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# Metal Contamination of Ganga River (India) as Influenced by Atmospheric Deposition

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**Abstract** Metal contamination of Ganga river in relation to atmospheric deposition was investigated. The data revealed that, although Cr and Cu remained below their maximum admissible concentrations, levels of Cd and Pb in mid-stream waters at five out of six stations were higher than their respective maximum admissible concentration. About 62% of water samples contained Ni above its maximum admissible concentration of 20 μg $L^{-1}$. Metal concentrations in water showed significant correlation and seasonal synchrony with atmospheric deposition. The study forms the first report on air-driven metal contamination of Ganga and has relevance from human health perspectives.

**Keywords** Heavy metal · Atmospheric deposition · Seasonal variability · Ganga River

The rising contaminations of soil, water and agricultural produce with potentially toxic heavy metals have become an important concern world-wide. Heavy metals are implicated in several major human diseases including carcinogenesis-induced tumor promotion (Schwartz 1994). Contaminated soils and irrigation waters have been shown to provide the main route for dietary intake of heavy metals through agricultural produce (Sharma et al. 2007). Some recent observations have indicated that air-borne heavy metals are increasingly becoming an important source of contamination of soil and plant produce even for those areas situated away from the emission sources (Sharma et al. 2007). Urban and peri-urban areas are worst affected by air-borne contaminations (Pandey and Pandey 2009).

The impacts of long-range atmospheric transport and deposition of pollutant aerosols on terrestrial systems are well documented from long-back (Pandey and Agrawal 1994), impact of such depositions on aquatic habitats especially on river systems have received attention only recently (Thornton and Dise 1998). Some earlier studies have indicated sizable atmospheric input of trace metals to lake systems (Eisenreich 1980; Bragazza 2006). Recent researches have indicated rising trends in atmospheric deposition of toxic metals in different parts of the world including the Indian sub-continent (Azimi et al. 2003; Singh and Agrawal 2005). For developing countries in particular, this problem is rapidly rising due to newly establishing industries coupled with fastened urban growth and lack of efficient control measures (Borbely–Kiss et al. 1999; Pandey and Pandey 2009). Furthermore, unlike most of the surface discharge sources which contaminate soil and water bodies under limited spatial range, aerial emission often follows long-range atmospheric transport and contaminates wider range of ecosystems down-wind of the emission sources. In river systems, where the stream-flow restricts mid-stream access of land-borne contaminants, atmospheric deposition directly adds contaminants on to the water surfaces. Thus, despite all efforts to minimize environmental contamination, atmospherically driven toxic metals will continue to contaminate ecosystems including surface water resources. At a time when human health has become a global priority, a better understanding of atmospheric deposition-linked heavy metal contamination of fresh water resources has particular significance. In the present study, an attempt was made to examine variations in the concentrations of five heavy metals in mid-stream water of Ganga river in relation to their inputs through atmospheric

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deposition at Varanasi. This has relevance since the holy river Ganga is the centre of tourist attraction as well as an important source of irrigational and drinking water supply.

## Materials and Methods

The 2 years (March, 2006–February, 2008) of study was conducted at six sampling stations of Ganga river at Varanasi, India. The study area lies between 25° 18′N latitude and 83° 1′E longitude in the midst of eastern Gangetic plane at 76.19 m above msl. The climate of the region is tropical monsoonal with dominant westerly winds. The city of Varanasi is situated at the west margin of the river.

Six sampling stations, selected along a 20 km long tract of Ganga river, represents three sampling sites each. A description of different sampling locations is presented in Table 1. Bulk atmospheric deposition was continuously collected using bulk samplers and analyzed at fortnightly cycle for each sampling site. These collection systems were maintained at a height of 2 m to avoid contamination of re-suspended soil particulates and were devised to avoid bird nesting as described in Pandey and Pandey (2009). Deposition collectors of similar design were used by Singh and Agrawal (2005) in India. Deposition collectors were placed in pairs so that at least two parallel measurements can be carried out. Immediately after collection, the samples of atmospheric deposition were acidified with $HNO_3$ (special purity, Merck), filtered and stored in dark at ambient temperature before analysis. The effect of fortnightly exposition of deposition collectors at ambient temperature on the stability of samples was examined in preliminary studies before the beginning of these long-term experiments. Only 0.2%–0.4% changes in the concentrations of standard solutions were observed indicating that fortnightly exposure of the collectors had no significant effect on the amount of heavy metals collected during this period.

