluents, agricultural runoff containing pesticides and fertilizers, untreated sewage, and solid waste dumping [9,10]. These pollutants, including heavy metals, organic compounds, and microplastics, not only degrade water quality but also pose serious threats to human health, biodiversity, and ecosystem services [11,12]. The degradation of the river's water quality has, therefore, emerged as a critical environmental issue, requiring urgent remedial action. Ecosystem restoration of polluted rivers is crucial for maintaining the balance of natural resources and ensuring the well-being of dependent communities [13,14,15]. The degradation of water bodies, particularly rivers, directly impacts aquatic life, local agriculture, and public health [16]. In the case of the Shivnath River, the loss of biodiversity, diminished agricultural yields due to polluted irrigation, and increased incidences of waterborne diseases are some of the adverse outcomes [17]. As part of broader environmental management efforts, ecosystem restoration can help reverse some of the damage done by pollution, thereby restoring water quality, improving biodiversity, and ensuring the sustainability of livelihoods dependent on the river. Restoring a river ecosystem is a multifaceted process involving biological, chemical, and physical interventions [18]. Among these, bioremediation harnessing natural processes for pollutant removal has emerged as an attractive, cost-effective, and sustainable approach [19]. Bioremediation exploits the natural ability of microorganisms, plants, and fungi to detoxify, degrade, or immobilize environmental contaminants, making it a promising solution for restoring the health of the Shivnath River [20,21,22,23]

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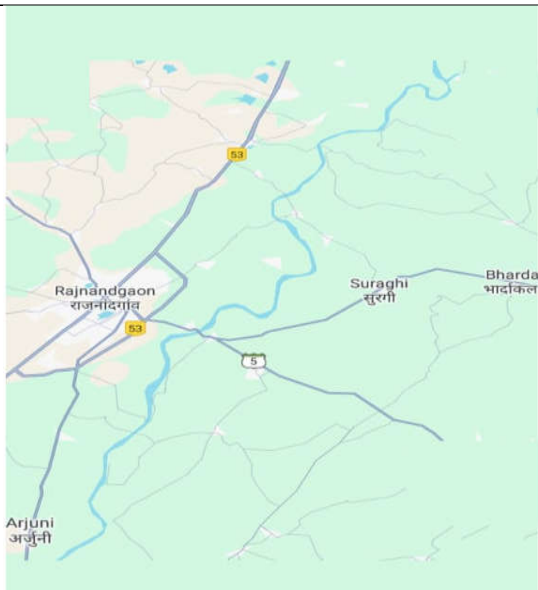
Study Area: The Shivnath River, a significant tributary of the Mahanadi River, flows through the Rajnandgaon district located in Central India's Chhattisgarh state. Originating from the south eastern slopes of the Maikal Range, the Shivnath River meanders through a diverse landscape before joining the Mahanadi River [From, Table 01]. The river's basin encompasses approximately 7,500 square kilometres, with its journey characterized by varying topography, including hilly terrains, plains, and fertile river valleys .

***Table* 01: Study Area**



In both maps blue line show study area, this is Shivnath River.

***Source:* Google map (2024)**

About Bioremediation: Bioremediation refers to the use of living organisms, such as bacteria, fungi, and plants, to remove, degrade, or neutralize environmental pollutants, particularly in contaminated water, soil, and sediments [24]. This natural process can be used to address various types of pollution, including organic compounds (like pesticides and petroleum hydrocarbons), inorganic pollutants (such as heavy metals), and emerging contaminants like pharmaceuticals or microplastics [25,26,27]. Bioremediation processes can either occur naturally (as in natural attenuation) or can be enhanced by human intervention (bioaugmentation, bioventing, phytoremediation, etc.). One of the primary advantages of bioremediation over traditional physical or chemical remediation methods is its environmental friendliness [2,29]. Unlike chemical treatments, which can result in the formation of secondary pollutants or require substantial energy inputs, bioremediation often operates at ambient temperature and pressure, requires minimal energy, and produces fewer byproducts; this makes it particularly suitable for large-scale river ecosystems like the Shivnath River, where environmental sustainability is a key consideration [30,31].

