

## Evaluation of health risk and heavy metal pollution status in the Bhima River water Kalaburagi, Karnataka, India

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### Abstract

The current investigation aimed to examine the present status of pollution in the Bhima River using indices (degree of contamination, heavy metal evaluation index, & heavy metal pollution index) and health risk assessment (non-carcinogenic & carcinogenic) by choosing some heavy metals like copper (Cu), chromium (Cr), manganese (Mn), cadmium (Cd), nickel (Ni), lead (Pb), & zinc (Zn). Eight samples of surface water were collected monthly from October 2021 to September 2022 and analyzed by an atomic absorption spectrometer. The absorptions of heavy metals into sequence  $Mn > Zn > Cu > Pb > Ni > Cr > Cd$  have been observed. Pb, Cd, and Ni concentrations were considerably higher in samples collected near sewage runoff and along bridges. The calculated pollution indices indicate that five of the eight sampling sites are extremely polluted. Carcinogenic & Non-carcinogenic dangers were tabulated for adults, children, & infants according to the quantity of heavy metal content in an average daily consumption of water. For adults, children, as well as infants, the estimated non-carcinogenic standards were 3, 5, and 2, respectively. The computed carcinogenic risk levels for Pb, Cd, and Ni exceed the  $10^{-6}$ - $10^{-4}$  acceptable limit. Indices and risk assessment values suggest that river water is not acceptable for ingestion by all age groups. Additionally, principal component analysis and cluster analysis disclosed that agricultural runoff, lead battery usage, sewage sludge, and bridge construction were the foremost sources of water quality degradation in the study zone. The development of a public drinking water supply is advised by this research to lessen negative impacts of heavy metal poisoning upon human health. Before making the water available for use by the public, it needs also be treated.



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## Introduction

Water is a fundamentally occurring substance that is essential for all living creatures to live and also serves as a life supporter, accounting for 70–90% of all living cells.<sup>1</sup> Natural freshwater layers like rivers, lakes, and wetlands are the chief water supply sources for meeting the regular needs of water required by households, agriculture, and industries.<sup>2,3</sup> It is a universal solvent and has been widely consumed by all living creatures. So, it's often turned out to be a source of innumerable infections.<sup>4</sup> According to the World Health Organisation (WHO), people worldwide must be provided with clean and safe drinking water. The availability of safe water has become the biggest concern for people in most developing countries.<sup>5</sup>

A river is world's significant natural resources because it supports a diverse range of aquatic species and aids in biodiversity protection.<sup>6</sup> Because of the easy access to essential resources, the river banks have drawn inhabitants since prehistoric times. As a result, rivers are regarded as the lifeline of human civilization.<sup>7</sup> Unplanned urbanization and industrial growth grew along the river's bank.<sup>8</sup> A considerable volume of industrial and agricultural waste is being thrown into rivers with the hope that the toxic agents will be diluted and detoxified by the action of numerous detoxifying agents.<sup>9</sup> Water pollution has risen at an alarming rate in India as a consequence of severe industrialization along with urbanization, with around 70% of rivers in India being contaminated.<sup>9-11</sup>

Heavy metals have been one of the significant pollutants of surface water in recent decades.<sup>12</sup> The use of heavy metal contaminated water for agricultural and other field activities, not only the soil and productivity of crops are affected, but also the health of animals and humans are affected by the food and water.<sup>13</sup> Heavy metals contamination is a protracted and irrevocable process.<sup>14</sup> High amounts of heavy metals like zinc, cadmium, arsenic, cobalt, copper, chromium, nickel, mercury, and lead were often found in the environment as a consequence of anthropogenic activity.<sup>15</sup>

In the industrialized human society, metals have sundry applications and play an important role.<sup>16</sup> A few heavy metals like Cu, Fe, Zn, and Mn are vital to the physiological and biochemical systems. However,

toxicity ensues when the concentration of metals increases beyond a specific limit.<sup>17</sup> In recent years, a variety of methods have been used for assessing heavy metal pollution in water along with its effects of it on human health, including the use of polluting manifestations like heavy metal pollution index (HPI), degree of contamination (Cd), heavy metal evaluation index (HEI), & health risk assessments like non-carcinogenic and carcinogenic.<sup>18</sup> These are valuable tools for water quality decision-makers, ecologists, and civil authorities. Since they provide an overall pollution level index and surface water quality status.<sup>19</sup> Indices are used to calculate the potability of water. As a result, it has been regarded as one of the most valuable methods for determining water contamination.<sup>20</sup> International Agency for Research on Cancer (IARC) considers metals like Cd, Cr, Ni, and Pb to be carcinogenic.<sup>21</sup> Numerous studies on the heavy metal pollution indices & risk assessing in ground and surface water have been published in various parts of the world.<sup>3,18,22,23,24</sup>

