Water quality assessment of Narmada River along the different topographical regions of the central India

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ABSTRACT
This study was performed to assess water quality in the Narmada River, the third-longest river in India. Water samples were collected from 6 major sampling stations with 17 sampling points. Nine water quality parameters were analyzed to calculate the water quality index (WQI), followed by multivariate statistical evaluation. The results indicated that water quality in the upper Narmada varied from excellent to very poor - comprising excellent for approximately 12%, good for 17%, poor for 59%, and very poor for 12% of pre-monsoon samples, but excellent for 17%, good for 12%, and poor for 71% of post-monsoon. While the general water quality in the Narmada was poor, anthropogenic inputs such as domestic sewage and agricultural runoff influenced some parameters - e.g. BOD, nitrate, and total coliform. More studies are required for completing water quality evaluation.

Introduction
Rivers are a vital source of freshwater for life but are deteriorating due to the release of industrial and domestic wastewaters (Desai, 2014), agricultural runoff, etc. (Khatri & Tyagi, 2015; Ongley, 1998). India has a massive network of rivers whose total annual discharge is about 1,953 km² (Kumar, Singh, & Sharma, 2005). Rivers like the Beas, Brahmaputra, Mahi, Narmada, and Pennar are relatively clean, while others like the Brahni, Ganga, Godavari, Kaveri, Krishna, Mahanadi, Satluj, and Yamuna, etc., are highly polluted. Most Indian rivers are contaminated due to discharges of organic and inorganic contaminants, viruses and bacteria, etc. (Bhardwaj, 2005; Kurunthachalam, 2013). Urbanized parts of India generate large volumes of sewage which are often discharged into water bodies without proper treatment (Central Pollution Control Board [CPCB], 2018a, 2018b; Shukla & Gedam, 2018), while agriculture practices in watersheds are also major sources of river pollution (Khatri & Tyagi, 2015).

Narmada is one of the most important rivers in India which originates from the Amarkantak, Madhya Pradesh in central India, and flows through the Maikal and Satpura hills. It flows 1,312 km west through the states of Madhya Pradesh, Maharashtra, and Gujarat, of which 1,077 km is within Madhya Pradesh (Gupta, Chakrapani, Selvaraj, & Kao, 2011). In its upper reaches, around Amarkantak, the Narmada is surrounded by dense forest. It runs from the hills of Amarkantak, toward Dindori, Mandala, Jabalpur, Narsinghpur, and Hoshangabad, fulfilling the water demands of the large population as it passes (Census of India, 2011) - Table 1.

Like the other major rivers in India - e.g. the Ganges and Yamuna – the Narmada is facing stress from several pollution sources between its origin at Amarkantak and Hoshangabad. Threats (potential sources, see Table 2) may arise from religious activities, public gatherings, bathing, and domestic effluent discharges. Approximately 100 km from its origin, agricultural activities in the Narmada watershed is intensive, which may also contribute to pollution through surface runoff. Industrial activities, restaurants, and lodges on the river banks also release sewage to the river through small drains. Major towns/cities such as Dindori, Mandala, and Narsinghpur along the river lack sewage treatment plants, making the river more vulnerable to sewage pollution.

Several studies have been carried on different aspects of water quality in the river, including those by (Mishra & Kumar, 2020; Gupta, Pandey, & Hussain, 2017; Sharma, Dixit, Jain, Shah, & Vishwakarma, 2008; Sharma, Bora, & Shukla, 2013; Soni et al., 2013; Zingde, Chander, Rokade, & Desai, 1981). These are all based on specific locations, and dealt with relatively few parameters and particular seasons. Because of this they are fragmentary and do not present a clear and complete picture of the river’s water quality. There are no reported, recent water quality data on the river. Gupta et al. (2017); did their experiments on water quality between 2009 and 2012. Mishra and Kumar...
have reported water quality of the Narmada River only for the winter season.

