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Biomonitoring of Metals in Ganga Water at Different Ghats of Haridwar: Implications of Constructed Wetland for Sewage Detoxification

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Abstract An assessment of Ganga river water quality at different ghats of Haridwar, showed high TDS (782.15 mg L^{-1}) and BOD (21.76 mg L^{-1}) levels at the mixing points of sewage discharge channels and the water was found to be contaminated with appreciable amounts of toxic metals; Cu, Pb, Zn, Cr and Mn (0.178, 0.566, 0.199, 0.177 and 0.160 mg L^{-1}). The Ganga water supported exuberant growth of algae and aquatic macrophytes in littoral zone of river, which accumulated appreciable amount of metals in their tissues. Results showed possibility of using metal accumulation potential of plants and algae for monitoring low level of metal contamination *vis-a-vis* their use in renovating sewage by treating into especially designed constructed wetland.

Keywords Aquatic macrophytes · Algae · Metal · Ganga ghat

River water quality impairment is strongly related to the increasing anthropogenic influences in watershed, such as changing land use pattern, increasing wastewater discharge and fertilizer application (Li et al. 2009). Direct discharge of sewage into the river without any treatment or partially treated, affected the quality of Ganga water which contributed to 75 % of total river pollution. Sewage, contain metals of variable toxicity, persistence of which in the aquatic environment leads to their bioaccumulation and biomagnification in the food chain (Valls and Lorenzo 2002; Gochfeld 2003). The status of water quality in rivers and the changes produced due to anthropogenic activities is the first step towards establishing an efficient water management system. Various plants and algae growing in littoral zone of river are of particular importance to monitor pollution level as they accumulate metals inside their tissue and have been used in phytoremediation as a part of constructed wetland system. Some algal forms undergo certain changes and adapt themselves to the stress environment, while sensitive species exhibit toxic responses in a qualitative and quantitative manner. Constructed wetland systems mimic the treatment that occurs in natural wetlands by relying on plants and a combination of naturally occurring biological, chemical and physical processes to remove pollutants from the water (USEPA 1993). However, the difference of effectiveness of metal removal varied in different plants, in both the capacity to accumulate the metal in roots and in the proportion of metal transferred to aerial parts (Suñe et al. 2007).Various aquatic plants of different life forms (floating, submerged, rooted and emergent) growing in catchment area of Ganga river possess property of accumulation and detoxification of metal present in the river water (Rai et al. 2011) In the present study, Ganga water from different ghats of Haridwar, algae and aquatic species growing therein, has been analysed with respect to metal accumulation for possible utilization of these species as a pollution monitor and abator in especially designed constructed wetland for treatment of metal containing sewage.

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Materials and Methods

Ten sites located along with the bank of river Ganga at Haridwar, (Uttarakhand, India) were selected for plant, algae and water samples collection. These sites were, outlet of Matrisadan, Vedvyas ghat, Birla ghat, Akhandsacchidanand ghat, Ram ghat, Shamshan ghat, Dhobi ghat, Mixing point at Jagjeetpur, Ganda nala at Jwalapur and Shantikunj. Acidified water samples were stored in acid washed plastic container (2 L capacity) and brought to the laboratory along with plant and algal samples for further analysis. Some parameters like; DO, pH, temperature, electrical conductivity, and turbidity were determined at sampling sites with the help of portable water analysis kit (Decible). Unacidified water samples were collected in BOD bottles and brought to the laboratory for determining BOD. All the physiochemical parameters were determined in triplicate by using standard method for examination of water and waste water (APHA 1995). The plants of the selected areas were; *Polygonum hydropiper, Alternenthera lilacina, Spilanthes* sp., *Saccharum munja, Potamogeton crispus, Cyperus rotundus, Fimbristylis* sp. *Eichhornia crassipes, Colocasia* sp. and *Ludwigia* sp., and algal species belonging to green and blue green algae were also collected from all sites in bulk, washed thrice with distilled water and then oven dried at 90°C to constant weight. The different metal contents viz. Cr, Cu, Zn, Pb, and Mn in samples were determined after digestion with HNO_3/$HClO_4$ (3:1, v/v) mixture at 80°C and absorbance was recorded on atomic absorption spectrophotometer (GBC Avanta $\sum$). Analytical data quality of metals was ensured through repeated analysis (n = 5) of EPA quality control samples in water and results were found within certified values. The translocation factor (the ratio of metals in shoot versus roots) was also studied which indicates that metals accumulated by the aquatic plants were largely retained in roots. The extent of translocation within plants also depends on the metal and plant species concerned. Translocation ratio (TR) was calculated by the formula:

$$TR = [Metal_{Shoot}]/[Metal_{Root}]$$

Relationships between plant accumulation and pollutant levels in water were studied by using the Pearson linear correlation method.

