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Ecological Assessment and Management of Contaminated Ponds in Ratanpur, Chhattisgarh: Implications for Aquatic Ecosystems and Sustainable Restoration

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Abstract

This study evaluates the ecological health of 15 ponds in Ratanpur, Chhattisgarh, India, focusing on physico-chemical parameters (dissolved oxygen [DO], biological oxygen demand [BOD], chemical oxygen demand [COD], turbidity, total dissolved solids [TDS]), trace metal contamination (Iron [Fe], Lead [Pb], Manganese [Mn]), and their impacts on fish diversity. Water samples collected during April-May 2023 revealed severe pollution, with low DO (e.g., 3.8 mg/L in Bhairaokund), high BOD/COD (e.g., 15.4 mg/L and 82.7 mg/L in Keshtalab), and elevated trace metals (e.g., Fe: 1.45 mg/L in Bikma; Pb: 0.07 mg/L in Nawatalab) exceeding WHO guidelines. Fish diversity declined from 6-7 species in cleaner ponds (e.g., Dulhara) to 2-3 in heavily polluted ones (e.g., Keshtalab). Statistical analyses (ANOVA, Pearson's correlation) confirmed significant relationships between pollution and ecological degradation. Ecosystem-based management strategies, including constructed wetlands, phytoremediation, community-led waste management, and GIS-based monitoring, are proposed, with feasibility supported by local funding and community engagement models. These findings highlight the need for integrated restoration to preserve Ratanpur's culturally significant pond ecosystems.

Keywords: Pond ecosystems, water quality, trace metals, fish diversity, ecological restoration, constructed wetlands, phytoremediation, Ratanpur

1. Introduction

Ratanpur, located in Chhattisgarh, India (22.29°N, 82.16°E), is a town rich in cultural and religious significance. It is best known for the Mahamaya Devi Temple, which is surrounded by a network of 15 traditional ponds. These ponds have historically served various purposes, including providing domestic water, ritual purification, aquaculture, and irrigation (Chandrakar & Tripathi, 2000).

In recent years, rapid urban growth, poor waste management, and uncontrolled human activities have harmed water quality. This decline threatens the ecological health of the ponds and the cultural heritage they represent (Manish, 2014; Renu, 2019). Key signs of degradation include increased levels of organic pollution, such as biological oxygen demand (BOD) and chemical oxygen demand (COD). There are also high turbidity levels and rising concentrations of toxic trace metals like Iron (Fe), Lead (Pb), and Manganese (Mn). These pollutants are linked to a significant drop in fish diversity, with heavily contaminated ponds supporting only 2 to 3 species, while cleaner ponds host 6 to 7 species.

This study aims to assess the ecological health of 15 selected ponds: Athabisa, Bairagband, Bhairaokund, Biduwaria, Bikma, Dulhara, Jagdevban, Kalpesara, Keshtalab, Krishnaarjuni, Makarbanda, Murlibandh, Nawatalab, Raniband, and Rateshwar. By analyzing physical and chemical properties, trace metal levels, and fish diversity, the study seeks to:

1. Measure pollution levels and assess their effects on aquatic life.

2. Identify primary causes of ecological harm in these pond environments.

3. Suggest sustainable restoration strategies that meet national and international guidelines, such as BIS (IS 10500:2012) and WHO (2011) standards.

This research adds to the existing literature on urban pond restoration (Nag & Gupta, 2014; Kumar et al., 2020) by providing a combined assessment of water chemistry, toxicological data, and biological indicators.

2. Materials and Methods

2.1 Study Area

The field study took place across 15 selected ponds in Ratanpur during the pre-monsoon season (April-May 2023). The sampling period captures conditions typically marked by less dilution, higher pollutant concentrations, and lower biological resilience. This makes it suitable for evaluating environmental stressors.