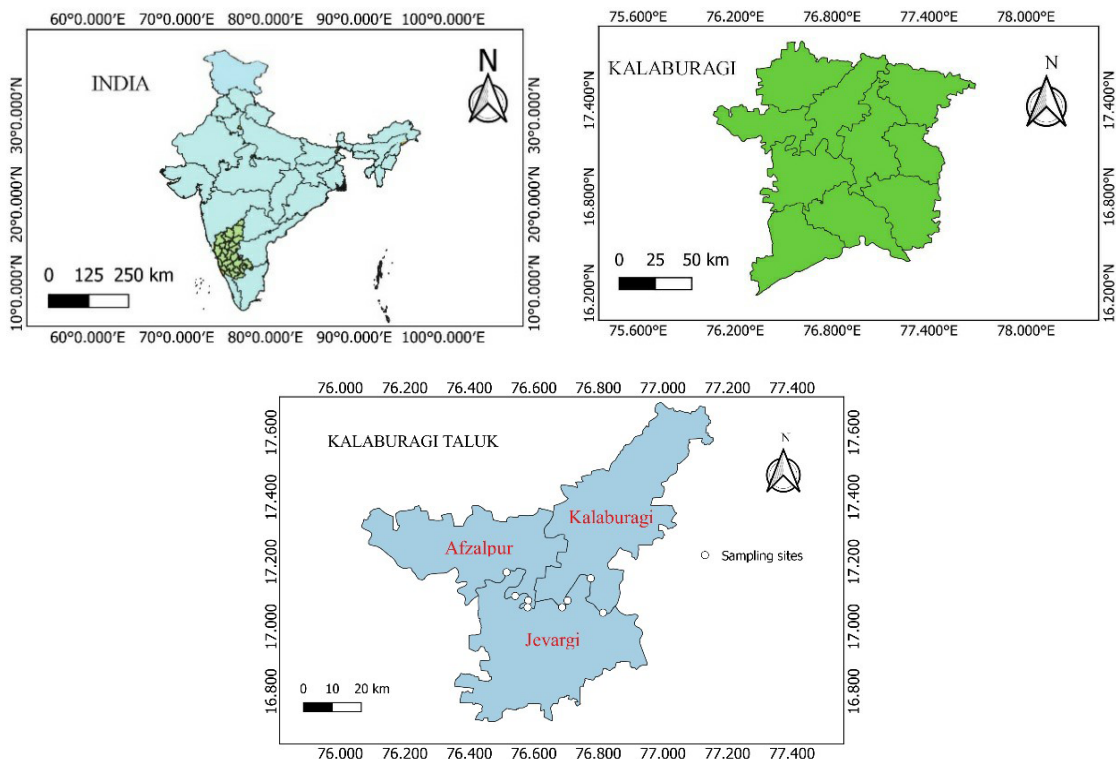
Ganiyu<sup>18</sup> sought to assess the contamination status of hand-dug wells along the Ona River in terms of human and ecological health threats. All examined water samples were found to be "practically unpolluted" to "somewhat contaminated" in terms of integrated pollution indexes. In regards of the ecological risk index (ER), cadmium had a significant to very high risk in all collected water samples, but manganese and zinc had a low risk in all collected samples. The order of contributing ratios by examined metals for non-carcinogenic risk was Cd>Pb>Zn>Fe>Mn. The computed target hazard quotient owing to ingested HMs exceeds the acceptable limit in the order of adults for three human demographic groupings, and urged to enhance hygiene habits, pre-treating of water before usage being most critical, provision of potable pipe-borne water supply to the inhabitants.

Khan<sup>24</sup> assessed heavy metal contamination in the Ganga Alluvial Plain, India, concentrating on six metals: As, Fe, Cd, Pb, Mn, and Cr. They concluded that the river's hazardous status is visible from the HPI values, with 60% of the sites falling in the critically contaminated portion, 30% in the highly contaminated sector, and just 10% in the slightly contaminated segment and reported that untreated sewage system discharge from domestic and industrial wastewater, as well as agricultural

runoff, is recognised latent source of heavy metal contamination in river water and Mishra and Kumar<sup>3</sup> assessed the NSFQI, CPI, & HPI were used for assessing overall water pollution quality of Narmada River. The river's average NSFQI, HPI, and CPI were determined to be 70.35, 1.35, & 1.98, respectively, indicating as river water is moderately contaminated & unfit for drinking. Furthermore, RAI and CRI are used to assess the likelihood of cancer risk to human health from river water exposure. Significantly, RAI and CRI values less than one indicate a significant risk of cancer owing to higher concentrations of copper ( $\text{Cu} > 50 \mu\text{g/L}$ ), lead ( $\text{Pb} > 10 \mu\text{g/L}$ ), & manganese ( $\text{Mn} > 100 \mu\text{g/L}$ ).

River Bhima, one of the most important water bodies in North Karnataka, is embellished with stories from religion and mythology and is worshipped at several locations along its banks. It is currently polluted as a result of human activity. Many researchers, including Kumar,<sup>25</sup> Pawar,<sup>26</sup> Saikiran and Patil,<sup>27</sup> Pardeshi,<sup>28</sup> Patil,<sup>29</sup> and Prabhavati,<sup>30</sup> have studied the Bhima river's water quality using physio-chemical characteristics. They found that sewage runoff,

agricultural discharge, industrial effluents, and anthropogenic interferences are the main causes of the river's declining water quality. Studies on the effects of heavy metals from the Bhima River on water, fish, and sediment have been done by a few authors, including Vaishnavi and Gupta,<sup>31</sup> assessed metal contamination in Mula, Mutha and Pavana, a tributary of Bhima river, Shindhe,<sup>32</sup> investigated buildup of heavy metal concentrations in various body parts of Chillapi fish from the Ujjani Reservoir, which receives water from a number of rivers including the Mula, Mutha, and Bhima, and Chinmalli and Vijaykumar,<sup>33</sup> worked on the heavy metal contamination in Bhima river sediment from Kalaburagi region. Thus, now it's essential to know the current status of metal pollutants in the river water. No inclusive study on water contamination was directed into Bhima River of Kalaburagi region. Present study inspects metals like Cd, Cr, Cu, Ni, Pb, Mn, and Zn & evaluates various findings to compile a complete database. To estimate the surface water quality of river, pollution indices like HPI, HEI, Cd, & health-risk assessment are computed.



**Fig.1: Kalaburagi district Map representing 8 sampling stations (Source: QGIS 3.16)**

## Materials and Methods

### Study Area

The Bhima River flows through the district of Kalaburagi in Karnataka (Fig. 1), which is located into Northern region of Karnataka state ( $76^{\circ} 04''$  to  $77^{\circ} 42''$  Longitude and  $16^{\circ} 12''$  to  $17^{\circ} 46''$  Latitude) and is located 454 meter above mean sea level (MSL). The river is one of tributaries of the river Krishna. It originates in the Bhimashankar foothills of Maharashtra's Western Ghats and flows for approximately 75 kilometres along the shared state boundary of Karnataka and Maharashtra before entering Karnataka near the town of Sheshgiri, and flows for a distance of about 294 km entirely in Karnataka and joins the Krishna River near Yadgiri district.<sup>34</sup> The study area covers Aflazpur and Jevargi talukas of the Kalaburagi district, through which the Bhima River passes. Eight sampling locations were chosen to assess the heavy metal concentration.