Therefore, water quality determination using physicochemical and biological parameters, to enable comparison with relevant standards is necessary. It is difficult to assess the total water quality at a given time. Discrete water quality variables cannot reflect the actual water quality status and it is difficult for them to express quality for several purposes such as drinking, bathing, gardening, etc. Because of these issues, the water quality index (WQI) method has been used, as it can reduce the datasets to distinct values in simplified form. The categorization of WQI as excellent (WQI < 50); good (50 to 100); poor (100 to 200); very poor (200 to 300) is done which express the overall state of a water body and its suitability for various purposes such as drinking, agriculture, and industrial, etc.).

Despite analyzing numerous datasets of different physicochemical water parameters, still it remains difficult to interpret the outcomes and identify the polluted sites. In order to remove these limitations and deduce the exact ecological status of river water quality, multivariate statistical techniques were used (Li, Li, & Zhang, 2011). Techniques like principal component analysis (PCA), factor analysis (FA) and cluster analysis (CA), have all been used (Shrestha & Kazama, 2007). These techniques help in understanding the sources influencing the water system (Narany, Ramli, Aris, Sulaiman, & Fakharian, 2014). Sampling station clustering (Gatica, Almeida, Mallea, Del, & Gonzalez, 2012) helps to find similar locations and distinguish polluted sites.

Considering the importance of the Narmada River and the scarcity of ecological data on the river water quality, the present study was proposed. It is an attempt to examine water quality in the upper reaches of the Narmada River, from Amarkantak to Hoshangabad districts of Madhya Pradesh state. Both spatial-temporal, pre- & post-monsoon variations in water quality have been calculated to derive WQI, as well as PCA, FA, and CA were used to assess the river water quality.

### Materials and methods

#### Study area and sampling sites

The study covered the upper stretch of the Narmada River, starting from its source at Amarkantak to Hoshangabad, Madhya Pradesh (Figure 1). The Narmada basin’s coordinates are 72°32’ E to 81°45’ E and 21°20’ N to 23°45’ N, with the drainage area is 98,796 km² (Gupta & Chakrpani, 2005). The river runs between the Vindhyan and Satpura ranges, to its north and south, respectively.

To perform this study, a total of 17 sampling points from six sampling sites (Amarkantak, Dindori, Mandala, Jabalpur, Narsinghpur, and Hoshangabad) were selected for the detailed investigation (Figure 1, Table 2). These sites were determined after a systematic survey and based on the perceived degree of threat to the river from various sources – e.g. natural, domestic, social/religious, etc.

#### Sample collection and analysis

The study was conducted in 2017–18 in the pre- (May) and post- (October) monsoon seasons. Samples were

### Table 1. Population distribution along the upper Narmada River (Census of India, 2011).

| District          | Total population | Urban popula- | Rural popula- | Population |
|-------------------|------------------|---------------|---------------|------------|
|                   |                  | tion (%)      | tion (%)      | density    |
|                   |                  |               |               | (per km²)  |
| Anuppur           | 749,237          | 27.4          | 72.6          | 200        |
| Dindori           | 704,524          | 4.6           | 95.4          | 94         |
| Mandala           | 1,034,905        | 12.3          | 87.7          | 182        |
| Jabalpur          | 2,463,289        | 58.5          | 41.5          | 473        |
| Narsinghpur       | 1,091,854        | 18.6          | 81.4          | 213        |
| Hoshangabad       | 1,241,350        | 31.4          | 68.6          | 185        |