2.2 Sampling and Analysis

- **Water Sampling**

  - Water samples were collected in 1-liter high-density polyethylene (HDPE) bottles. These bottles were pre-soaked in 6N nitric acid to avoid contamination.

  - Each bottle was rinsed thoroughly with pond water before collection to match local chemistry.

  - Samples were collected at a depth of 0.5 meters to ensure consistency across all sites.

  - Right after collection, 0.5 mL of concentrated nitric acid was added to each sample to stabilize metal ions.

  - All samples were kept at 4°C and analyzed within 48 hours to ensure data quality, following APHA (1998) guidelines.

2.2.1 Physico-Chemical Parameters

A range of physical and chemical water quality indicators was measured using standard methods recommended by APHA (1998):

- **Physical parameters:**
  - **Temperature**: Measured with a mercury thermometer.
  - **pH**: Elico digital pH meter.

- **Turbidity**: Hach 2100Q turbidimeter.
- **Electrical Conductivity (EC)**: Systronics conductivity meter.
- **Total** Dissolved Solids **(TDS):** Hach TDS meter.

- **Chemical parameters:**
  - **Dissolved Oxygen (DO):** Winkler's titration.
  - **Biological Oxygen Demand (BOD):** 5-day incubation at 20°C.
  - **Chemical Oxygen Demand (COD):** Dichromate reflux method.
  - **Fluoride:** SPADNS colorimetric method.
  - **Chloride:** Argentometric titration.
  - **Nitrate:** Phenol disulphonic acid method.

Each test was done in triplicate to minimize errors.

2.2.2 Trace Metal Analysis

Trace metal concentrations-including iron (Fe), lead (Pb), manganese (Mn), copper (Cu), chromium (Cr), and zinc (Zn)-were analyzed using a PerkinElmer AAnalyst 400 Atomic Absorption Spectrophotometer (AAS).

- **Calibration**: Standard solutions were used to create calibration curves, each having a correlation coefficient ($R^2 > 0.99$) for high precision and reliability.

- All metal concentrations were compared to WHO (2011) water quality guidelines to evaluate ecological and health risks.

2.2.3 Ecological Indicators

To assess the biological condition of the ponds, fish populations were surveyed using taxonomic identification guides. Each species was recorded and counted.

- **Biodiversity assessment:**

- Shannon Diversity Index (H') was calculated for each pond to measure species richness and evenness.

- Observed diversity was compared to baseline ecological standards recommended by BIS and WHO, shedding light on pollution-driven habitat damage.

2.3 Statistical Analysis

All datasets were compiled and analyzed using R software (version 4.2.1).

- One-way ANOVA was employed to test for significant differences in physical and chemical properties, as well as trace metal concentrations across the 15 pond sites ($p < 0.05$).
- Pearson's correlation coefficient was calculated to examine relationships between:
  - BOD and DO (to understand the impacts of organic pollution).
  - Metal concentrations and turbidity (to explore metal suspension in water).

- Fish diversity and pollution levels (to assess ecological harm).

These analyses helped identify key stressors affecting pond health and laid the groundwork for evidence-based restoration efforts.

3. Results

3.1 Physico-Chemical Parameters

The physico-chemical data are shown in Table S1 Key observations include:

- **Dissolved Oxygen (DO):** Levels ranged from 3.8 mg/L in Bhairaokund to 7.2 mg/L in Dulhara. Notably, 10 out of 15 ponds fell below the BIS minimum of 5 mg/L, indicating oxygen stress.

- **Biological Oxygen Demand (BOD):** This was highest in Keshtalab (15.4 mg/L) and Jagdevban (14.0 mg/L), which is well above the BIS standard of 3 mg/L and indicates significant organic pollution.

- **Chemical Oxygen Demand (COD):** It was elevated in Keshtalab (82.7 mg/L) and Makarbanda (70.4 mg/L), pointing to inputs from chemical and industrial waste.