### Sample Collection

Surface water samples were collected monthly into 1 litre pre-rinsed polyethylene bottles from eight distinct, pre-determined places over a year, from October 2021 to September 2022. Site S1, S3, and S6 were situated near the temple region, especially Site S1 have the high religious practices and anthropogenic activities. Site S2 is selected based upon on less human interferences. Site S4, S7, and S8 have followed with recent bridge construction activities. Whereas, S6 have the highest human interferences and have direct sewage disposed region. The different sampling locations are represented in (Table 1). The samples had been acidified with concentrated HNO<sub>3</sub> (Nitric acid) and stored in an icebox at 4°C. A GPS device has been utilized for recording the coordinates of sample collection locations.

**Table 1: Site & geographic coordinates of sampling location**

Names of study sites	Study site codes	Latitude	Longitude
Gangapur	S1	17° 10' 06"	76° 30' 57"
Sagnur	S2	17° 05' 57"	76° 32' 34"
Chinmalla	S3	17° 04' 53"	76° 34' 57"
Nelogi	S4	17° 03' 45"	76° 34' 02"
Harwal	S5	17° 03' 39"	76° 41' 12"
Rasangi	S6	17° 04' 51"	76° 42' 15"
Saradgi -B	S7	17° 09' 02"	76° 46' 39"
Jevargi	S8	17° 02' 34"	76° 48' 50"

### Sample Digestion and Analysis

A volume of a 100ml sample of water was obtained into a beaker and digested by adding 5ml of concentrated nitric acid (HNO<sub>3</sub>) on a hot plate until the quantity was reduced to 25 ml. Later, samples were filtered in a 100ml volumetric flask utilizing Whatman No.44 filter paper, filling it to optimum volume with distilled water.<sup>12</sup> Heavy metal analysis for copper (Cu), zinc (Zn), nickel (Ni), chromium (Cr), manganese (Mn), lead (Pb), & cadmium (Cd) were performed using an atomic absorption spectrophotometer (AAS).

### Heavy Metal Pollution Index

By associating it with the desirable limit of drinking water given by various organizations, HPI is utilized

for estimating the total quality of water depending upon heavy metal concentration.<sup>35</sup> The unit weight of each metal is assigned a range of 0 to 1, and it reflects the comparative significance of one metal over another.<sup>36</sup> The HPI has been deliberated upon by the below equations.<sup>37</sup> The unit weight of each parameter was determined by equation 1 and 2.

$$W_i = K / S_i \quad \dots(1)$$

$$K = 1 / \sum_{i=1}^n 1/S_i \quad \dots(2)$$

$W_i$  signifies the unit weight of heavy metal was assigned according to the formula,<sup>18,23</sup> K represents proportionality constant, and  $S_i$  denotes the recommended standard range for each parameter.

A quality rating for heavy metals was obtained using Eq. 3 (Table 2).

$$Q_i = \sum_{i=1}^n M_i - I_i / S_i - I_i ) \times 100 \quad \dots(3)$$

Where  $Q_i$  is the quality rating score,  $M_i$  stands for measured concentration of an  $i$ th heavy metal,  $I_i$

represents ideal standard range of an  $i$ th parameter, and  $n$  indicates total number of heavy metals measured for this study.

HPI was estimated using Eq. 4

$$HPI = \sum_{i=1}^n W_i Q_i / \sum_{i=1}^n W_i \quad \dots(4)$$

**Table 2: Standard range, Ideal range, and Highest admissible range for the analysed elements (mg/L).<sup>38</sup> elements (mg/L).<sup>38</sup>**

Parameters	Recommended Standard range (Si)	Ideal range (Ii)	Highest admissible range (HAR)
Cu	1.5	0.05	1.5
Ni	0.02	0	0.02
Cr	0.05	0	0.05
Mn	0.3	0.1	0.3
Cd	0.003	0	0.003
Pb	0.01	0	0.01
Zn	15	5	15

Cu-copper, Cd-cadmium, Cr-chromium, Pb-lead, Mn-manganese, Ni-nickel, Zn-zinc

**Degree of Contamination**

A degree of contamination ( $C_d$ ) was proposed by Backman<sup>39</sup> to valuate heavy metals into groundwater and stated that same method could be followed to verify the contamination degree for surface water. The element with analytical values less than the maximum allowable concentration has not been considered. The current study approved a modified version of Edet and offiong.<sup>40</sup> The degree of contamination in gathered samples was calculated by Eq. 5 and 6.<sup>39,40</sup>

Calculating the contamination parameter ( $C_{fi}$ ) by the relation below

$$C_{fi} = C_{Ai} / C_{Ni} - 1 \quad \dots(5)$$

Here,  $C_{fi}$  defines the factor of contamination for an  $i$ th metal,  $C_{Ai}$  denotes the observed concentration of an  $i$ th metal,  $C_{Ni}$  represented the higher allowable concentration of an  $i$ th metal, ( $N$  signifies normal values).

Degree of contamination ( $C_d$ )

$$C_d = \sum_{i=1}^n C_{fi} \quad \dots(6)$$

**Heavy Metal Evaluation Index**

The HEI index is utilized as a heavy metal pollution indicator, which indicates the pollution in the region to its maximum permissible heavy metal in potable water.<sup>41</sup> HEI was calculated by the equation.<sup>40</sup>

$$HEI = \sum_{i=1}^n H_c / H_{mac} \quad \dots(7)$$

$H_c$  is the obtained heavy metal concentration, and  $H_{mac}$  is the maximum permissible range of heavy metals.