### Table 2. Detailed locations of sampling sites and pollution sources.

| Sampling Sites | Geographic Locations | Sampling sites | Potential pollution sources to the river |
|----------------|----------------------|----------------|----------------------------------------|
| Site 1 to site 4 |                        | 1. Narmany kund | Forest runoff, ritual bathing, washing clothes/utensils, vehicles, some household discharges, etc. |
|                 | Amarkantak (22°40.371’ N 81°45.547’ E) | 2. Ram ghat | |
|                 |                      | 3. Vivekanand ghat | |
| Site 5 – 7 | Dindori (22°56.812’ N 81°04.627’ E) | 4. Kapil dhara | Domestic sewage and effluent discharges, bathing, washing vehicles. |
| Site 8-10 | Mandala (22°36.320’ N 80°21.760’ E) | 5. Chandan ghat | |
| Site 10–13 | Jabalpur (23°08.001’ N 79°48.018’ E) | 6. Dindori Bus stand | |
| Site 14–15 | Narsinghpur (22°47.659’ N 77°46.844’ E) | 7. Manode | |
| Site 16–17 | Hoshangabad (22°45.774’ N 77°42.954’ E) | 8. Sangam ghat | Ritual activity near river banks, and wastewater discharge from densely populated towns. |
|                 |                      | 9. Rapti ghat | |
|                 |                      | 10. Ranrez ghat | |
|                 |                      | 11. Gwari ghat | |
|                 |                      | 12. Tilwara ghat | |
|                 |                      | 13. Bheda ghat | |
|                 |                      | 14. Barman ghat | |
|                 |                      | 15. Bandarbhan ghat | Agricultural runoff and occasional religious rituals. |
|                 |                      | 16. Buhdi ghat | Urban effluents – e.g. domestic and industrial effluents. |
|                 |                      | 17. Sethani ghat | |
collected in 1 liter, polyethylene terephthalate (PET) bottles, apart from those for determining dissolved oxygen (DO) and biochemical oxygen demand (BOD), which were collected in BOD bottles. All bottles were prewashed thrice with the sample, before collection. The DO samples were fixed on-site, and all the samples were stored in iceboxes and taken within the day to the laboratory for analysis.

Parameters such as temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity were determined on-site using a portable Oakton multi-parameter tester and a pH meter from Hanna. Total coliform data was collected from the Madhya Pradesh Pollution Control Board. Coordinates of sampling locations were recorded using portable GPS (Garmin Etrex-20). The Winkler method was adopted for DO and BOD determination, the titrimetric analysis was used to estimate alkalinity and EDTA for analysis of both total and calcium hardness. Chloride was determined using the argentometric method, and NO$_3^-$ was estimated by spectrophotometry (Thermo-Fisher Scientific, Evolution 201 UV-Vis Spectrophotometer). Standard protocols were followed for other analyses (APHA, 2012).

Multivariate analysis

Correlation

Correlation analysis is a statistical technique used to represent links between variable pairs. Correlation coefficient values close to +1 or −1, denote the probability of a linear relationship between the variables x and y. The correlation has been used in many studies to interpret physicochemical parameters in relation to water (Bhandari and Nayal, 2008) – Equation (1).

\[
r = \frac{N \sum (XiYi) - (\sum Xi)(\sum Yi)}{\sqrt{[N \sum Xi^2 - (\sum Xi)^2][N \sum Yi^2 - (\sum Yi)^2]}}
\]  

Where \( r \) = correlation coefficient
\( Xi \) and \( Yi \) represent two different parameters, and \( N \) = total number of observations.

Principal component analysis (PCA)

PCA was used to modify the original datasets into a new and uncorrelated set – i.e., a linear combination of the original sets (Vasco, 2012). It helps to extract the information from major parameters by eliminating those of lower importance with minimal loss of original information (Kannel, Lee, Lee, Kanel, & Khan, 2007; Mishra, Kumar, Yadav, & Singhal, 2018). After extracting the principal components, factor analysis (through “varimax rotation”) was used to simplify the datasets, revealing the same information as contained in the original sets (Shrestha & Kazama, 2007).

Cluster analysis (CA)

CA was used to sort out and form clusters of objects based on similarities (Paly & Shankar, 2016). Subgroups were merged based on similarities until they form a distinct cluster. The average linking method is used to extract clusters from water quality data. Hierarchical cluster analysis (HCA) is displayed graphically using tree diagrams – i.e., dendrogram (Alkarkhi, Ahmad, & Easa, 2009).