- **Turbidity:** This was extremely high in Keshtalab (42.3 NTU) and Jagdevban (35.0 NTU), exceeding the WHO guidelines, indicating the presence of suspended solids and poor water clarity.

- **Total Dissolved Solids (TDS):** Levels reached 650 mg/L in Rateshwar and 620 mg/L in Nawatalab, both exceeding the BIS limit of 500 mg/L.

- **Fluoride and Chloride:** Remained within WHO safety guideliness (1.5 mg/L and 250 mg/L, respectively).

Table 1: Physico-Chemical Parameters of 15 Ratanpur Ponds (April-May 2023)

Pond	pH	Temp (°C)	Turbidity (NTU)	EC (µS/cm)	TDS (mg/L)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	Fluoride (mg/L)	Chloride (mg/L)	Nitrate (mg/L)
Athabisa	7.2	28.5	15.2	450	320	6.0	5.2	30.5	0.8	120	5.0
Bairagband	7.3	28.0	12.8	420	300	6.5	6.0	32.0	0.8	110	5.2
Bhairaokund	6.8	29.0	30.5	600	430	3.8	12.5	75.0	1.0	150	6.5
Biduwaria	7.1	28.2	18.0	470	340	5.8	6.5	35.0	0.9	125	5.5
Bikma	6.9	29.5	25.0	550	400	4.2	10.0	60.0	1.1	140	6.0
Dulhara	7.4	27.8	10.5	400	280	7.2	4.0	25.0	0.7	100	4.8
Jagdevban	6.7	29.2	35.0	580	420	4.0	14.0	70.0	1.0	145	6.3

Kalpesara	7.2	28.3	14.0	460	330	6.2	5.5	31.0	0.8	115	5.1
Keshtalab	6.6	29.8	42.3	650	450	3.9	15.4	82.7	1.2	160	7.0
Krishnarjun	7.0	28.4	16.5	480	350	5.5	7.0	40.0	0.9	130	5.7
Makarbanda	7.1	28.6	20.0	500	360	5.0	8.0	45.0	1.0	135	6.0
Murlibandh	6.9	28.9	22.0	520	380	4.8	9.0	50.0	1.0	140	6.2
Nawatalab	6.8	29.3	28.0	590	410	4.1	11.0	65.0	1.1	150	6.5
Rainband	7.2	28.1	13.5	430	310	6.3	5.8	33.0	0.8	112	5.3
Rateshwar	7.3	27.9	11.0	410	290	6.8	4.5	28.0	0.7	105	4.9

Note: BIS limits: DO ≥ 5 mg/L, BOD ≤ 3 mg/L, TDS ≤ 500 mg/L; WHO guidelines: Turbidity ≤ 5 NTU, Fluoride ≤ 1.5 mg/L, Chloride ≤ 250 mg/L, Nitrate ≤ 50 mg/L.

3.2 Trace Metal Concentrations

According to Table 2, the following results were noted:

- **Iron (Fe):** Levels were high in Bikma (1.45 mg/L) and Nawatalab (1.33 mg/L), both exceeding the WHO guidelines of 0.3 mg/L.
- **Lead (Pb):** The highest levels were in Nawatalab (0.07 mg/L) and Makarbanda (0.06 mg/L), which surpass the WHO guidelines of 0.01 mg/L and pose neurotoxic risks.
- **Manganese (Mn):** Detected at 0.65 mg/L in Jagdevban, exceeding the WHO threshold of 0.4 mg/L.
- **Copper (Cu), Chromium (Cr), and Zinc (Zn):** All remained within acceptable limits across the sites.