Results and Discussion

Physicochemical characteristics of different water samples collected from various sites of Haridwar have been depicted in Table 1. The pH varied from 7.32 to 7.93, while turbidity ranged from 12.07 to 62.47 NTU. The maximum value of dissolve oxygen (DO) was recorded at Ramghat (7.74 mg L^{-1}) while minimum biological oxygen demand (BOD) was observed at Vedvyas ghat (5.65 mg L^{-1}). The highest value of phosphate (PO_4^{-3}) was detected at Dhobi ghat because of high discharge of detergents. Total suspended solids (TSS) and total dissolved solids (TDS) were recorded maximum in Ganda nala at Jwalapur (444.42 and 1020.28 mg L^{-1}, respectively). The concentration of different metals (Cu, Cr, Pb, Zn, Mn) in Ganga water at different sites also has been depicted in Table. During analysis the value of Cr was found more than EPA standard at each site but in Ganda nala at Jwalapur, its value was maximum (0.196 mg L^{-1}). The maximum concentration of Pb (0.69 mg L^{-1}) and Zn (0.219 mg L^{-1}) were found at outlet of Matrisadan, however, that of for Mn (0.16 mg L^{-1}) and Cu (0.178 mg L^{-1}) were found at Akhandsacchidanand ghat and Shamshan ghat, respectively.

Out of thirteen algal species, nine belonged to green while four were from blue green algae. Almost all the algal forms encountered at all sites but Akhandsacchidanand ghat and Shamshan ghat bearing the minimal algal population.

Frequent presence of *Oscillatoria* sp. indicated a high degree of eutrophication at mixing point of sewage into the water bodies. Green algae *Ulothrix* sp., *Spirogyra* sp., *Cladophora* sp. and *Hydrodictyon reticulatum* were found in abundance at all the sites (data not shown). Impact of metal accumulation on algal diversity demonstrated trace metal contamination favouring growth, while that of metal (Cr and Pb) affects it adversely. Of all the metals accumulated in all the algal forms, Cr was maximally accumulated metal as shown by blue green algae, *Aphanicapsa grevillei* (2730.01 µg g^{-1} dw). In green algae, the maximum Cr content was recorded in *Cosmarium* sp. (2246.71 µg g^{-1} dw). Zn and Mn were found maximum in *Ulothrix* sp. and *Chlorococcum* sp., respectively (Table 2).

The highest level of Cu and Pb content was found in *Cladophora* sp. (76.34 µg g^{-1} dw) and *Ulothrix* sp. (518.37 µg g^{-1} dw). Metal content in different parts of selected plants from different sites is shown in Fig. 1A. As reported earlier (Satyakala and Jamil 1992; Zaranyika and Ndapwadza 1995; Chandra and Kulshreshtha 2004) results showed that the roots accumulated higher concentration of metals than shoots. Cardwell et al. (2002) stated that low concentration of metals in the shoots of aquatic plants may be due to the low mobility of metals from root to shoot. The formation of complex compounds with COOH group may inhibit the translocation of metal to shoot (Chandra et al. 1997). Variability of all studied metals in different parts of the plants may be due to compartmentalization and translocation in the vascular system (Kim et al. 2003). In the present study the roots of *P. crispus* accumulated higher amount of Cu (45.766 µg g^{-1} dw) even at low Cu concentration present in water at Vedvyas ghat, showing greater capacity to absorb Cu from surroundings. Similarly, Peng et al. (2008) showed enrichment capacity of roots of *P. pectinatus* and *P. malaianus*, in which Cu concentrations reached to 1,130 and 945 mg kg^{-1} dw, respectively, when exposed to 5,000 g

Table 1 Physico-chemical parameters of Ganga water at different sites along the bank of Ganga river at Haridwar, Uttarakhand, India