**Risk Assessment for Human Health**

The United Agency for Environmental Protection (USEPA)<sup>42</sup> for human health risk valuation prototypical is used to estimate carcinogenic and non-carcinogenic risk for heavy metals with a concentration over the Bureau of Indian Standards tolerable level (BIS).<sup>38</sup> Three main ways for humans to get exposed to trace metals are inhalation, dermal absorption, and direct ingestion. For water exposure, dermal absorption as well as ingestion, are the commonly anticipated ways.<sup>43</sup> In this study, ingestion of water is taken into consideration for the calculation of risk assessment. Non-carcinogenic

& carcinogenic risks related to heavy metals were estimated with use of equation 8-11.<sup>18,44,45</sup>

### Lifetime Average Daily Dose

The assessment of the expected magnitude of a negative health effect and its likelihood of happening as a result of exposure to hazardous chemicals over a certain time period is required when dealing with heavy metals in drinking water.<sup>46</sup> The Lifetime average daily dose (LADD) is quantified by the equations.<sup>45</sup>

$$\text{LADD} = C_{\text{obt}} \times \text{IR} \times \text{ED} \times \text{EF} / \text{BW} \times \text{AT} \quad \dots(8)$$

LADD represents lifetime typical daily dosage of heavy metal intake by potable water (mg/kg/day),  $C_{\text{obt}}$  is obtained heavy metal concentration of sample (mg/L), IR signifies the water consumption amount, which is 250ml per-day for infants (new-borns), aged 0 to 12 months, 1.5L per-day for children, and 3L per-day for adults.<sup>44,45,47</sup>

EF indicates the exposed rate (days/year), ED is the exposure duration, i.e., 68.8 years,<sup>48</sup> BW is regarded as body weight, 6.9kg for infants, 18.7kg for children, & 57.5kg for adults, respectively,<sup>49</sup> AT denotes the average time (days).

### Non-Carcinogenic Risk

A hazard quotient (HQ) is used to assess heavy metals potential non-carcinogenic risk, and is assessed by using the following equation.<sup>44,45,50</sup>

$$\text{HQ} = \text{LADD} / \text{RfD} \quad \dots(9)$$

Here, HQ represents the hazard quotient towards heavy metal ingestion through drinking water for each age group, LADD represents the lifetime typical everyday dosage of heavy metal intake by potable water (mg/kg/day), and RfD represents the oral reference dosage of heavy metal that a person could be exposed to throughout their life without experiencing any adverse effect upon health (mg/kg/day).<sup>45</sup> For Cd, Cr, Zn, and Mn, RfD values were derived from USEPA,<sup>51</sup> whereas for Ni and Pb, they were obtained by referring to Raja<sup>23</sup> and the Cu value was referred to by Vetrinmurugan,<sup>44</sup> 0.0005, 0.003, 0.3, 0.14, 0.1, 0.0035, and 0.005 respectively.

### Hazard Index

The sum of all hazardous quotients associated with heavy metals absorbed through the consumption of water is termed the hazard index (HI). The hazard index was calculated using equation 10.<sup>18</sup>

$$\text{HI} = \sum_{i=1}^n \text{HQ}_i \quad \dots(10)$$

### Carcinogenic Risk

Cancer risk is assessed as the cumulative chances of an individual in an environmental scenario acquiring cancer as a consequence of exposure to heavy metals throughout of their lifetime.<sup>18,46</sup> The carcinogenic risk was calculated using following equation.<sup>23</sup>

$$\text{CR} = \text{LADD} \times \text{CSF} \quad \dots(11)$$

Here, CR is a carcinogenic risk, LADD is a lifetime average daily dosage, and CSF is a carcinogenic risk factor.<sup>51</sup> The risk produced by specific heavy metals is indicated by CSF. The values of CSF attained by the Risk Assessment Information System (RAIS)<sup>52</sup> for Pb and Ni were 0.0085 and 0.91, respectively.<sup>52</sup> Cd had a CSF value of 0.38.<sup>23</sup>

### Multivariate Statistical Analysis and Spatial Plots

Cluster analysis (CA), as well as principal component analysis (PCA), have been carried out on PAST-4.03 to analyze the connection of water samples from these areas based on heavy metal levels. QGIS 3.16 software was utilized for creating spatial distribution plots of studied heavy metals.

### Result and Discussion

The standard, monitored, average, minimum, and maximum ranges of heavy metal concentration into water samples of eight different locations were summarised in Table 3, which follows order Mn>Zn>Cu>Pb>Ni>Cr>Cd. All surface samples contained Pb, Ni, and Cd values greater than the BIS acceptable limit of 0.01mg/L, 0.02mg/L, & 0.003mg/L, respectively.<sup>38</sup> In all analyzed water samples, the Zn concentration has been observed well within the maximum desired range of 15 mg/L,<sup>38</sup> i.e., ranging from 0.0486 to 0.0887mg/L by typical range of 0.0639mg/L. Zn distribution scheme displays that the highest concentration was



found at sampling stations like S5 and S6 (Fig.2a). The average concentration of Cu in sample of water into study region was 0.0631 mg/L & fluctuated from 0.0428-0.1547 mg/L within BIS range of 1.5 mg/L. A maximum concentration was observed at sampling station S6 (Fig.2b). The observed Mn value oscillated from 0.0414 to 0.1850 mg/L, having a typical range of 0.0928 mg/L less than BIS standards of 0.3mg/L. Spatial distribution of Mn shows that the highest level was seen at sampling stations like S4 and S5 (Fig.2c). All the analyzed samples indicate the Cr value of 0.0043 to 0.0219 mg/L, having an average of 0.0133mg/L within permitted range of 0.05 mg/L.<sup>38</sup> Maximum Cr values were observed in sampling stations S5, S7, and S8 (Fig.2d).