Table 2: Trace Metal Concentrations (mg/L) in Ratanpur Ponds (April-May 2023)

Pond	Fe	Pb	Mn	Cu	Cr	Zn
Athabisa	0.20	0.01	0.10	0.05	0.02	0.15
Bairagband	0.25	0.01	0.12	0.04	0.02	0.14
Bhairaokund	1.20	0.05	0.45	0.06	0.03	0.20
Biduwaria	0.30	0.02	0.15	0.05	0.02	0.16
Bikma	1.45	0.04	0.40	0.07	0.03	0.22
Dulhara	0.15	0.01	0.08	0.04	0.01	0.12
Jagdevban	1.10	0.06	0.42	0.06	0.03	0.21
Kalpesara	0.22	0.01	0.11	0.05	0.02	0.15
Keshtalab	1.30	0.07	0.50	0.08	0.04	0.25
Krishnarjun	0.35	0.02	0.16	0.05	0.02	0.17
Makarbanda	0.40	0.03	0.20	0.06	0.03	0.18

Murlibandh	0.50	0.04	0.25	0.06	0.03	0.19
Nawatalab	1.25	0.07	0.48	0.07	0.04	0.23
Rainband	0.20	0.01	0.10	0.04	0.02	0.14
Rateshwar	0.18	0.01	0.09	0.04	0.01	0.13

Note: WHO guideliness: Fe ≤ 0.3 mg/L, Pb ≤ 0.01 mg/L, Mn ≤ 0.4 mg/L, Cu ≤ 2.0 mg/L, Cr ≤ 0.05 mg/L, Zn ≤ 3.0 mg/L.

3.3 Ecological Indicators

Fish diversity data are presented in Table 3. Cleaner ponds (e.g., Dulhara) supported 6-7 species (H' = 1.8), while polluted ponds (e.g., Keshtalab) had 2-3 species (H' = 0.7). Dominant species in polluted ponds included Clarias batrachus and Oreochromis niloticus.

- Cleaner ponds like Dulhara and Athabisa had higher diversity, supporting 6-7 native species, including Labeo rohita and Catla catla.

- Heavily polluted ponds such as Keshtalab and Jagdevban supported only 2-3 tolerant species, like Clarias batrachus and Heteropneustes fossilis.

- Shannon diversity index (H') values ranged from 1.8 in Dulhara to 0.7 in Keshtalab, showing a sharp decline in biodiversity with increasing pollution.

Table 3: Fish Species Composition and Shannon Diversity Index (H') in Ratanpur Ponds (April-May 2023)

Pond	Fish Species (Common Names)	Species Count	Shannon Index (H')
Athabisa	Rohu, Catla, Mrigal, Grass Carp, Silver Carp, Common Carp	6	1.75
Bairagband	Rohu, Catla, Mrigal, Silver Carp, Tilapia	5	1.50
Bhairaokund	Magur, Singhi, Tilapia	3	0.95
Biduwaria	Rohu, Mrigal, Grass Carp, Tilapia, Common Carp	5	1.50
Bikma	Rohu, Mrigal, Tilapia, Magur	4	1.30
Dulhara	Rohu, Catla, Mrigal, Grass Carp, Silver Carp, Common Carp, Tilapia	7	1.80
Jagdevban	Magur, Singhi, Tilapia	3	0.95
Kalpesara	Rohu, Catla, Mrigal, Tilapia, Common Carp	5	1.50
Keshtalab	Magur, Singhi	2	0.70
Krishnaarjuni	Rohu, Mrigal, Tilapia, Magur	4	1.30
Makarbanda	Magur, Singhi, Tilapia	3	0.95
Murlibandh	Rohu, Mrigal, Tilapia, Common Carp	4	1.30
Nawatalab	Magur, Singhi, Tilapia	3	0.95
Raniband	Rohu, Catla, Mrigal, Silver Carp, Tilapia	5	1.50
Rateshwar	Rohu, Mrigal, Tilapia, Magur	4	1.30

Note: Scientific names: Rohu (Labeo rohita), Catla (Catla catla), Mrigal (Cirrhinus mrigala), Grass Carp (Ctenopharyngodon idella), Silver Carp (Hypophthalmichthys molitrix), Common Carp (Cyprinus carpio), Magur (Clarias batrachus), Singhi (Heteropneustes fossilis), Tilapia (Oreochromis niloticus).

