Implications of traditional commercial practices on the current environmental status of River Yamuna in the Delhi- Mathura-Agra region, India

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Abstract
The River Yamuna is regarded as a holy river in Indian mythology. It originates in the Himalayas and several important cities, pilgrimage centres and temple towns are located along its banks. It is a source of water supply to these cities and also receives their wastewaters from domestic and industrial activities. This study aims to assess the environmental and human health implications of traditional commercial practices such as electroplating and jewellery making in the cottage industries along the banks of River Yamuna in the Delhi-Mathura-Agra region. Human exposure to contaminants from overbank soil and also through the food chain from crops grown on floodplains are considered through analyses of overbank and floodplain soils with special reference to toxic trace metals such as silver, cadmium, copper, and zinc. The findings of study show that the overbank and floodplain soils at the temple town of Mathura are highly contaminated with silver and cadmium, and are above normal background concentrations for copper and zinc. This leads to suggest that the traditional and cultural activities of jewellery-making and electroplating works at Mathura are contributing a high metal load to its overbank and floodplain soils and are a cause for concern for human health.

Keywords

River Yamuna, traditions, pollution, commercial activity, industrial discharges

Introduction

The River Yamuna is one of the most prominent rivers of India. It originates in the Himalaya, flows through the plains of Haryana, Uttar Pradesh and Delhi, merging with the River Ganga at Allahabad. Important cities such as Delhi, Mathura and Agra are located on its banks (CPCB, 2006). It is not only the main source of water supply to these cities for domestic, irrigation and industrial purposes, but also receives their wastewater discharges (Farago et al., 1989; Rawat et al., 2003) to include domestic and industrial waste, such as waste from households, dairy farms, and animal slaughtering houses. Disposal of dead bodies of infants and ash from human cremation into the river are practiced as regular traditional acts. Also, religious activities introduce offerings of flowers, idols and metal containers directly into the river.

The River is regarded as a holy river in Indian mythology and various pilgrimage centres and temple towns, such as Mathura, are located along its banks. It is a cultural icon and worshipped as a goddess in Indian culture where many people begin their day by chanting glories of the River (saveyamuna, 2013). The River also supports a range of cottage industries on its banks and in its basin. With regards to agriculture, the Yamuna basin is highly fertile with high yielding food grain (Rai et al., 2012). The River floodplain is used for growing agricultural crops such as rice, and the riverbed is used for farming of vegetables and fruits when the river water shrinks to a minimum in the summer periods.

On a daily basis, the River water is used by the local population and cattle for bathing and washing. Moreover, the more disadvantaged sections of the society depend upon the river water to wash their clothes and utensils. Millions of people in cities such as Delhi, Mathura and Agra bath in the river on religious festivals and cultural occasions, which is particularly prominent in Mathura being an important pilgrimage centre as one of the seven most holy places for Hindus in India (Ministry of MSME, 2013).

This study aims to assess the environmental and human health implications of traditional commercial practices along the banks of River Yamuna in the Delhi-Mathura-Agra region, with special emphasis on toxic trace metal contamination. The metals considered in this study are silver (Ag), cadmium (Cd), copper (Cu), and zinc (Zn) as field studies indicated that these metals are used for electroplating and jewellery making in the cottage industries located on the river banks, especially in Mathura.

Methods

Study area and sampling strategies

The study area included a stretch of River Yamuna passing through the ancient cities of Delhi, Mathura, and Agra, India (Figure 1).

Figure 1: A map of India showing the cities of Delhi, Mathura and Agra located on the banks of River Yamuna

Delhi, also known as the National Capital Territory of India (NCR), has a population of nearly 22 million residents (UN, 2012). Delhi has been continuously inhabited since the 6th century BC (Asher, 2000). It has been reported that the earliest known settlement in Delhi was close to the River Yamuna between 1000 BC and fourth century AD, and was identified with the city of Indraprastha mentioned in the Mahabharata, a major epic of ancient India (WhereInCity, 2013). Delhi borders the Indian states of Haryana on the north, west and south, and Uttar Pradesh (UP) to the east. The River Yamuna flows for 48 km through the city, from Palla village in the north to Jaitpur in the southeast (Dakshini and Soni, 1979). It is not only the main source of water supply to the city, but receives wastewater discharges from a number of major and minor drains (Mehra et al., 2000; Rawat et al., 2003). The floodplains of River Yamuna provide fertile alluvial soil which are used regularly to grow crops. The Yamuna is the only major river flowing through Delhi.