Recorded Pb concentration data shows that five of 8 sampling stations were observed to be marginally higher than the desirable range of 0.01 mg/L<sup>38</sup> at the stations like S4, S5, S6, S7, & S8 (Fig.2e). The Pb range was 0.0072 to 0.1073mg/L, having average of 0.0579 mg/L. Except for S3 site, remaining sampling stations exceed the desirable limit of Cd value of 0.003 mg/L<sup>38</sup> (Fig. 2f), having a mean of 0.0099 mg/L ranging from 0.0029 to 0.0145 mg/L. Ni values were higher than permissible limit of 0.02

mg/L at 75% of sampling stations, averaging 0.0368 mg/L, with concentrations oscillating from 0.0169 to 0.0617 mg/L. The maximum concentrations of Ni were reported at the S4, S5, and S6 sites (Fig.2g). The distribution plot (Fig. 2) of heavy metals shows that sites like S4, S5, S6, S7 and S8 were highly contaminated with Pb, Cd, and Ni. The prime non-point causes of heavy metals in Bhima River were lead & cadmium, which was the main causes of lead and cadmium due to immoderate use of fertilizers, pesticides, and lead batteries.<sup>53</sup> (b) sewage disposal and household waste may be the source of Ni, Cr, Pb, Cd, Zn, and Cu.<sup>54</sup> (c) Bridge construction is the major contamination source of most of the heavy metals.

### Spatial Distribution

The spatial distribution maps give baseline data to prevent and regulate heavy metal pollution of water and assist in identifying safe and risky zones.<sup>55</sup> Ni, Pb, and Cd in river water had a similar pattern of distribution, with greater concentrations near the S4, S5 and S6 of the research region and lower concentrations towards the S1, S2, and S3. The Spatial comparative concentration of heavy metal are represented in Fig. 2.

**Table 3: Concentration of heavy metals in different sampling stations (mg/L)**

Metals	Zn	Cu	Mn	Cr	Pb	Cd	Ni
Sites							
S1	0.0551	0.0546	0.0637	0.0043	0.0087	0.0116	0.0143
S2	0.0486	0.0428	0.0414	0.0046	0.0072	0.0033	0.0169
S3	0.0488	0.0490	0.0527	0.0062	0.0081	0.0029	0.0242
S4	0.0603	0.0540	0.1728	0.0142	0.0442	0.0143	0.0527
S5	0.0887	0.0603	0.1850	0.0219	0.0991	0.0145	0.0617
S6	0.0842	0.1547	0.0859	0.0144	0.0948	0.0083	0.0498
S7	0.0687	0.0447	0.0538	0.0197	0.0940	0.0141	0.0313
S8	0.0569	0.0450	0.0874	0.0212	0.1073	0.0105	0.0442
Average	0.0693	0.0631	0.0928	0.0133	0.0579	0.0099	0.0368
Minimum	0.0486	0.0428	0.0141	0.0043	0.0072	0.0029	0.0169
Maximum	0.0887	0.1547	0.1850	0.0219	0.1073	0.0145	0.0617
WHO (2012)	5 – 15	0.05– 1.5	0.1 – 0.3	0.05	0.01	0.003	0.02