Water collectors were rinsed with nitric acid and mid-stream water samples were collected from all the sampling stations of river Ganga at the depths of 10–15 cm at fortnightly intervals. All water samples were preserved with $HNO_3$. For analysis, a 50 ml water sample was digested with 10 ml of concentrated $HNO_3$ at 80°C (APHA 1989). The solution was filtered through Whatman No. 42 filter paper and diluted to 50 ml with double distilled water. Concentrations of heavy metals in acid digested filtrates of particulate and water samples were determined with an Atomic Absorption Spectrophotometer (Perkin Elmer model 2130, USA), fitted with a specific lamp of particular metal using appropriate drift blank. The detection limits ($\mu g\ ml^{-1}$) of heavy metals were 0.0005 (Cd); 0.002 (Cr); 0.001 (Cu); 0.004 (Ni) and 0.01 (Pb). The chemicals used for analysis were Merck analytical grade. Quality control measures were taken to assess contamination and reliability of data. Blank and drift standards (Sisco Research Laboratory Pvt. Ltd., India) were run after five reading to calibrate the instrument. Analytical variances of the data obtained remained below 10% for all metals.

Significant effects of site and time were assessed by using analysis of variance (ANOVA) following appropriate transformations whenever required. Correlation coefficients ($r$) were determined to test the linearity of relationships between heavy metal concentrations in water and values of atmospheric deposition. Standard error of means (SEM) and coefficient of variation (CV) across time were computed for expressing data variability. The statistical analyses were done using SPSS Programme.

## Results and Discussion

The data on atmospheric deposition of heavy metals are presented in Fig. 1. Since between-year variations were not significant, the data represent mean of both the consecutive

**Table 1** Sampling sites and their characteristics

| S. no. | Sampling site | Characteristics |
|---|---|---|
| 1. | Adalpura, Adlpr | 2 km upstream to Sheetla Mata temple; least anthropogenic interference; away from urban-surface discharge; traffic volume during rush hours: 100–240 vehicles $h^{-1}$ |
| 2. | Bypass upstream, Bypus | 2 km upstream to bypass highway bridge; very high frequency of heavy duty vehicle; offside to urban discharge; traffic volume during rush hours: 1,500–2,500 vehicles $h^{-1}$ |
| 3. | Samne Ghat, Smnght | Near panton bridge; marginal urban-surface discharge; traffic volume during rush hours: ~1,000 vehicles $h^{-1}$ |
| 4. | Assi Ghat, Asght | Near Assi Ghat; receive urban-surface discharge; high stream flow; traffic volume during rush hours: ~1,000 vehicles $h^{-1}$ |
| 5. | Dashaswamedh Ghat, Dsmdght | Near Dashaswamedh Ghat; marginal urban-surface discharge; traffic volume during rush hours: ~1,150 vehicles $h^{-1}$ |
| 6. | Raj Ghat downstream, Rjghtds | 3 km downstream to Malviya bridge; high frequency of heavy duty vehicle; down stream influence, down-wind; high stream flow; traffic volume during rush hours: 1,200–2,100 |