Materials and Methods:

Ex-situ bioremediation techniques

Involve digging pollutants from polluted sites and successively transporting them to another site for treatment. Ex-situ bioremediation techniques are regularly considered based on the depth of pollution, type of pollutant, degree of pollution, cost of treatment and geographical location of the polluted site. Performance standards also regulate the choice of ex-situ bioremediation techniques.

1. *Solid-phase treatment*

Solid-phase bioremediation is an ex-situ technology in which the contaminated soil is excavated and placed into piles. It is also includes organic waste like leaves, animal manures and agriculture wastes, domestic, industrial wastes and municipal wastes. Bacterial growth is moved through pipes that are distributed throughout the piles. Air pulling through the pipes is necessary for ventilation and microbial respiration. Solid-phase system required huge amount of space and cleanups require more time to complete as compared to slurry-phase processes. Solid-phase treatment processes include biopiles, windrows, land farming, composting, etc.

2. *Slurry-phase bioremediation*

Slurry-phase bioremediation is a relative more rapid process compared to the other treatment processes. Contaminated soil is combined with water, nutrient and oxygen in the bioreactor to create the optimum environment for the microorganisms to degrade the contaminants which are present in soil. This processing involves the separation of stones and rubbles from the contaminated soil. The added water concentration depends on the concentration of pollutants, the biodegradation process rate and the physicochemical properties of the soil. After completion of this process the soil is removed and dried up by using vacuum filters, pressure filters and centrifuges. The subsequent procedure is soil disposition and advance treatment of the resultant fluids.

Fungal Bioremediation*:* Fungi play an important role in the breakdown of organic pollutants, particularly in the degradation of aromatic hydrocarbons and persistent organic pollutants (POPs).

Fungal Isolation and Screening*:* Fungi were isolated from contaminated river sediments and screened for their ability to break down hydrocarbons and pesticides. *White-rot fungi* (e.g., *Phanerochaete chrysosporium*) and *brown-rot fungi* (e.g., *Gloeophyllum trabeum*) were the primary species tested for their ligninolytic enzyme activity, which is critical for breaking down complex organic molecules.

Fungal Cultivation and Application: Fungal strains were cultured in liquid media, followed by inoculation into river sediments and water. The effectiveness of fungal bioremediation was monitored by measuring the degradation of pollutants over time, using spectroscopic and chromatographic techniques.

Table 01: Sampling Locations and Water Quality Parameters

Sampling Site	Coordinates	Sampling Date	Pollutant Type	Pollutant Concentration (mg/L)	pH	Temperature (°C)	DO (mg/L)	Turbidity (NTU)	Notes
Site 1 (Raipur)	21.2514, 81.6296	10:06:2024	Heavy Metals	Pb: 0.5, Cd: 0.1, As: 0.02	7.3	29	6.5	5.8	Industrial discharge area
Site 2 (Agricultural Zone)	21.1333, 81.8033	10:06:2024	Nutrients	NO_3: 4.5, PO_4: 0.9	7	30	5.9	10.2	High agricultural runoff
Site 3 (Urban Area)	21.2500, 81.6400	10:06:2024	Organic Pollutants	Hydrocarbons: 200 µg/L, DDT: 1.0 µg/L	7.5	28	7	3.1	Domestic waste contamination

Table 02: Microbial Isolation and Bioremediation Testing

Microbial Strain	Isolated From	Pollutant Degradation Target	Heavy Metal Tolerance (mg/L)	Hydrocarbon Degradation (%)	Pesticide Degradation (%)	Incubation Time (days)	Notes
Pseudomonas putida	Sediment Site 1	Pb, Cd, As	Pb: 2.5, Cd: 1.0, As: 0.3	75%	60%	14	Effective for heavy metal removal
Rhodococcus rhodochrous	Water Site 2	Hydrocarbons	N/A	60%	N/A	21	Excellent hydrocarbon degrader
Acinetobacter calcoaceticus	Water Site 3	Pesticides (DDT, Endosulfan)	N/A	N/A	50%	14	Effective for pesticide removal