Microsoft Office 2013 and SPSS (Statistical Package for Social Sciences, version-10.0) were used to extract correlation matrix and for multivariate analysis (PCA and CA) respectively.
**Water quality index (WQI)**

Globally, various water quality indices have been developed for monitoring surface water quality of rivers such as the Weighted Arithmetic Water Quality Index, National Sanitation Foundation Water Quality Index, Comprehensive Pollution Index, Carlson’s trophic index, and Canadian Council of Ministers of the Environment Water Quality Index (Batabyal & Chakraborty, 2015; Gupta et al., 2017; Kumar, Sharma, & Rai, 2017; Mishra & Kumar, 2020; Mishra, Kumar, & Shukla, 2016).

Assessment of the water quality of the upper Narmada River in the broad context of surface water quality was done using the Weighted Arithmetic Water Quality Index (WQI), which is a rating indicating the interaction of multiple water parameters on total water quality (Kannel et al., 2007). To calculate WQI, the Indian water quality standard (BIS, 1991; Indian Council of Medical Research [ICMR], 1975) was adopted. Normally, to calculate WQI, each variable (pH, TDS, alkalinity, chloride, total hardness, DO, BOD, and nitrate, along with the bacterial loads, were determined in this study) was weighted (wi), Table 3.

The relative weight (Wi) of each water parameter was calculated using Equation (2):

\[ Wi = \frac{w_i}{\sum_{i=1}^{n} w_i} \]  
(2)

where, Wi = relative weight,  
wi = the weighting for each variable, and  
n = number of parameters.

Subsequently, a quality rating (qi) was calculated for each parameter using Equation (3):

\[ q_i = \frac{C_i}{S_i} \times 100 \]  
(3)

where qi = quality rating,  
Ci = actual parameter concentration, and  
Si = water parameter MAC (BIS, 1991).

Ultimately, to estimate WQI, the sub-index (SI) was calculated:

\[ 2S2I_2 \equiv Wi \times qi \]  
(4)

\[ 2WQI = \sum_{i=1}^{n} 2nS2I_{2i-n} \]  
(5)

where, SIi = sub-index of ith parameter;  
Wi = relative weight of ith parameter;  
qi = quality rating based on concentration of ith parameter, and  
n = number of parameters.

**Results and discussion**

**Narmada river water quality – physicochemical parameters**

The analytical results for the river water samples are shown in Table 4. The pH of the Narmada River varied from slightly acidic to alkaline (Figure 2(a)). During the pre-monsoon season, the minimum pH was 6.9 at Narmada main Kund (origin point of Narmada) and the maximum was 8.8 at Rangrej ghat. For post-monsoon, the minimum pH was 6.2, also at Narmada main kund, and the maximum was 8.9, at Budhni ghat. Pre-monsoon, there was a strong positive correlation between pH, EC, and total hardness (0.8) – Table 5. A moderate correlation of pH and TDS (0.6) was also observed, indicating the presence of inorganic salts and some organic matter in the water (Sawyer, McCarty, & Parkin, 1994) e.g. from natural geological sources and/or anthropogenic activities (domestic, agriculture and/or industry) (Daniels et al., 2016). Post-monsoon correlations – Table 6 – indicated that pH correlated strongly with total hardness (0.8), and well with EC, TDS, and alkalinity (0.7). Total hardness, whether temporary or permanent, affects TDS directly, which, in turn, has a strong effect on pH. Gupta et al. (2017) and Sharma et al. (2013); reported pH values of 7.2–9.4 and 7.7–8.48, respectively for the Narmada River.