Mathura lies in the fertile plains of north central India. The city is located 145 km south-east of Delhi, and 58 km north-west of Agra in the state of Uttar Pradesh. It is one of the oldest cities of India (~ 325 BC) situated on the west bank of the River Yamuna. Mathura is linked to stories of Lord Krishna as his place of birth (Ministry of MSME, 2013).

Mathura has a number of small scale cottage industries (Figure 2a) such as electroplating, jewellery making, bleaching and dye works which are located on the banks of the River Yamuna. Also, the floodplains of the River Yamuna are used for growing rice (Figure 2b).

Field observations have shown that wastewaters discharged from the cottage industries go through little or no pre-treatment before being discharged into the River. This leads to the enrichment of contaminants into the river body. Moreover, during the monsoon periods, floods carry these contaminants on to the plains thus passing them on the soils where agricultural crops are grown (Figure 2b), and also into the residences of relatively poor people, which are built along the river banks (Figure 2c).

The city of **Agra** is located 200 km south of Delhi. It is popularly known as the city of the Taj Mahal. It is an industrial town supporting a range of chemical industries and electroplating units. Wastewaters being discharged into the river are not diluted before discharge, hence reducing the self purifying capacity of the River. The volume of river is highly reduced during the non-monsoon periods almost appearing as a drain (Figure 2d) (CPCB, 2006), where the floodplains are used to grow crops.

Figure 2: (a) a cottage industry along the banks of River Yamuna, Mathura; (b) agricultural crops growing on the floodplains of River Yamuna, Mathura; (c) houses built along the banks of River Yamuna, Mathura; (d) depletion of volume of water and crop growth on floodplains in Agra

Sampling Sites and Sampling Strategies

Sampling was carried out in the month of January with temperature ranging between 15-20 ^{0}C, and access was available to floodplains which may become flooded during the monsoons (June-July). Overbank soils were collected from sampling sites upstream and downstream of point discharges into the River. The sampling sites included Najafgarh, Powerhouse, Barapula, and Kalkaji drains at Delhi, Gau, Swami, Rajghat, Bangalee and Dhruv 'ghat' drains at Mathura (Figure 2b, 2c) and Foundry

Nagar, Old City, Cremation Ground and Taj Mahal at Agra (Figure 2d). In the case of floodplain soils, three sampling sites were selected as horizontal transects from each overbank site at a distance of 50 m apart as FP1, FP2, and FP3. All soil samples (0-10 cm) were collected in Kraft bags (made of wet strength brown paper).

Composite sampling was carried out at each sampling site where samples were collected from three sampling points; at each sampling point, three sub-samples were collected, at 1m spacing of an arbitrary triangle, which were then bulked together, thus resulting in representative samples covering the study area (Keith, 1991 and 1996). For example, at Mathura samples were collected from 5 sites as follows: at each site, samples were collected from three sampling points, and at each sampling point, three sub-samples were collected to obtain a representative sample; thus the representative sample from each site being a composite of nine soils.

Soil samples were air dried in Kraft bags, ground with a pestle and mortar, and then dry sieved to obtain the <2 mm particle size fraction. The <2 mm fraction was oven dried at 50 ^{0}C, and tema milled (zirconium oxide mill) in agate pots to 100 μm grain size for analysis (Mehra et al., 2000).

Analyses of samples

pH: Soil pH was measured in the laboratory using a soil:distilled water ratio of 1:2.5 (w:w) using a glass electrode (Sakata, 1987).

‘Total’ metal analyses in overbank and floodplain soil samples

Replicate samples (0.25 g) were digested by nitric and perchloric acids (Thompson and Wood, 1982) and analysed for a range of elements (silver, cadmium, copper, zinc) by Inductively Coupled Plasma Emission Spectroscopy (ICP-AES).

Quality control: Quality control of data generation was carried out by using sample replicates, blanks and certified reference material (Soil: NRCCRM).

Analysis of soil samples for determination of metal concentrations was carried out in duplicate with regular running of 10 % reagent blanks and analysis of certified reference material. Analysis of sample duplicates were within ±10 %. Analysis of reagent blanks showed that there was no contamination or interference from the reagents. The certified reference material percentage recovery for metals was within ±10 % of the reference values.

Statistical Analysis: Microsoft Office Excel 2003 was used to determine the descriptive statistics and Student’s t-test for the data.

Results and Discussion

pH of overbank and floodplain soils

Table 1 shows the means and ranges of pH in the overbank and floodplain soils in the study areas. Mean soil pH at all sites was near neutral, although the maximum values were found to be in the alkaline range. These are in agreement with previous studies for Delhi (Farago et al., 1989; Mehra et al., 2000; Ahmad, 2009). This indicates that the industrial activities over the years have not altered the soil pH. pH values between the different cities for overbank and floodplain soils were not found to be statistically significantly different ($p > 0.05$).