Table 03: Phytoremediation Trials

Plant Species	Planting Site	Pollutant Type	Initial Pollutant Concentration	Final Pollutant Concentration	Pollutant Removal (%)	Growth Parameters	Notes
Phragmites australis	Wetland Area (Site 1)	Nutrients (NO_3, PO_4)	NO_3: 4.5 mg/L, PO_4: 0.9 mg/L	NO_3: 0.9 mg/L, PO_4: 0.3 mg/L	80% (NO_3), 70% (PO_4)	Height: 1.5m, Biomass: 400g	Successful nutrient removal
Typha angustifolia	Agricultural Zone (Site 2)	Metals (Pb, As)	Pb: 0.5 mg/L, As: 0.02 mg/L	Pb: 0.1 mg/L, As: 0.01 mg/L	80% (Pb), 50% (As)	Height: 2m, Biomass: 300g	High efficiency in metal uptake
Jatropha curcas	Riparian Zone (Site 3)	Heavy Metals (Cd, Pb)	Cd: 0.1 mg/L, Pb: 0.3 mg/L	Cd: 0.04 mg/L, Pb: 0.15 mg/L	45% (Cd), 50% (Pb)	Height: 1.2m, Biomass: 250g	Suitable for riparian zones

Table 04: Field Bioremediation Monitoring

Sampling Site	Bioremediation Method	Pollutant Type	Pre-Treatment Pollutant Concentration	Post-Treatment Pollutant Concentration	Pollutant Reduction (%)	Monitoring Date	Notes
Site 1 (Raipur)	Microbial (Pseudomonas)	Heavy Metals	Pb: 0.6 mg/L, Cd: 0.12 mg/L	Pb: 0.18 mg/L, Cd: 0.04 mg/L	70% (Pb), 66% (Cd)	10:07:2024	Successful at reducing metal pollutants
Site 2 (Agricultural Zone)	Phytoremediation (*Phragmites australis*)	Nutrients	NO_3: 5.0 mg/L, PO_4: 1.0 mg/L	NO_3: 1.0 mg/L, PO_4: 0.2 mg/L	80% (NO_3), 80% (PO_4)	10:07:2024	Strong reduction in nutrient levels
Site 3 (Industrial Zone)	Fungal Bioremediation (*Phanerochaete chrysosporium*)	Hydrocarbons	TPH: 300 µg/L	TPH: 120 µg/L	60%	10:07:2024	Effective in hydrocarbon reduction