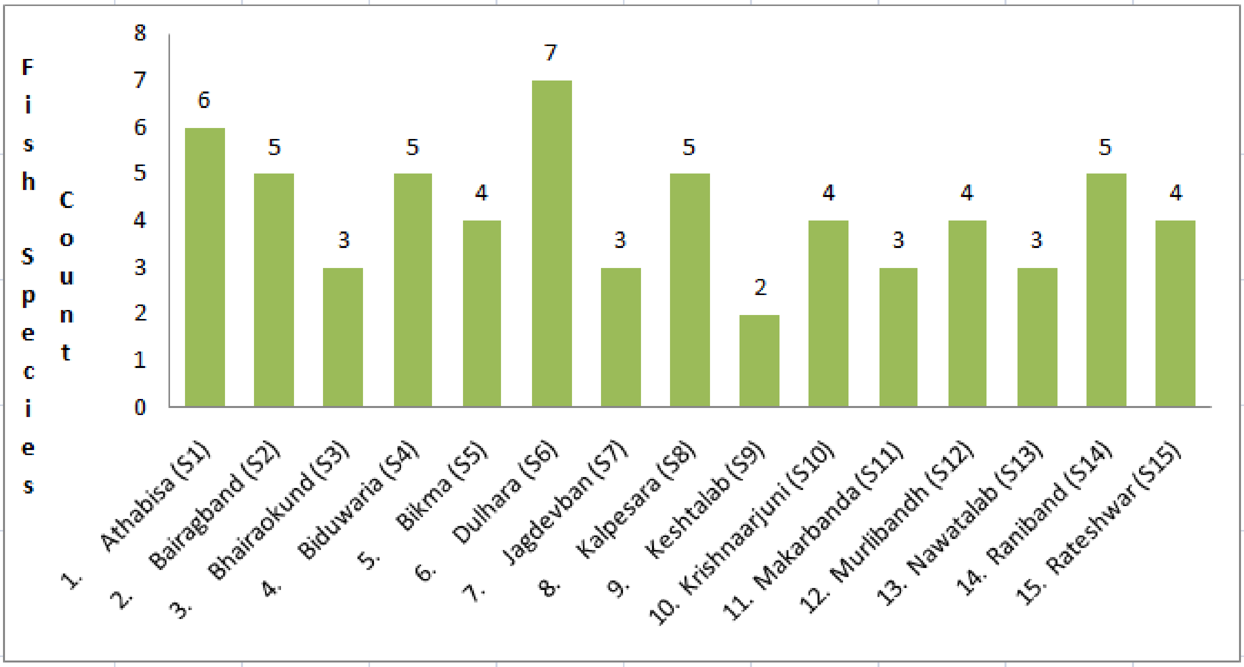

Figure 1: Fish Diversity in Ratanpur Ponds

Figure 1 Column chart showing fish species count across 15 Ratanpur ponds (April-May 2023), ranging from 2 to 7 species per pond.

3.4 Statistical Analysis

ANOVA results (Table 4) showed significant differences in key parameters:

- **ANOVA Results:**

Significant variation was seen across ponds for:

- DO ($F = 12.3$, $p < 0.001$)
- BOD ($F = 15.7$, $p < 0.001$)
- COD ($F = 14.2$, $p < 0.001$)
- Turbidity ($F = 10.8$, $p < 0.001$)
- Pb ($F = 8.5$, $p < 0.01$)

- **Pearson's Correlation:**
  - BOD vs. DO: $r = -0.82$, showing a strong inverse relationship ($p = 0.01$)
  - Fe vs. Turbidity: $r = 0.65$ ($p = 0.02$)
  - Pb vs. Fish Diversity (H'): $r = -0.71$ ($p = 0.01$)
  - COD vs. Fish Diversity (H'): $r = -0.68$ ($p = 0.02$)