**Table 3.** Relative parameter weights.

| Parameter                  | MAC (SI) | Weight (W) | Relative weight (W) |
|---------------------------|----------|------------|---------------------|
| pH                        | 85        | 4          | 0.11                |
| TDS (mg/l)                | 500      | 4          | 0.11                |
| Alkalinity (mg-CaCO₃/l)   | 120       | 4          | 0.11                |
| Chloride (mg/l)           | 250       | 3          | 0.09                |
| Total hardness (mg-CaCO₃/l) | 300  | 2          | 0.06                |
| DO (mg/l)                 | 5         | 4          | 0.11                |
| BOD (mg/l)                | 5         | 4          | 0.11                |
| Nitrate (mg-N₂O₅/l)       | 45        | 5          | 0.14                |
| Total Coliform (MPN/100 ml) | 5     | 5          | 0.14                |

*MAC or equivalent (BIS, 1991).  
Where W derived for this study.

**Table 4.** Pre- and post-monsoon water quality in the Narmada River.

| Parameters | MAC | Source | Pre-monsoon | Post-monsoon |
|------------|-----|--------|-------------|--------------|
| pH         | 6.5–8.5 | BIS, 1991 | 6.9–8.8 | 6.2–8.9 |
| EC (μS/cm) | – | ICMR, 1975 | 83.1–323 | 74.8–336 |
| TDS (mg/l) | 500 | BIS, 1991 | 59–230 | 52.9–238 |
| Alkalinity | BIS, 1991 | 10–118 | 52–228 |
| Chloride (mg/l) | 250 | BIS, 1991 | 8.5–138.5 | 32–88.8 |
| T. Hardness (mg-CaCO₃/l) | BIS, 1991 | 34–146 | 46–184 |
| DO (mg/l) | 5 | ICMR, 1975 | 3.2–13.6 | 2.6–12.2 |
| BOD (mg/l) | 5 | ICMR, 1975 | 1.1–10.8 | 0.4–9.8 |
| Nitrate | BIS | 0.03–2.5 | 0.2–2.4 |
| Total Coliform (MPN/100 ml) | 5 | BIS | 2–50 | 2–46 |

*ICMR- Indian Council of Medical Research, 1975; BIS- Bureau of Indian Standards, 1991.*
The lowest ECs in the Narmada River were found at Kapildhara (83.1 μS/cm) and the highest at Barman ghat (323 μS/cm), in the pre-monsoon season. Post-monsoon, the minimum was also at Kapildhara (74.8 μS/cm), with the maximum at Sethani ghat (336 μS/cm) (Figure 2(b)). Low EC indicates low levels of mineralization in the study area, perhaps because of the relatively inert bedrock materials (Gupta & Paul, 2013). EC was strongly correlated with TDS and total hardness, >0.8, in both seasons (Tables 5 & 6). TDS
concentrations in the river are shown in Figure 2(c). The lowest pre-monsoon TDS reported was 59 mg/l at Kapildhara, and the highest 230 mg/l at Barman ghat. The lowest post-monsoon TDS concentration was reported from Kapildhara (52.9 mg/l), the highest at Sethani ghat (238 mg/l). Similar TDS concentrations in the range in 108–234 mg/l were also stated in another study conducted on the Narmada river by Gupta et al. (2017). TDS and total hardness concentrations are moderately well correlated (0.6) at pre-monsoon – Table 5 – but strongly correlated (0.9) at post-monsoon.

The alkalinity concentration ranged from 10 mg/l at Bandarban ghat to 118 mg/l at Bheda ghat, pre-monsoon, and 52 mg/l at Narmada main kund to 228 mg/l at Sethani ghat, post-monsoon (Figure 2(d)). It was highly correlated with total hardness (0.9), post-monsoon – Table 6.

Pre-monsoon chloride concentrations ranged from 8.5 mg/l at Tilwara ghat to 138.5 mg/l at Vivekanand ghat, and post-monsoon from 32 mg/l at Rapta ghat to 88.8 mg/l at Ram ghat (Figure 2(e)). Chloride and nitrate concentrations were moderately correlated (0.6), pre-monsoon, Table 5, and chloride were strongly correlated with DO and BOD (0.8) post-monsoon, Table 6. Pre-monsoon, the total hardness concentration ranged from 34 mg/l at Kapil dhara to 146 mg/l at Chandan ghat, and, post-monsoon from 46 mg/l at Kapil dhara to 184 mg/l at Barman ghat. (Figure 2(f)).