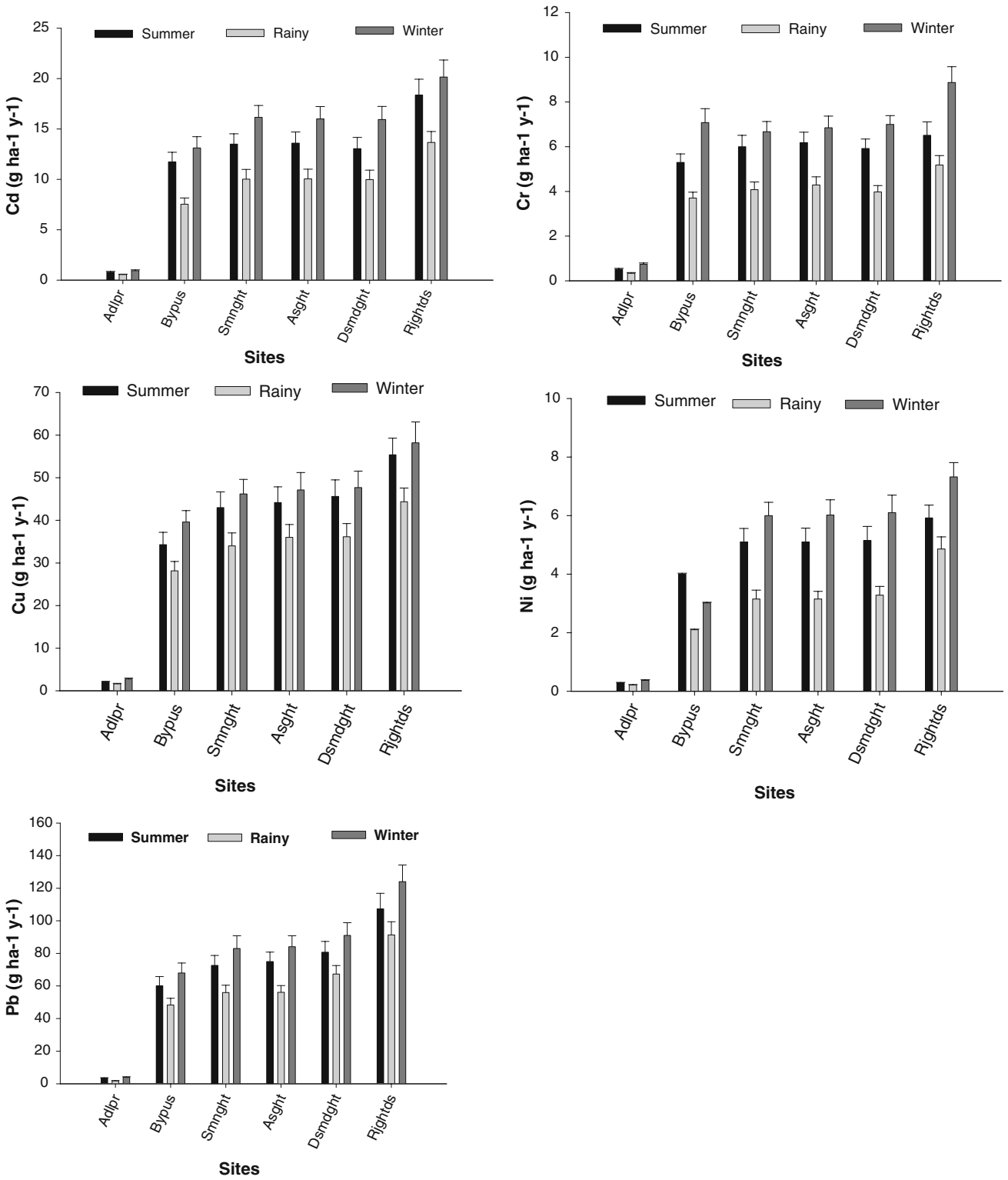


**Fig. 1** Atmospheric deposition of heavy metals at selected river sites of Varanasi. Values are mean (n = 30) ± 1 SE

years of study. Atmospheric deposition was highest for Pb (1.80–124.00 g $ha^{-1}$ $y^{-1}$) and lowest for Cd (0.56–20.15 g $ha^{-1}$ $y^{-1}$), the values appeared high at source oriented sites. Metal depositions observed in this study are comparable to those observed at source and non-source oriented locations of Indian tropics (Singh and Agrawal 2005; Pandey and Pandey 2009). Between-site variations in metal deposition were found to be significant (Table 2).