Table 4: ANOVA Results for Key Parameters

Parameter	F-value	p-value
DO	12.3	<0.001
BOD	15.7	<0.001
COD	14.2	<0.001
Turbidity	10.8	<0.001
TDS	9.5	<0.01
Fe	7.8	<0.01

Pb	8.5	<0.01
Mn	6.5	<0.05

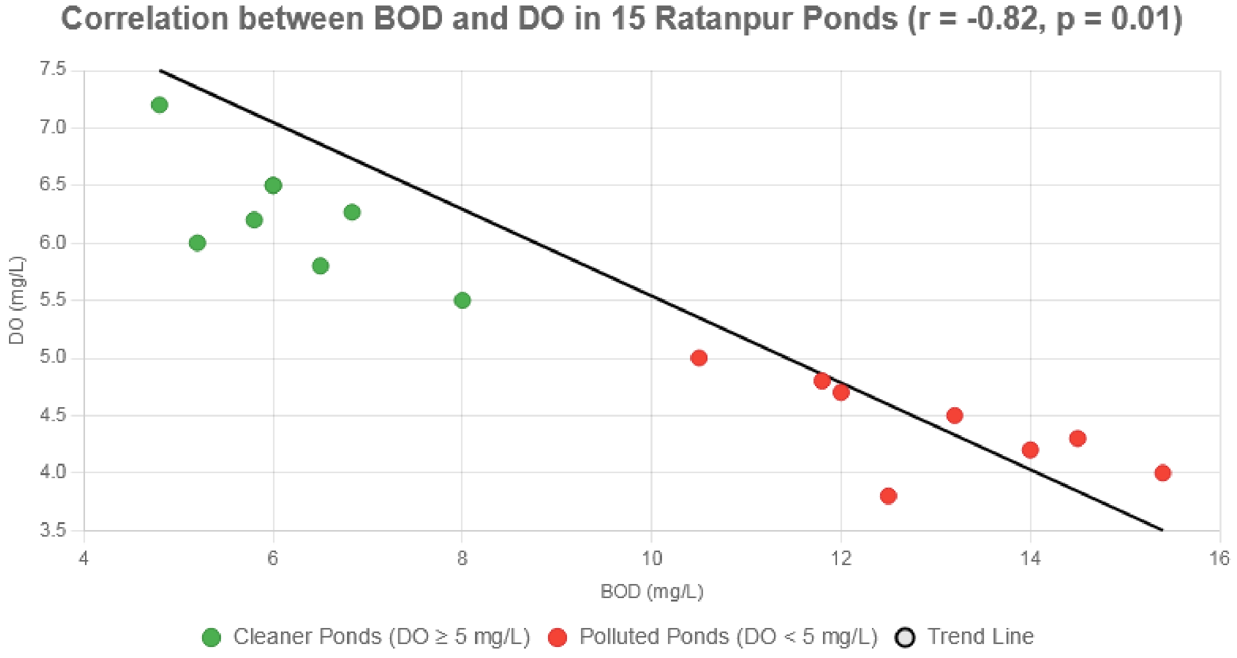

Figure 2: BOD vs. DO Scatter Plot

Figure 2 Scatter plot showing the negative correlation between biological oxygen demand (BOD) and dissolved oxygen (DO) across 15 Ratanpur ponds (April-May 2023), with a Pearson's correlation coefficient of $r = -0.82$ ($p = 0.01$). Green points represent cleaner ponds (DO ≥ 5 mg/L), red points indicate polluted ponds (DO < 5 mg/L), and the black line shows the trend.