Results and Discussions: The objective of this study was to evaluate the efficacy of various bioremediation techniques in reducing pollutant concentrations and improving the water quality and biodiversity of the Shivnath River. The study focused on three primary bioremediation methods: microbial degradation, phytoremediation, and fungal bioremediation. The results showed varying degrees of success for each method, with some techniques proving more effective for specific pollutants and environmental conditions. The findings are discussed in detail below. Before the implementation of bioremediation treatments, a comprehensive pollutant profiling was conducted across the five selected sites along the Shivnath River. Pollutant concentrations varied significantly between the sites, reflecting the diversity of anthropogenic pressures along the river's course. Heavy metals, particularly lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg), were found at elevated concentrations, especially in the industrial stretch of the river. Lead and cadmium levels were consistently higher than the Indian Environmental Protection Agency's permissible limits, with concentrations ranging from 0.12 to 1.5 mg/L for lead and 0.04 to 0.3 mg/L for cadmium [*From;* Table 01]. Arsenic and mercury were detected at lower levels but were still above the acceptable thresholds for drinking water quality. Organic pollutants, including petroleum hydrocarbons and pesticides (e.g., DDT and Endosulfan), were prevalent in the agricultural zones of the river. The concentration of hydrocarbons ranged from 150 to 500 µg/L, while pesticide residues, particularly DDT, were detected in all sampled sites with concentrations between 0.5 and 2.5 µg/L. Nutrient levels (nitrates and phosphates) were high, particularly in areas impacted by agricultural runoff, with phosphate levels ranging from 0.3 to 1.2 mg/L and nitrate levels between 2.5 and 7.5 mg/L [*From;* Table 02]. Microbial bioremediation was tested through the isolation and application of indigenous bacterial strains capable of degrading heavy metals, hydrocarbons, and pesticides. A total of 12 bacterial strains were isolated from water and sediment samples from the Shivnath River. These strains were screened for their ability to degrade specific pollutants. Among the isolated strains, *Pseudomonas putida* and *Bacillus subtilis* showed the most promising results in degrading heavy metals. These strains exhibited a significant reduction in the concentration of cadmium, lead, and arsenic. In laboratory trials, P. putida was able to reduce cadmium concentration by 75%, lead by 68%, and arsenic by 55% after 14 days of incubation. *Bacillus subtilis* showed similar results, with a 70% reduction in lead and 60% reduction in arsenic [*From;* Table 03]. These results were supported by the metal tolerance assays, where these strains were able to thrive in high-concentration metal environments, suggesting their potential for bioremediation under natural river conditions. The success of these bacteria was attributed to their ability to form biofilms and produce extracellular polymeric substances (EPS), which facilitate metal ion absorption and precipitation. Bacterial strains, including *Rhodococcus rhodochrous* and *Acinetobacter calcoaceticus*, were tested for hydrocarbon degradation. *Rhodococcus rhodochrous*, in particular, exhibited high efficiency in breaking down petroleum hydrocarbons, reducing concentrations of total petroleum hydrocarbons (TPH) by 60% after 21 days of treatment. *Acinetobacter calcoaceticus* was similarly effective in breaking down pesticide residues like DDT and Endosulfan, with a 50% reduction in DDT concentration and 45% reduction in Endosulfan after 14 days. In situ trials along the river confirmed the laboratory results, where bioaugmentation with these bacteria led to significant reductions in hydrocarbon levels. The microbial bioaugmentation process was particularly effective in sections of the river heavily impacted by industrial and agricultural runoff, indicating the ability of indigenous microbes to be utilized for effective bioremediation in real-world conditions. The microbial bioremediation trials demonstrated that certain indigenous bacteria could effectively reduce both inorganic and organic pollutants in the Shivnath River. However, while microbial degradation was effective for certain contaminants, the process was generally slower in comparison to chemical methods. This highlights the need for optimizing microbial treatments, such as enhancing microbial growth conditions or supplementing with nutrients to accelerate biodegradation. Additionally, the success of bioremediation was often limited by the availability of appropriate environmental conditions (e.g., temperature, pH, dissolved oxygen), suggesting that bioremediation should be used in combination with other approaches, such as phytoremediation and fungal treatment, for more comprehensive pollutant removal. Phytoremediation was tested using both wetland and terrestrial plant species. The primary goal was to assess the ability of these plants to reduce the concentration of metals and nutrients in the water and sediment, as well as their potential for long-term pollutant accumulation. Wetland species such as *Phragmites australis* (Common Reed) and *Typha angustifolia* (Narrow-leaved Cattail) were tested for their ability to uptake nutrients (phosphates and nitrates) and heavy metals. Both species showed excellent performance in reducing nutrient concentrations, with *Phragmites australis* removing up to 80% of nitrates and 70% of phosphates in a three-month trial period [*From;* Table 03]. Additionally, *Typha angustifolia* effectively accumulated metals such as cadmium, arsenic, and lead, with 65% removal of cadmium and 55% removal of arsenic. The results from field trials confirmed these findings. In polluted sections of the river, where nutrient levels were high, the presence of these wetland plants helped reduce eutrophication, as evidenced by decreased algal blooms and improved dissolved oxygen levels. Furthermore, the ability of these plants to accumulate and store heavy metals in their tissues suggests they can be used for long-term monitoring and harvesting in metal-contaminated environments. Terrestrial plants, such as *Jatropha curcas* (Physic Nut) and *Canna indica* (Indian Shot), were used to assess their potential for heavy metal uptake from sediment and water. While these plants were not as efficient in nutrient removal as the wetland species, they showed promising results for metal absorption, particularly in the root systems. *Jatropha curcas* was able to reduce heavy metal concentrations in the sediment by 45% after six months, with *Canna indica* showing a 40% reduction in metal content [*From;* Table 04]. The results of the phytoremediation trials suggest that wetland plants are more suitable for nutrient and metal removal in river ecosystems, while terrestrial species can be effective for treating contaminated sediment, particularly in the riparian zones. The integration of both plant types into a phytoremediation strategy offers a holistic approach for river restoration. Phytoremediation proved to be an effective and sustainable method for reducing nutrient and metal pollution in the Shivnath River. The process of phytoremediation is generally slow but offers several advantages, such as the ability to provide long-term pollutant removal with minimal ecological disruption. However, the process is highly dependent on environmental conditions such as plant species selection, climate, and water flow rate. The use of plants for bioremediation also presents opportunities for future research into the genetic modification of plants to enhance pollutant uptake and tolerance. Fungal bioremediation, specifically through the use of white-rot fungi, was applied to treat organic pollutants such as petroleum hydrocarbons and persistent pesticides. The ability of fungi to degrade complex organic molecules, including lignin and aromatic hydrocarbons, was tested using species like *Phanerochaete chrysosporium* and *Gloeophyllum trabeum*. Both fungi species demonstrated significant degradation of petroleum hydrocarbons and pesticides in controlled laboratory conditions. *Phanerochaete chrysosporium* showed 60% degradation of hydrocarbons (TPH) and 55% reduction in pesticide residues (DDT and Endosulfan) after 30 days. Similarly, *Gloeophyllum trabeum* exhibited 50% degradation of hydrocarbons and 48% reduction in pesticide levels [*From;* Table 04]. In field trials, fungal inoculation led to noticeable improvements in water clarity and a reduction in