Table 1 Soil pH in the overbank and floodplain soils in the study sites

	Delhi (n= 6)	Mathura (n= 5)	Agra (n= 9)
Overbank soils			
Mean	7.58	7.78	7.64
Range	7.20 – 7.88	7.22 – 8.69	6.58 – 8.12
SD	0.24	0.55	0.46
Floodplain soils			
Mean	7.84	7.69	7.65
Range	7.58 – 8.12	6.73 – 8.29	7.00 – 8.64
SD	0.20	0.63	0.53

n = number of study sites; SD = standard deviation

Elemental content of overbank and floodplain soils

Mean elemental concentrations in River Yamuna overbank soils are given in Figure 3. Generally, all metal concentrations in overbank soils follow the order:
Mathura >> Agra > Delhi (with the exception of copper which has similar mean soil concentrations at Delhi and Agra at 26.5 and 25.8 mg/kg, respectively).

Concentrations of silver in background soils generally do not exceed 100 μg/g, however, in mining area soils, its content can be as high as 44 mg/kg (lenntech, 2013). Figure 3 shows that the silver content of overbank soils at Mathura is highly elevated at >10 mg/kg, with slight contamination at Agra.

Cadmium concentrations in overbank soils at all sites exceed 1 mg/kg. According to Kabata-Pendias (2010), background cadmium levels in soils should not exceed 0.5 mg/kg, and higher values reflect anthropogenic impact on the Cd status of top soils. Alloway (1990) has reported that cadmium values between 1-3 mg/kg can be classified as slight contamination of soils, and Ander et al (2013) have reported background concentrations of cadmium in British soils to be 1 mg/kg. Results in Figure 3 therefore show that there is slight contamination of cadmium in soils at Delhi and Agra, however, the concentrations are highly elevated at Mathura.

Concentrations of copper and zinc are within the normal background range in overbank soils at Delhi and Agra, but are much higher at Mathura (normal background soil concentrations reported by Kabata-Pendias (2010) range between 6-60 mg/kg for copper and 17-125 mg/kg for zinc). It is noted that Ahmad (2009) reported much higher concentrations of these metals in soils from two areas of Delhi, but this may be attributable to specific sources of contamination at the reported sites.

Overall, these results show that between the three study areas, Mathura has the highest pollution loading in terms of silver, cadmium, copper and zinc, also these concentrations are statistically significantly higher at Mathura than at Delhi and Agra ($p < 0.05$). These findings are supported by field observations, where electroplating and jewellery-making activities were highly prevalent along the 'ghats' of Mathura as compared with Delhi and Agra river banks.

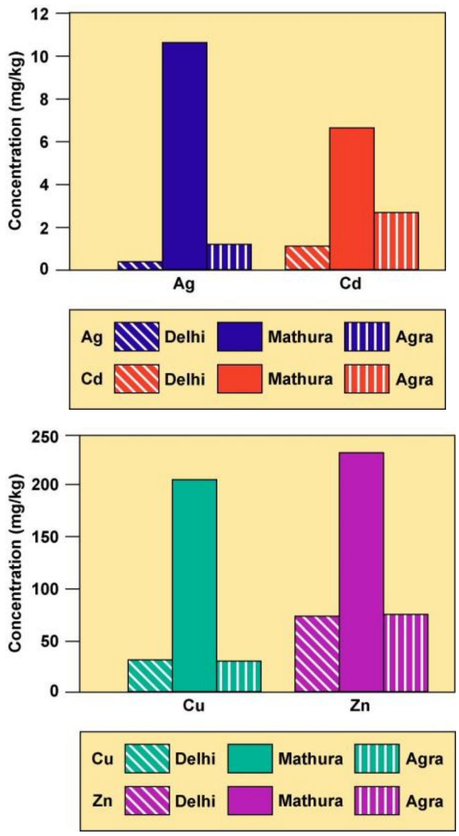

Figure 3. Mean elemental concentrations in the River Yamuna overbank soils (n = 6 for Delhi, 5 for Mathura, 9 for Agra) (Ag = silver; Cd = cadmium; Cu = copper, Zn = zinc)

Mean elemental concentrations in River Yamuna floodplain soils are given in Table 2. Generally, all metal concentrations in floodplain soils at FP1, FP2 and FP3 sites follow the order:

Mathura >> Agra > Delhi (with the exception of copper which is slightly higher at Delhi than at Agra at FP2 and FP3 sites).