The concentration of DO in water depends on numerous parameters including pressure and temperature, chemical content, and biological activity – e.g. photosynthesis, etc. The lowest pre-monsoon DO concentration reported was 3.2 mg/l at Tilwara ghat and the maximum 13.6 mg/l at Ram ghat. Post-monsoon the minimum DO concentration reported was at Rangej ghat (2.6 mg/l) and the maximum at Ram ghat (12.2 mg/l); Rapta ghat also reported rather low DO concentration, at 3 mg/l (Figure 2(g)). Both ghats are in the middle of Mandla, one of the oldest towns in Madhya Pradesh, suggesting that sewage discharge to the river might be degrading its water quality. Similar results for DO in the range of 2.4–7.8 mg/l and 8.05–12.6 mg/l were also reported by Gupta et al. (2017) and Sharma et al. (2013). A positive correlation of pre-monsoon DO with nitrate concentrations (0.5) indicates some interdependence with DO. In both the pre- and post-monsoon seasons DO concentrations showed a strong positive correlation with BOD (>0.8) – Tables 5 & 6.

Pre-monsoon BOD ranged from 1.1 mg/l at Bheda ghat to 10.8 mg/l at the Dindori Bus stand. Dindori is an old town and the river receives sewage discharges.

Table 5. Correlation matrix – Narmada River physicochemical parameters pre-monsoon (N = 17, p < .05).

| Correlations   | pH | EC (μS/cm) | TDS | Alkalinity | Chloride | T. Hardness | DO | BOD | Nitrate |
|----------------|----|------------|-----|------------|----------|-------------|----|-----|--------|
| pH             | 1.0|            |     |            |          |             |    |     |        |
| EC (μS/cm)     | 0.8| 1.0        |     |            |          |             |    |     |        |
| TDS            | 0.6| 0.8        | 1.0 |            |          |             |    |     |        |
| Alkalinity     | -0.5| 0.0       | -0.2| 1.0        |          |             |    |     |        |
| Chloride       | -0.5| 0.0       | -0.2| -0.5       | 1.0      |             |    |     |        |
| T. Hardness    | 0.8| 0.9        | 0.6 | 0.2        | -0.7     | 1.0         |    |     |        |
| DO             | 0.1| -0.1       | -0.1| -0.5       | 0.4      | -0.2        | 1.0|     |        |
| BOD            | 0.1| 0.2        | 0.1 | -0.4       | 0.1      | 0.1         | 0.8| 1.0 |        |
| Nitrate        | -0.1| -0.3       | 0.0 | -0.3       | 0.6      | -0.4        | 0.5| 0.3 | 1.0    |

* Pearson Correlation is significant at the 0.05 level (2-tailed).

Table 6. Correlation matrix – Narmada River physicochemical parameters post-monsoon (N = 17, p < .05).

| Correlations   | pH | EC (μS/cm) | TDS | Alkalinity | Chloride | T. Hardness | DO | BOD | Nitrate |
|----------------|----|------------|-----|------------|----------|-------------|----|-----|--------|
| pH             | 1.0|            |     |            |          |             |    |     |        |
| EC (μS/cm)     | 0.7| 1.0        |     |            |          |             |    |     |        |
| TDS            | 0.7| 1.0        | 1.0 |            |          |             |    |     |        |
| Alkalinity     | 0.7| 1.0        | 1.0 | 1.0        |          |             |    |     |        |
| Chloride       | -0.3| -0.4       | -0.4| -0.4       | 1.0      |             |    |     |        |
| T. Hardness    | 0.8| 0.9        | 0.9 | 0.9        | -0.3     | 1.0         |    |     |        |
| DO             | -0.1| -0.5       | -0.5| -0.4       | 0.8      | -0.3        | 1.0|     |        |
| BOD            | -0.3| -0.7       | -0.7| -0.6       | 0.8      | -0.5        | 0.9| 1.0 |        |
| Nitrate        | -0.5| -0.3       | 0.3 | 0.4        | -0.1     | 0.3         | -0.5|     |        |