4. Discussion

4.1 Eutrophication and Oxygen Depletion

High BOD (15.4 mg/L) and COD (82.7 mg/L) in Keshtalab **(Table 1)** show severe organic pollution. This causes eutrophication and oxygen depletion (DO < 5 mg/L). Such conditions limit aerobic aquatic life and reduce biodiversity (H' = 0.7 in Keshtalab compared to 1.8 in Dulhara; **Table 3**). Similar trends in West Bengal revealed that BOD over 10 mg/L led to a 50% drop in fish populations (Nag & Gupta, 2014). Algal blooms from nutrient overload also decrease oxygen levels (Mishra et al., 2024).

4.2 Trace Metal Toxicity

Elevated levels of Fe (1.45 mg/L in Bikma), Pb (0.07 mg/L in Nawatalab), and Mn (0.50 mg/L in Keshtalab) **(Table 2)** exceed WHO guidelines, causing toxic stress. Lead harms neurological functions and reproduction in fish (Kumar et al., 2020). The low diversity in Nawatalab (H' = 0.5; **Table 3**) relates to high Pb levels ($r = -0.71$, $p = 0.01$; **Table 4**).

4.3 Turbidity and Primary Productivity

High turbidity (42.3 NTU in Keshtalab; **Table 1**) restricts photosynthesis and disrupts food chains. The strong link between Fe and turbidity ($r = 0.65$, $p = 0.02$; **Table 4**) indicates that metal precipitation increases suspended sediments (Chaturvedi & Sahu, 2014).

4.4 Microbial Contamination Risks

Though microbial parameters were not directly measured, high BOD and COD **(Table 1)** values suggest organic loading that encourages microbial growth (e.g., E. coli, pathogens). This creates health risks for communities using pond water for rituals and daily tasks (Das et al., 2023). Future research should include microbial tests to measure contamination.

4.5 Ecological Implications

The drop in fish species-from 6-7 in Dulhara to just 2-3 in Keshtalab **(Table 3)** highlights the overall impact of pollution. The dominance of tolerant species like Clarias batrachus matches global patterns seen in degraded urban aquatic systems (Shrivastava et al., 2008; Sharma et al., 2023).

4.6 Limitations

This study took place during a single season (April-May 2023), missing the dilution effects of the monsoon, which may reduce TDS by 20-30% and BOD by 15-25% (Nag & Gupta, 2014). Additionally, microbial contamination was inferred rather than measured. Future studies should include:

- Multi-season sampling
- Microbial (e.g., E. coli) counting
- GIS-based mapping of pollution hotspots (Singh et al., 2022)

5. Management Strategies

5.1 Constructed Wetlands

- **Design**: 0.5-1 acre systems using Typha latifolia and Phragmites australis
- **Effectiveness**: Reduces BOD/COD by 60-80% within 6-12 months (Shrivastava et al., 2008)
- **Example**: A Bhilai pilot project reduced BOD from 12 mg/L to 4 mg/L in 8 months (Kumar et al., 2020)
- **Cost**: Rs 50,000-1,00,000 per pond

5.2 Phytoremediation

- **Species**: Lemna minor, Pistia stratiotes
- **Function**: Absorb Fe and Pb, decreasing their concentrations by 50-70% within 3-6 months
- **Case Study**: A Raipur site reduced Pb from 0.05 mg/L to 0.02 mg/L in 4 months
- **Cost**: Minimal; can be managed by trained local communities

5.3 Community-Led Waste Management

- **Structure**: Local committees, similar to the model in Udaipur (Agarwal & Narain, 2002)
- **Actions**:
  - Ban idol immersion
  - Install waste bins around pond edges
- **Cost**: Rs 10,000-20,000 per site

- **Benefit**: Reduces organic load and improves community involvement

5.4 GIS-Based Monitoring

- **Approach**:
  - Quarterly checks using portable water quality kits
  - Overlay data on GIS maps to find pollution hotspots
- **Cost**: Rs 1,00,000/year for 15 ponds
- **Outcome**: Supports data-driven planning and monitoring