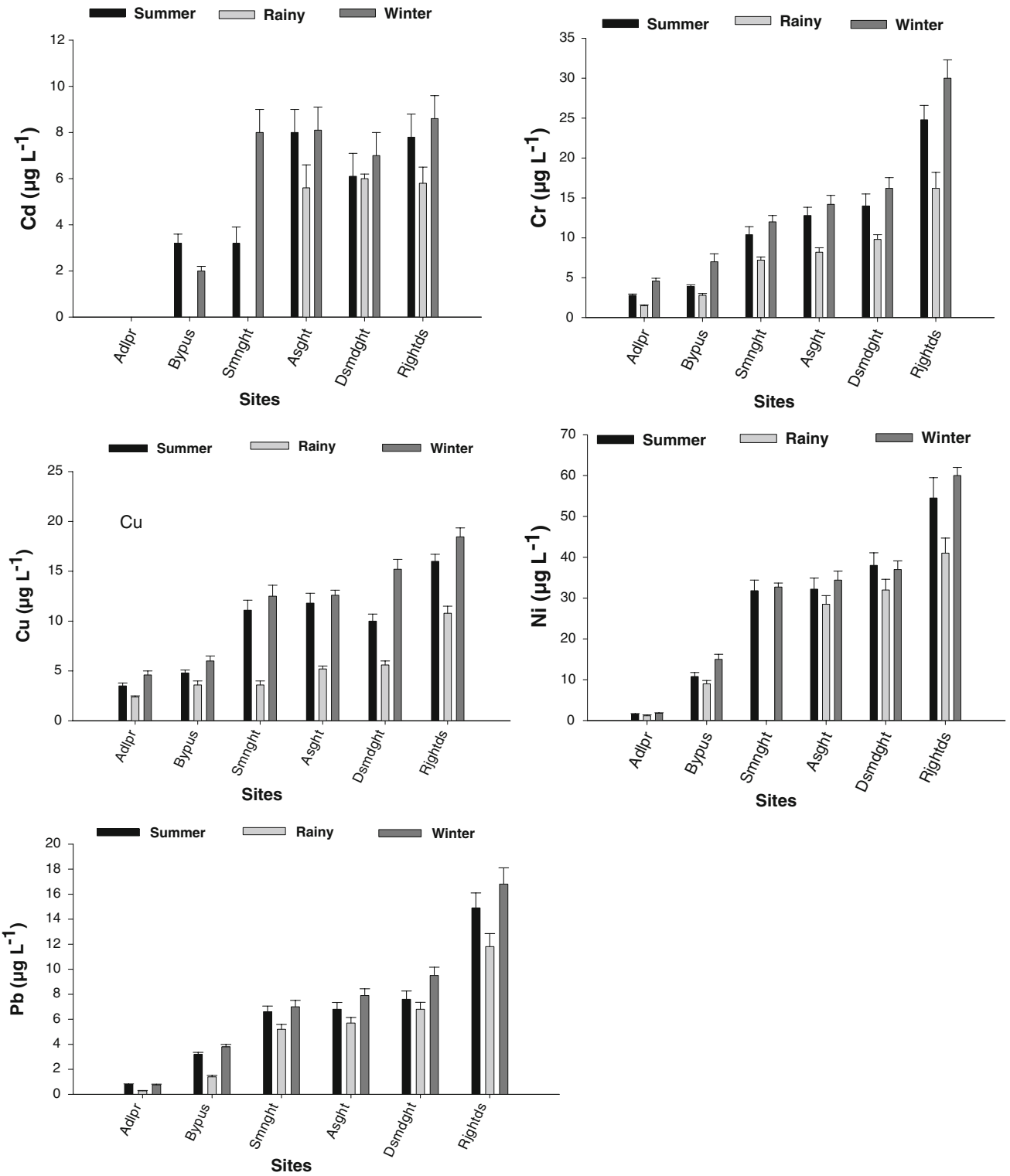


**Fig. 2** Concentrations of heavy metals in mid-stream water of Ganga river at Varanasi. Values are mean (n = 30) ± 1 SE. Values not appeared in the figure are below detectable limits

A comparison of metal levels in mid-stream water showed large differences and followed spatial trends similar to that of the atmospheric deposition (Fig. 2). Except for a few cases, corresponding to atmospheric deposition, concentrations of all the five metals increased almost consistently down-stream from site 1 (Adlpr) to site 6

(Rjghtds). Metal concentration in water was recorded maximum for Ni (1.20–60.00 μg $L^{-1}$) and minimum for Cd (ND – 8.6 μg $L^{-1}$). Almost similar observations have been made by Eder and Offiong (2002) for Lower Cross River Basin, Southeastern Nigeria. On time scale, metal concentrations in water were highest during winter followed by summer and rainy seasons (Fig. 2).

Although rising dietary contamination and inhalation have been considered to be the main route of heavy metal intake to humans, surface water contamination and subsequent intake through drinking have received serious attention relatively recently (Eder and Offiong 2002). In the present study, although the levels of Cr (1.50–29.60 μg $L^{-1}$) and Cu (2.41–18.45 μg $L^{-1}$) in mid-stream waters of all the six locations were below their respective maximum admissible concentration (MAC) of 50 and 1,000 μg $L^{-1}$, the concentrations of Cd (ND – 8.5 μg $L^{-1}$) were found to be greater than its MAC (3.0 μg $L^{-1}$) at 5 out of 6 locations sampled. Similarly, Pb concentrations (0.28–16.79 μg $L^{-1}$) at 5 out of 6 locations were higher than its MAC of 1.5 μg $L^{-1}$ (Siegel 2002). Eighty-seven percent of total water samples had Pb levels above the MAC of 1.5 μg $L^{-1}$, while 62% of the water samples showed Ni exceeding its MAC of 20 μg $L^{-1}$.