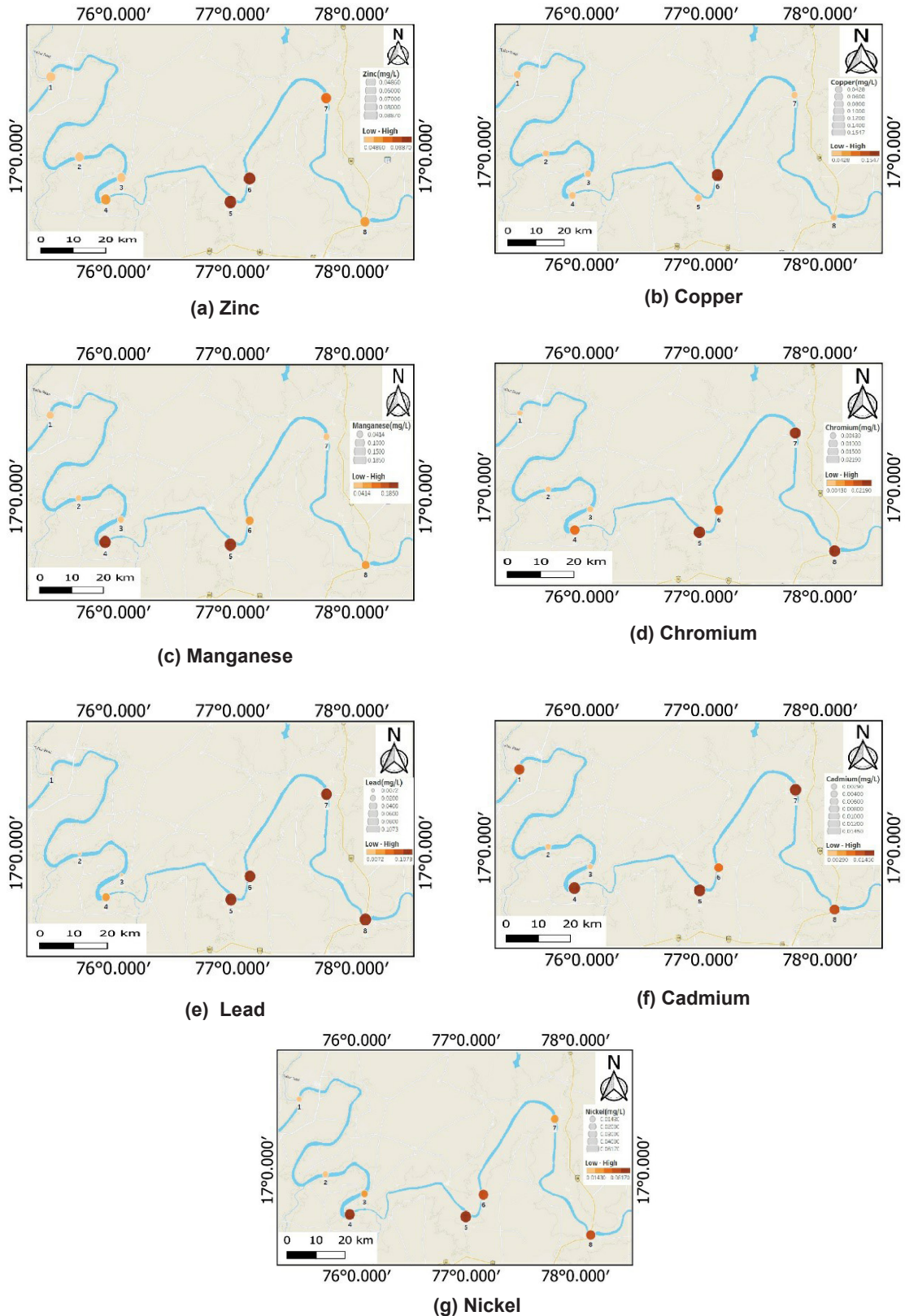


Fig 2: Spatial distribution of heavy metals in study area (mg/L) (Source: QGIS 3.16, and Tableau)



### Pollution Indexes

The calculated HPI, Cd, HEI, non-carcinogenic, and carcinogenic risks are given in Table 4. HPI values ranged from 92 to 589, where most were above the critical limit of 100.<sup>56</sup> According to Ghaderpoori,<sup>57</sup> water quality in HPI is categorized into three categories: 100 low threshold risk, equivalent to 100 threshold risk, and > 100 high threshold risk. If the HPI number is greater than 100, the water is deemed unsafe to drink.<sup>57</sup> Site S2 and S3 water samples were classified as low threshold risk and can be used for drinking purposes only after some specific treatment, like simple filtration. High threshold risks were assigned to sites S1, S4, S5, S6, S7, and S8. S5 recorded the highest HPI value of 589, whereas the lowest HPI value, i.e., 92, was observed at S3. The average HPI value was found to be 355.25. Khan<sup>24</sup> followed the same trend of higher HPI (22.6 to 263.9) in the Gomti river. Table 5 represents the Assessment of heavy metal pollution index range with earlier studies carried out in the different countries.

Backman<sup>38</sup> classified the degree of contamination of surface water into three grade scales,  $C_d=1$  (less contaminated),  $C_d=1-3$  (average contaminated), and  $C_d > 3$  (highly contaminated). The  $C_d$  value

attained in the current analysis varies from -4 to 12, having a mean value of 4.62. The highest Cd values were found at S5 and S8 sampling sites. Both Ukah,<sup>58</sup> and Rahman<sup>59</sup> reported comparable results with degrees of contamination ranging from negative to highly positive. Ukah<sup>58</sup> in Nigeria and Rahman<sup>59</sup> in Bangladesh measured contamination levels ranging from -3.2 to 50.7 and -1.43 to 8.12, respectively. Table 6 compares the findings to earlier studies conducted in other sites of the countries.

The heavy metal evaluation index value obtained in the present study varies from 3–19, with an average value of 5. The highest HEI value was reported at site S5, whereas the lowest was found at sites S2 and S3. Prasanna<sup>61</sup> have sorted HEI values into consideration of pollution levels. The distinct values of pollution are delineated with several mean values. Projected HEI values are reclassified for sample trails, lower (HEI 5), average (HEI 10), and higher (> 10). These values were consistent with Herojeet<sup>60</sup> values ranging between 9.45 and 29.08 in Himachal Pradesh. Table 7 contrasts the outcomes with past research carried out in various places around the globe. The comparative concentration of heavy metal pollution indices are represented in Fig. 3.

**Table 4: Values of HPI, Cd, HEI, Non-carcinogenic and carcinogenic risks**

Indices Sites	HPI	$C_d$	HEI	Non-carcinogenic risk			Carcinogenic risk		
				Infant	Children	Adult	Infant	Children	Adult
S1	279	-1	6	1	3	2	$6.3 \times 10^{-4}$	$1.4 \times 10^{-3}$	$9.1 \times 10^{-4}$
S2	95	-4	3	1	2	1	$6 \times 10^{-4}$	$1.3 \times 10^{-3}$	$8.7 \times 10^{-4}$
S3	92	-4	3	1	2	1	$8 \times 10^{-4}$	$1.8 \times 10^{-3}$	$1.2 \times 10^{-3}$
S4	428	6	13	2	5	3	$1.9 \times 10^{-3}$	$4.3 \times 10^{-3}$	$2.8 \times 10^{-3}$
S5	545	12	19	3	6	4	$2.2 \times 10^{-3}$	$5 \times 10^{-3}$	$3.2 \times 10^{-3}$
S6	394	8	15	3	7	4	$1.7 \times 10^{-3}$	$3.9 \times 10^{-3}$	$2.5 \times 10^{-3}$
S7	511	9	16	3	6	4	$1.2 \times 10^{-3}$	$2.7 \times 10^{-3}$	$1.8 \times 10^{-3}$
S8	465	10	17	3	6	4	$1.6 \times 10^{-3}$	$3.6 \times 10^{-3}$	$2.3 \times 10^{-3}$
Minimum	545	-4	3	1	2	2	$6 \times 10^{-4}$	$1.3 \times 10^{-3}$	$8.7 \times 10^{-4}$
Maximum	92	12	19	3	7	4	$2.2 \times 10^{-3}$	$5 \times 10^{-3}$	$3.2 \times 10^{-3}$
Average	351	5	12	2	5	3	$1.3 \times 10^{-3}$	$3 \times 10^{-3}$	$1.9 \times 10^{-3}$

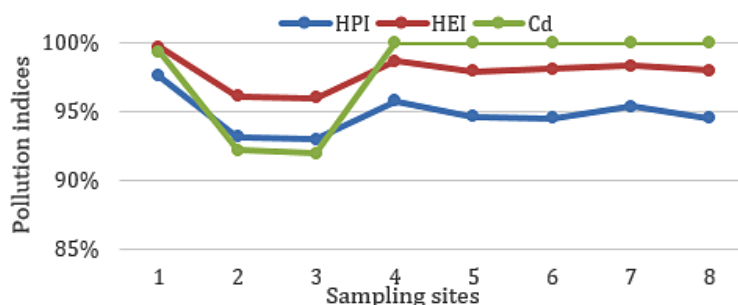


Fig. 3: Comparative values of Heavy metals pollution indices

Table 5: Assessment of heavy metal pollution index range with earlier studies carried out in the different countries.