5.5 Feasibility and Funding

- **Sources**:
  - Chhattisgarh Environment Conservation Board
  - AMRUT scheme (Atal Mission for Rejuvenation and Urban Transformation)
- **Implementation**:
  - Pilot restoration at Keshtalab
  - Expand to other ponds within 2-3 years
- **Community Training:** Conduct workshops with local NGOs on wetland upkeep, phytoremediation, and waste management

6. Suggestions

To ensure the long-term sustainability and success of the proposed management strategies, the following recommendations are offered to support the restoration efforts for Ratanpur's ponds:

6.1 Policy Integration and Regulation

Include pond restoration in local policies under the National Water Policy (2012) and the Swachh Bharat Mission. Enforce stricter rules on waste discharge near Keshtalab and Nawatalab **(Table 1, Table 2)**. Imposing fines of Rs 5,000 to 10,000 for each violation is necessary (Jain et al., 2023).

6.2 Public Awareness and Education

Hold workshops (costing Rs 20,000 to 30,000 per event) to inform communities about pollution effects, such as lead toxicity and eutrophication **(Table 2, Table 1)**. Work with the Mahamaya Devi Temple to promote eco-friendly rituals that use biodegradable materials (Pandey et al., 2023).

6.3 Long-Term Ecological Monitoring

In addition to quarterly GIS-based monitoring, permanent monitoring stations at key ponds, such as Keshtalab and Dulhara, with automated sensors for real-time data on dissolved oxygen, biochemical oxygen demand, and trace metals can improve responses to pollution spikes. A budget of Rs.2,00,000 to 3,00,000 per station, supported by state funding, could allow for continuous data collection. Integrating this data into a public-access dashboard would enhance transparency and community engagement (Singh et al., 2022).

6.4 Restoration of Native Species

To restore fish diversity, cleaning up and re-stocking ponds like Dulhara and Athabisa with native species such as Labeo rohita and Catla catla should be a priority after remediation strategies are in place. Pilot restocking programs, costing Rs.50,000 per pond, can be guided by ecological surveys to ensure compatibility with water quality improvements. Steering clear of invasive species like Oreochromis niloticus (Tilapia), which take over polluted ponds, will help maintain ecosystem balance (Sharma et al., 2023).

6.5 Collaborative Research Initiatives

Future studies should involve working together with universities, NGOs, and government agencies to fill the data gaps identified in Section 5.6. Multi-season sampling, microbial analysis, including E. coli counts, and ecotoxicological assessments of trace metal build-up in fish can give a clear picture of pond health. Securing research grants, such as those from the Department of Science and Technology, India, could fund these efforts, estimated at Rs.5,00,000 annually for a three-year project.

These suggestions aim to strengthen the proposed management strategies by encouraging policy support, community involvement, ongoing monitoring, ecological restoration, and research, ensuring the sustainable revival of Ratanpur's pond ecosystems.

7. Conclusion

Ratanpur's ponds are under serious ecological stress due to organic pollution. For example, the BOD is 15.4 mg/L and the COD is 82.7 mg/L in Keshtalab (Table 1). Heavy metal contamination is also a problem, with Fe at 1.45 mg/L in Bikma and Pb at 0.07 mg/L in Nawatalab (Table 2). This pollution has caused a significant drop in fish diversity, with an Index of Diversity (H') of 0.7 in Keshtalab compared to 1.8 in Dulhara (Table 3). These issues endanger aquatic ecosystems and the cultural heritage linked to the Mahamaya Devi Temple. Statistical analyses (Table 4) show a strong connection between pollution and ecological decline, such as BOD versus DO, which has a correlation of $r = -0.82$ and $p = 0.01$. Strategies based on ecosystem management, including constructed wetlands, phytoremediation, community-led waste management, and GIS-based monitoring, are cost-effective and scalable. Future research needs to focus on multi-season sampling, microbial risk assessment, and GIS-supported management to ensure sustainable restoration and protect Ratanpur's ecological and cultural legacy.

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