Similar to overbank soils, silver in floodplain soils is highly elevated at >10 mg/kg at Mathura. However, unlike overbank soils where contamination in Delhi is very marginal, slight contamination from silver is noted at both Delhi and Agra (Figure 3). Cadmium concentrations in floodplain soils at all sites generally exceed 1 mg/kg. Similar to the overbank soils results (Figure 3), soils in the floodplains show that there is slight contamination of cadmium at Delhi and Agra, however, the concentrations are much higher at Mathura. Concentrations of copper and zinc in the floodplain soils are within the normal background ranges of 6-60 mg/kg for copper and 17-125 mg/kg for zinc (Kabata-Pendias, 2010) at Delhi and Agra, but higher at Mathura.

Table 2 shows that metal concentrations in the floodplain soils across transects are similar up to 100 m from the river bank (FP1, FP2), but start to decrease further away from the river bank (FP3). Similar to the overbank soils (Figure 3), concentrations for all elements were higher at Mathura than at Delhi and Agra. Moreover, elemental concentrations between the different cities were statistically different between Delhi-Mathura, Delhi-Agra, and Mathura-Agra ($p < 0.05$), with the exception of silver, copper and zinc between Delhi-Agra where p values were 0.132, 0.686, and 0.053, respectively.

Table 2. Mean elemental concentrations in the River Yamuna floodplain soils

City Metals	Floodplain soils Metal Concentration (mg/kg)		
	FP1	FP2	FP3
Delhi (n= 6)			
Silver (Ag)	1.58	1.55	1.47
Cadmium (Cd)	0.98	1.02	1.00
Copper (Cu)	32	48	44
Zinc (Zn)	45	45	36
Mathura (n = 5)			
Silver (Ag)	10.89	11.37	7.06
Cadmium (Cd)	3.45	5.65	3.98
Copper (Cu)	116	159	115
Zinc (Zn)	189	208	173
Agra (n = 9)			
Silver (Ag)	2.32	2.02	1.67
Cadmium (Cd)	1.55	1.48	1.33
Copper (Cu)	35	42	40
Zinc (Zn)	50	57	50

(n = number of study sites)

Overall, the difference of metal concentrations between overbank (Figure 3) and floodplain soils (Table 2) were found to be variable. It is noteworthy that metal concentrations in the floodplains were generally lower than overbank soils at Mathura, suggesting the continuous input of contaminants from the cottage industries located along the River bank.

The findings of this study are important pointers regarding human health implications from metal contamination of overbank and floodplain soils particularly at Mathura which has the highest metal loading from silver and cadmium. Human exposure to high doses of toxic metals has been shown to result in a number of health problems. The adverse effects of chronic exposure to silver are a permanent bluish-gray discoloration of the skin (argyria) or eyes (argyrosis), other effects include liver and kidney damage, irritation of the eyes, skin, respiratory, and intestinal tract, and changes in blood cells (Drake and Hazelwood, 2005), whereas kidney and bone damage are associated with cadmium toxicity in humans (Godt et al., 2006). Figure 2b, 2d shows that the floodplains are used to grow crops, Figure 2c shows that the overbank soils are used for cleaning household dishes, and field observations show that children play in the river bank areas and are exposed to the soils directly. These observations indicate that the metal content of soils at Mathura pose a risk to human health through (a) absorption through the skin, hand-to-mouth activity, or ingestion through contaminants remaining on the dishes cleaned with overbank soil and river water, and (b) directly through the food chain by accumulation in the grains for human consumption, or indirectly through the consumption of milk and meat from the animals who have been fed on parts of the plants grown on floodplains as animal fodder. The study therefore shows that the traditional and cultural activities of jewellery-making and electroplating at Mathura are contributing to high metal loading in its overbank and floodplain soils and is a cause for concern for human health.

Conclusions

The findings of this study show that:

- The different industrial activities within each of the cities do not significantly affect the overbank and floodplain soil pH.
- Concentrations of silver and cadmium in the overbank soils are generally higher than background soil concentrations in all cities, but are highly elevated at Mathura; concentrations of copper and zinc are within normal background concentrations at Delhi and Agra, but are higher than normal background concentrations at Mathura.
- In the floodplain soils, silver concentrations are highly elevated at Mathura, with slight contamination at Delhi and Agra; there is slight contamination of cadmium in Delhi and Agra, however, the concentrations are much higher at Mathura; concentrations of copper and zinc are within normal background ranges at Delhi and Agra, but higher at Mathura.

- The traditional and cultural activities of jewellery-making and electroplating at Mathura are contributing a high metal load to its overbank and floodplain soils and are a cause for concern for human health.

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