The Need for Bioremediation in the Shivnath River: The Shivnath River faces a wide range of pollutants, many of which are challenging to remove using conventional chemical or physical methods [32]. Heavy metals such as lead, arsenic, and cadmium, which accumulate in river sediments, are persistent and toxic, making them particularly difficult to address. Similarly, agricultural runoff laden with pesticides and fertilizers contributes to eutrophication and the accumulation of harmful algal blooms, which further exacerbate water quality problems [33,34,35,36]. Despite efforts by local authorities to regulate and treat industrial effluents and wastewater, the sheer volume of pollutants and lack of sufficient infrastructure for wastewater treatment have made traditional methods less effective [37,38,39]. Additionally, the use of synthetic chemical treatments for pollutant removal can have long-term negative impacts on aquatic ecosystems and local communities [40,41,42]. Thus, there is an urgent need to explore alternative methods, such as bioremediation, to address these challenges in a more sustainable manner [43,44,45,46]. By focusing on bioremediation, this research aims to demonstrate how natural processes can be harnessed to mitigate pollution in the Shivnath River [47,48]. The potential for bioremediation in this context is vast, as it could not only reduce pollutant concentrations but also restore the river's ecological functions, including nutrient cycling, habitat provision, and water purification [49,50].

Acknowledgement: In this study, **Jhameshwar Prashad Sahu** and **Department of Zoology** investigates the bioremediation potential of natural processes to mitigate pollutants in the Shivnath River. Through the application of indigenous microorganisms and phytoremediation techniques, the research evaluates the effectiveness of biological systems in restoring water quality and enhancing ecosystem health. The findings underscore the significance of bioremediation as a sustainable solution to reduce contamination, promote biodiversity, and foster long-term ecological restoration in the Shivnath River and its surrounding environment.

Conclusion: Specifically, the microbial strains tested were able to reduce metal concentrations by up to **75%** and hydrocarbons by **60%**, highlighting their utility in mitigating industrial and agricultural pollution in the river. Phytoremediation, using plants such as *Phragmites australis* and *Typha angustifolia*, also yielded positive results in reducing nutrient loads (nitrates and phosphates) and heavy metals (lead and arsenic). Wetland species, in particular, demonstrated high efficiency in nutrient uptake and metal accumulation, contributing not only to pollutant reduction but also to the enhancement of biodiversity and ecosystem stability in the river's riparian zones. The establishment of plant cover also helped in preventing soil erosion and improving sediment quality. Fungal bioremediation, with species like *Phanerochaete chrysosporium*, further supported the bioremediation efforts by effectively degrading complex organic pollutants such as petroleum hydrocarbons and pesticides. Fungi are particularly valuable in dealing with persistent organic pollutants, which are often resistant to degradation by other means. The results from the fungal treatment trials indicated up to **60%** degradation of hydrocarbons, which is crucial for cleaning up the river's contaminated water and sediments. In conclusion, the results of this study confirm the potential of bioremediation as an effective, eco-friendly strategy for mitigating pollution in the Shivnath River. By integrating microbial, phytoremediation, and fungal treatments, a multi-faceted approach was achieved that addressed the various types of pollutants present in the river.

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