Sl. No	Site	Heavy metal pollution index		Reference
		Minimal	Maximal	
1	Tamil Nadu, India	999	3232	Raja <sup>23</sup>
2	Uttar Pradesh, India	22.6	263.9	Khan <sup>24</sup>
3	Lagos, Nigeria	0.035	2.84	Ukah <sup>58</sup>
4	Narayanganj City, Bangladesh	99.98	100.01	Rahman <sup>59</sup>
5	Himachal Pradesh, India	0.61	16.78	Herojeet <sup>60</sup>
6	Karnataka, India	92	545	Current study

Table 6: Assessment of degree of contamination range with earlier studies carried out in the different countries.

Sl. No	Site	Degree of contamination		Reference
		Minimal	Maximal	
1	Tamil Nadu, India	25	133	Raja <sup>23</sup>
2	Lagos, Nigeria	-3.24	50	Ukah <sup>58</sup>
3	Narayanganj City, Bangladesh	-1.43	8.12	Rahman <sup>59</sup>
4	Himachal Pradesh, India	0.23	19.43	Herojeet <sup>60</sup>
5	Karnataka, India	-4	12	Current study

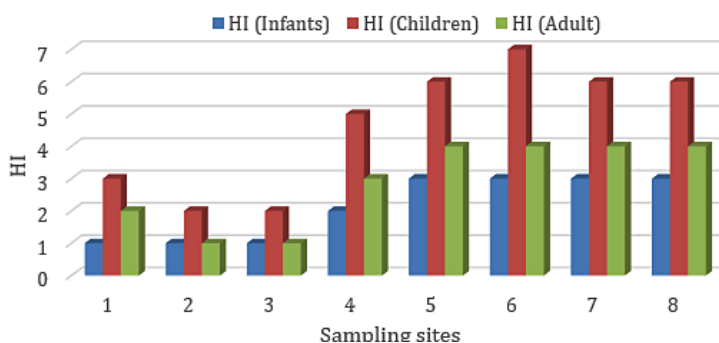
Table 7: Assessment of heavy metal evaluation index range with earlier studies carried out in the different countries.

Sl. No	Site	Heavy metal evaluation index		Reference
		Minimal	Maximal	
1	Tamil Nadu, India	42	140	Raja <sup>23</sup>
2	Lagos, Nigeria	0.7	59.7	Ukah <sup>58</sup>
3	Narayanganj City, Bangladesh	16.40	273.43	Rahman <sup>59</sup>
4	Himachal Pradesh, India	9.45	29.08	Herojee <sup>60</sup>
5	Karnataka, India	3	19	Current study

**Health Risk Assessments**

The non-carcinogenic risk for infants, children & adults was calculated for each of the seven heavy metals for which RfD standards were accessible. If  $HI \leq 1$ , is safe, &  $HI \geq 1$  might pose risk. For infants, children, and adults, the derived HI values ranged from 1-3 with a mean value of 2, 2-7 with an average of 5, and 1-4 with a mean value of 3, indicating that

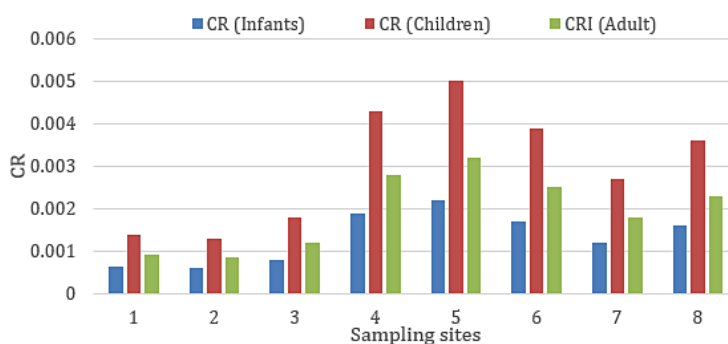
children have been at higher risk than adults and infants. The locations with the greatest HI values were sites S4 and S5. The non-carcinogenic risk is represented as children > adults > infants (Fig. 4). A similar result was observed by Vetrimurugan<sup>44</sup> and Wagh.<sup>62</sup> The assessment of non-carcinogenic range with past research conducted in several regions of the globe is shown in Table 8.



**Fig. 4: Site-wise values of Non-carcinogenic risk**

Cd, Ni, and Pb concentrations surpass the permissible range at most sampling stations. Carcinogenic elements categorized by IARC include these three metals. The Carcinogenic risk related to these three metals was deliberated. The calculated carcinogenic risk for infants was  $6 \times 10^{-4}$  to  $2.210^{-3}$ , with a mean value of  $1.310^{-3}$ . The highest CR for infants was recorded at the S5 sampling site. The range of CR for children was  $1.3 \times 10^{-3}$  to  $5 \times 10^{-3}$ , with an average of  $3 \times 10^{-3}$ . The highest CR value for children was found to be at S5. While the CR value for adults ranged between  $8.7 \times 10^{-4}$  and  $3.2 \times 10^{-3}$ , an average value of  $1.9 \times 10^{-3}$  was obtained. A high CR value

for adults was found at the S5 site (Fig 5). Usually, a risk value higher than  $10^{-4}$  shows an unbearable carcinogenic health risk, whereas a risk range of  $10^{-6}$  might be regarded as the maximal permissible level. If the risk value ranges from  $10^{-6}$  or  $10^{-4}$ , the health risk is accepted as bearable, and ranging from  $10^{-8}$  or  $10^{-7}$  is considered insignificant.<sup>8,63</sup> Considering risk assessment outcomes, it's clear that children are more susceptible to carcinogenic effects than adults & infants. Similar findings were observed by Zahm and Devesa.<sup>64</sup> Table 9 compares the carcinogenic results with prior study done in various parts of the globe.