* Pearson Correlation is significant at the 0.05 level (2-tailed).
there. Ritual activities and bathing in Narmada which is practiced every day is also a major source of pollution. Post-monsoon, the minimum BOD was 0.4 mg/l at Sethani ghat and the maximum was 9.8 mg/l at Ram ghat. Ram ghat receives open drainage carrying household discharges from Amarkantak town (Figure 2(h)). However, the maximum BOD value has been increased in this present study when compared with previous studies conducted by Gupta et al. (2017) (maximum BOD 2.18 mg/l), and Sharma et al. (2013) (maximum BOD 12.6 mg/l).

The pre-monsoon nitrate concentration ranged from 0.03 mg-NO_3/l at Gwari ghat to 2.5 mg-NO_3/l at Ram ghat and post-monsoon from 0.2 mg-NO_3/l at Ram ghat to 2.4 mg-NO_3/l at Sethani ghat (Figure 2(i)). Ram ghat, at the source of the river, is mostly used by devotees and locals for bathing and washing clothes and utensils.

The total coliform concentration ranged from 2–50 MPN/100 ml and 2–46 MPN/100 ml for pre-monsoon and post-monsoon, respectively (Figure 2(j)). It might be contributed due to the discharge of untreated sewage in the river (Shah & Joshi, 2017).

### PCA and FA

It is difficult to understand and identify surface water quality problems using large datasets, so, major contributing factors were identified using PCA, continuing with FA by varimax rotation. Before the PCA/FA test, KMO & Bartlett’s Test of Sphericity ($P < .001$), was used and gave 0.601 (pre-monsoon) and 0.619 (post-monsoon). This was done to assess sampling adequacy for further PCA/FA analysis. KMO ranges from 0 to 1, where KMO>0.6 is acceptable for PCA/FA. Principal components having eigenvalue >1 have been considered.

#### Pre-monsoon

The PCA/FA analysis (Table 7) showed three principal components with eigenvalue >1, the others were rejected. PC (1) showed positive loading of EC (0.891), TDS (0.974), and total hardness (0.728), with a variance of 28.9%. PC (2) showed positive loading of total hardness (0.667), with negative chlorides (−0.959) and nitrate (−0.593), with a variance of 26.6%. PC (3) showed positive loading of DO (0.908) and BOD (0.862), and negative alkalinity (−0.596), with a variance of 25.6%.

#### Post-monsoon

The post-monsoon PCA/FA analysis (Table 7) showed only two principal components governing water quality. PC (1) showed positive loading of pH (0.871), EC (0.940), TDS (0.938), alkalinity (0.936), and total hardness (0.966), and negative loading of BOD (−0.501), with variance 52.4%. PC (2) showed positive loading of chloride (0.959), DO (0.98), and BOD (0.846), with variance 32.9%.

### HCA

Sampling sites reporting similar physicochemical water quality were grouped using HCA to generate dendrogram (Figures 3(a & b)). Clusters comprising 3 and 2 groups, for the pre- and post-monsoon seasons, respectively, were generated. For the pre-monsoon season – Figure 3(a) – Cluster 1 includes sampling sites Gwari ghat, Tilwara ghat, and Bheda ghat. Cluster 2 comprised sampling sites in Amarkantak – Narmada main Kund, Ram ghat, Vivekanand ghat, and Kapildhara. Cluster 3 covers sampling sites Barman ghat, Bandarban ghat, Chandan ghat, Dindori Bus stand, Manode, Sangam ghat, Rapta ghat, Ramarez ghat, Budhni ghat, and Sethani ghat, all of which are moderately polluted.