Site-wise variation in the concentrations of different heavy metals in mid-stream river water as indicated by ANOVA was significant (Table 2). Correlation analysis indicated significant ($p < 0.01$) relationships between the mean levels of heavy metals in water and their respective deposition (Table 3), suggesting that at least some of the observed variability could be attributed to variations in atmospheric deposition recorded at different locations. Similar observations have been made by Thorton and Dise (1998) in a number of streams in English Lake District of Cumbria. The total aerial metal input (Cd + Cr + Cu + Ni + Pb), ranged from 4.51 to 218.51 g $ha^{-1}$ $y^{-1}$ and with few exceptions, increased almost consistently from Adlpr (site 1) to Rjghtds (site 6). Synchrony between atmospheric deposition and total metal concentration in water (5.38–133.85 μg $L^{-1}$) further indicate atmospheric deposition-linked heavy metal contamination of mid-stream water. Temporal variability although remained high (cv = 0.122–0.336) for heavy metal levels in water than those observed for atmospheric deposition (cv = 0.115–0.326), the differences between mean cv values of these two functions were not significant, suggesting that the atmospheric deposition could be the major contributor to mid-stream water contamination. Vehicular emission is the main contributor to atmospheric pollution load in Varanasi (Pandey et al. 1992). The dominant south-westerly wind could further raise atmospheric transport and deposition of heavy metals to Ganga river. The river also receives urban surface run-off periodically. However, since stream flow restricts cross-stream lateral mixing of surface-fed materials, atmospheric deposition appeared to be a major factor for mid-stream metal contamination. Except for the Adlpr site (a non-source oriented site), all the sampling locations showed that more than 86% of the water samples contained about 2–36 fold higher levels of heavy metals under the influence of emission sources. These 5 locations fall into medium to high concentration zones (Eder and Offiong 2002). Significant between-site variations and down-stream rising levels of metals could be due to the cumulative effect of stream flow and atmospheric deposition.

Our study demonstrates that Ganga river at Varanasi receives sizably high atmospheric inputs of Cd, Cr, Cu, Ni and Pb. About 78%, 62% and 87% of water samples showed, Cd, Ni and Pb levels above their respective maximum admissible concentration, suggesting that the atmospheric deposition can sizably contribute to surface water contamination of potentially toxic metals. This has merit attention from human health perspectives since Ganga water is also used for drinking purpose by a large population. Our observations form the first report on atmospheric deposition-linked mid-stream heavy metal contamination of Ganga river.

**Table 2** Test of significance (ANOVA) for atmospheric deposition and concentrations of heavy metals in Ganga water

| Variables | Cd | Cr | Cu | Ni | Pb |
|---|---|---|---|---|---|
| Atmospheric deposition | | | | | |
| Site (S) | 72.58 | 44.15 | 34.50 | 76.26 | 128.35 |
| Season (s) | 56.98 | 33.65 | 32.61 | 47.85 | 79.24 |
| S × s | 41.60 | 11.95 | 19.85 | 28.76 | 41.80 |
| River water | | | | | |
| Site (S) | 92.66 | 24.85 | 29.08 | 27.50 | 86.30 |
| Season (s) | 44.26 | 14.10 | 21.96 | 13.38 | 46.09 |
| S × s | 28.60 | 10.18 | 90.56 | 12.50 | 40.62 |

Values are significant at $p < 0.001$

**Table 3** Correlation between heavy metal concentration in mid-stream river water and their respective input through atmospheric deposition

| Variable | Cd | Cr | Cu | Ni | Pb |
|---|---|---|---|---|---|
| Cd | 0.566** | | | | |
| Cr | 0.359 | 0.490** | | | |
| Cu | 0.430* | 0.350 | 0.532** | | |
| Ni | 0.218 | 0.430* | 0.363 | 0.470* | |
| Pb | 0.450* | 0.431* | 0.428* | 0.398 | 0.574* |

* $p < 0.05$, ** $p < 0.01$

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