**Fig. 5: Site-wise values of Carcinogenic risk**

**Table 8: Assessment of non-carcinogenic range with earlier work carried out in the different sites of the globe.**

SI. No	Site	Non-carcinogenic risk			Reference
		Infants	Children	Adult	
1	Southwest, Nigeria	0.061	0.046	0.0135	Ganiyu <sup>18</sup>
2	Tamil Nadu, India	8.3	18.3	11.9	Vetrimurugan <sup>44</sup>
3	Nasik, India	10.41	23.05	14.99	Wagh <sup>62</sup>
4	Ebonyi, Nigeria	-	5.69	2.45	Ugbede <sup>65</sup>
5	Karnataka, India	2	5	3	Present study

**Table 9: Assessment of carcinogenic range with earlier work carried out in the different sites of the globe.**

SI. No	Site	Carcinogenic risk			Reference
		Infants	Children	Adult	
1	Southwest, Nigeria	4.41	2.76	0.92	Ganiyu <sup>18</sup>
2	Karnataka, India	1.3x10 <sup>-3</sup>	3x10 <sup>-3</sup>	1.9x10 <sup>-3</sup>	Present study

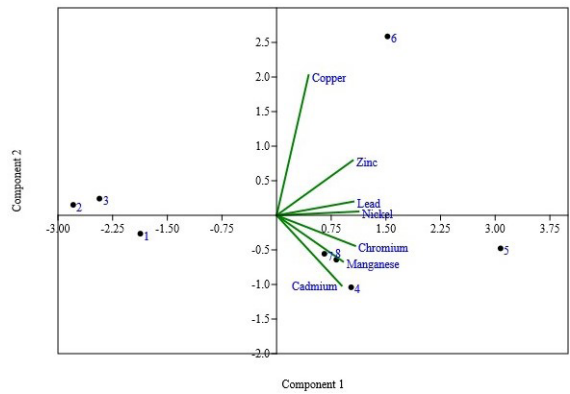
**Principal Components Analysis**

Principal component analysis separated into two major components (Table 5) with an eigenvalue greater than one was used to account for 81.60% of the total variance. PC1 accounting to 63.49% of the total variance is donated by the succeeding variables like Mn, Zn, Cr, Cd, Ni, and Pb. Lead, Ni,

Pb, as well as Cd are sourced from lead batteries, bridge construction, and vehicle gas emissions from traffic through bridges. Zn, Mn, and Cr sourced from agricultural runoff and sewage sludge. PC2 shows good relations with copper. Components contribute to 18.11% of the total variance. This characterizes anthropogenic activities (Fig. 6)

**Table 5: Principal components values of analysed heavy metals**

Heavy metals	PC1	PC2
Zn	0.411	0.312
Cu	0.172	0.797
Mn	0.358	-0.263
Cr	0.424	-0.173
Pb	0.415	0.078
Cd	0.351	-0.399
Ni	0.442	0.021
Eigen value	4.444	1.268
Total variance (%)	63.49	18.11

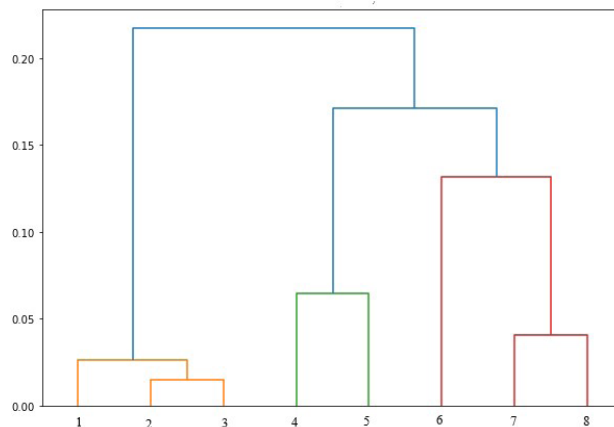


**Fig. 6: Principal component analysis biplot illustrating the effect of heavy metal on Bhima River water quality. The sampling sites are denoted as black dots**

**Cluster Analysis**

The primary purpose of hierarchical cluster analysis is to figure out the best tactic to assemble items with comparable attributes into clusters. The dendrogram shows two primary groups for the research area sample locations: The eight river water sample locations were designated by eight sampling points

and are divided into two groups (Fig. 7). Cluster one comprises three sampling points 1, 2, and 3 all of which have been polluted as a result of human activity. Cluster two includes five sampling points 4, 5, 6, 7, and 8 which were contaminated due to agricultural runoff, sewage sludge, lead batteries, and bridge construction.



**Fig. 7: Dendrogram derived from the hierarchical cluster analysis indicating similarities among the sampling sites**

**Conclusion**

The present study reveals that the Bhima River in the Kalaburagi district is contaminated by numerous metals, and the possible pollutant sources are agricultural runoff, sewage sludge, use of lead batteries, and bridge construction located in the study area. Determined pollution indices indicate that 5 out of 8 sampling stations are extremely contaminated. According to the data assembled by

calculating non-carcinogenic and carcinogenic risks, the sampling stations like S1, S2, and S3 appeared to have the low health risk potential. In contrast, the remaining stations were approved to hold higher health risk potential. It indicates that children within this region consuming the contaminated water will pose high health hazards compared to infants and adults. Surface water samples taken near bridges and sewage runoff contain significant Cd, Pb, and



Ni content, as shown by the geographic distribution plots. The conclusions of our analysis can be used as a preliminary point for additional study into the effects of heavy metal concentrations in drinking water. The high metal content in the river is chief source of worry. Consistent water quality monitoring in this area is crucial for preserving the river's scenic value and fostering aquatic biodiversity.

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#### Conflict of Interest

The authors declare no conflict of interest.

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