There are two post-monsoon clusters (Figure 3(b)). Cluster 1 covers sampling stations Manode, Sangam ghat, Rapta ghat, Ramarez ghat, Ram ghat, and Vivekanand ghat. Cluster 2 includes Chandan ghat, Dindori Bus stand, Gwari ghat, Tilwara ghat, Barman ghat, and Sethani ghat. The sites in cluster 2 are in a densely populated area, which might have influenced water quality.

### Water quality index (WQI)

To understand pollution levels in the river, a WQI was calculated using nine physio-chemical parameters, i.e., pH, TDS, BOD, DO, alkalinity, chloride, total hardness, nitrate, and total coliform. Following Batabyal and Chakraborty (2015); WQI values were divided into different categories: excellent (WQI < 50); good (50 to 100); poor (100 to 200); very poor (200 to 300). During pre-monsoon the river water sample fell into all the five classes, “excellent to very poor”, and “excellent to poor” in post-monsoon (Figure 4; Table 7).

WQI at site 1, 2, 3 i.e., Narmada main Kund, ram ghat, and Vivekananda ghat situated at the origin of the
river were found to be in good quality because at this locations the water is in running condition without any obstructions to its flow having self-cleansing capacity, whereas at site 4 (Kapil Dhara) the water is collected through a check dam which forms a small pond again and it’s overflow further continues as Narmada river, sampling at Kapildhara was possible only from this dam which remains stagnant, due to its stagnant condition water quality might be poor at this site.

Site 5 (Chandan ghat) which is about ~90 km from Kapildhara, is located in the upstream of the Dindori region, during its course it flows through the hilly regions and bedrocks getting self-cleaning, with less human interaction. So, the water quality at this ghat is of good to excellent quality. Further at site 6 (Dindori Bus stand) quality of water was found to be poor because at this location the river receives effluent through drains. Further, from the site (7–10) i.e., Manode, Sangam ghat, Rapta ghat, and Ranrez ghat all these ghat lie in the Mandala district which is one of the oldest towns of Madhya Pradesh, is densely populated. Municipal effluent is discharged in Narmada through the small drains in the river Narmada. At this site, pilgrims often visit to perform ritual activities and bathing. All these activities make water quality poor at these sites.

At sites (11–14) i.e., Gwari ghat; Tilwara ghat; Bheda ghat; and Barman ghat also water quality was found to be poor, this is because of the anthropogenic activities. Site 15 (Bandarban ghat) is located in Narsinghpur district and the water quality at this site was found to be excellent.

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Figure 3. (a) A component plot of water parameters in rotated space for pre-monsoon. (b) A component plot of water parameters in rotated space for post-monsoon.
Water quality at sampling sites 16–17, Budhni ghat, and Sethani ghat which were situated in Hoshangabad district, at approximately ~650 Km from the origin of the river Narmada were found to be poor. These sites are highly active due to human intervention and religious happenings thus polluting the river. The security paper mill in Hoshangabad also discharges its effluent in the Narmada River through a small drain near Budhni ghat which degrades its water quality. Overall poor water quality was observed during both seasons.

Conclusions

The physicochemical characteristics of the Narmada River have been evaluated at 17 different sampling points along the stretch of the river located between Amarkantak to Hoshangabad. Further, analyzed values were used to calculate WQI, PCA, and HCA. The calculated WQI implies that the river water quality was poor at present and is not suitable for daily needs in both seasons. Further, PCA
explained three and two PCs for pre- and post-monsoon season respectively. Based on similar water quality parameters HCA generated three and two groups, for the pre- and post-monsoon seasons, respectively. These groups visually reflected the spatial and temporal changes in water quality seasonally and indicated that urban pressure is mostly playing a crucial role in the alteration of its water quality. The major source of pollution was from agricultural runoff, municipal, and domestic sewage inputs. Overall it can be concluded that the water quality of the river Narmada is poor, it needs to be treated before use. The information obtained from this research can help decision-makers in proper management and protection of the Narmada River.

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