Sites	pH	Turb. (NTU)	Cond. (µs cm^{-1})	DO	BOD	TSS	TDS	PO_4^{-3}	Cl^{-1}	Cu	Cr	Pb	Zn	Mn
Outlet of Matrisadan	7.86 ± 0.03	49.00 ± 2.64	134.87 ± 3.55	2.65 ± 0.17	13.17 ± 1.53	194.29 ± 2.28	313.83 ± 3.01	4.58 ± 0.06	47.95 ± 1.28	0.117 ± 0.001	0.043 ± 0.003	0.69 ± 0.001	0.219 ± 0.003	0.029 ± 0.002
Ram ghat	7.76 ± 0.02	19.38 ± 2.17	142.67 ± 0.70	7.74 ± 0.55	5.70 ± 0.53	216.47 ± 1.29	474.02 ± 1.56	1.66 ± 0.49	41.54 ± 1.68	0.147 ± 0.002	0.132 ± 0.005	0.25 ± 0.002	0.192 ± 0.002	0.0572 ± 0.001
Birla ghat	7.41 ± 0.01	13.40 ± 1.08	116.06 ± 0.71	7.39 ± 0.23	7.30 ± 0.33	211.74 ± 0.83	351.83 ± 0.95	1.86 ± 0.58	60.22 ± 2.19	0.159 ± 0.003	0.090 ± 0.015	0.245 ± 0.006	0.181 ± 0.003	0.093 ± 0.005
Akhandsacch-idanand ghat	7.47 ± 0.02	24.31 ± 0.36	132.44 ± 0.40	7.15 ± 0.45	6.73 ± 0.65	181.61 ± 1.39	320.73 ± 0.96	3.117 ± 0.32	16.46 ± 1.70	0.155 ± 0.003	0.167 ± 0.005	0.284 ± 0.003	0.176 ± 0.002	0.16 ± 0.015
Vedvyas ghat	7.59 ± 0.01	15.5 ± 0.45	184.65 ± 0.82	7.11 ± 0.44	5.65 ± 0.33	131.61 ± 1.05	261.72 ± 1.12	1.72 ± 0.15	34.76 ± 1.78	0.142 ± 0.007	0.136 ± 0.003	0.566 ± 0.002	0.155 ± 0.002	0.034 ± 0.005
Shamsan ghat	7.84 ± 0.03	12.07 ± 0.77	142.64 ± 0.99	4.76 ± 0.40	9.68 ± 0.54	210.81 ± 0.90	581.30 ± 1.15	2.57 ± 1.16	55.27 ± 1.35	0.178 ± 0.002	0.122 ± 0.009	0.213 ± 0.002	0.199 ± 0.002	0.075 ± 0.003
Dhobi ghat	8.32 ± 0.01	13.91 ± 0.14	150.98 ± 1.41	2.59 ± 0.26	8.93 ± 0.17	258.88 ± 1.87	782.15 ± 1.02	7.24 ± 0.79	62.41 ± 0.49	0.159 ± 0.002	0.177 ± 0.004	0.192 ± 0.002	0.113 ± 0.002	0.034 ± 0.002
Mixing point at Jagjeetpur	7.32 ± 0.01	15.34 ± 0.06	138.1 ± 0.43	3.55 ± 0.43	17.07 ± 0.85	312.90 ± 2.85	705.17 ± 0.85	5.73 ± 0.86	50.07 ± 1.11	0.129 ± 0.001	0.181 ± 0.005	0.159 ± 0.001	0.172 ± 0.008	0.0287 ± 0.01
Ganda nala at Jwala pur	8.01 ± 0.01	62.47 ± 1.02	186.21 ± 0.71	0.96 ± 0.11	88.99 ± 1.59	444.42 ± 0.98	1020.3 ± 2.35	5.253 ± 0.29	115.38 ± 2.77	0.101 ± 0.003	0.196 ± 0.004	0.108 ± 0.03	0.119 ± 0.004	0.0421 ± 0.003
Shantikunj	7.93 ± 0.01	19.13 ± 1.96	133.38 ± 1.18	2.92 ± 0.65	21.76 ± 0.58	244.91 ± 1.02	658.76 ± 1.10	6.32 ± 1.09	85.04 ± 1.90	0.162 ± 0.006	0.153 ± 0.002	0.112 ± 0.001	0.153 ± 0.009	0.0389 ± 0.02

All units are in mg L^{-1} or otherwise stated

Turb turbidity, *Cond* conductivity, *DO* dissolve oxygen, *BOD* biological oxygen demand, *TSS* total suspended solids, *TDS* total dissolve solids

Table 2 Metal content (μg g^{-1} dw) in different algal species collected from different sites along the bank of Ganga river at Haridwar, Uttarakhand, India

Genus/Species	Cu	Pb	Zn	Mn	Cr
Blue green algae					
Oscillatoria tenuis	15.35 ± 0.57	284.56 ± 9.26	312.41 ± 13.78	122.78 ± 12.66	1067.38 ± 24.90
Phormedium bohneri	37.64 ± 1.42	108.05 ± 8.97	110.72 ± 7.65	144.01 ± 7.34	1523.40 ± 46.48
Aphanocapsa grevillei	68.53 ± 2.75	214.1 ± 18.56	210.97 ± 4.60	183.30 ± 3.98	2730.01 ± 44.69
Nostoc muscorum	15.61 ± 1.27	185.15 ± 6.74	169.07 ± 12.68	153.65 ± 2.30	1037.82 ± 10.06
Green algae					
Cladophora sp.	76.34 ± 5.29	202.97 ± 5.25	345.95 ± 7.54	835.15 ± 33.02	1129.91 ± 35.91
Ulothrix sp.	53.6 ± 3.88	518.37 ± 18.40	766.38 ± 10.51	760.97 ± 35.55	2263.16 ± 115.41
Spirogyra adnata	44.48 ± 4.06	235.83 ± 5.47	482.09 ± 15.81	707.30 ± 10.48	2119.90 ± 97.84
Chlorococcum sp.	28.31 ± 3.48	159.01 ± 8.09	721.41 ± 58.49	924.45 ± 50.11	1545.38 ± 53.70
Mougeotia sp.	72.84 ± 8.23	232.33 ± 11.59	199.93 ± 7.18	655.28 ± 21.71	2233.93 ± 196.34
Chlamydomonas sp.	56.58 ± 3.37	165.76 ± 16.39	276.73 ± 12.77	737.48 ± 18.44	1527.64 ± 50.01
H. reticulatum	15.94 ± 1.35	222.78 ± 29.22	175.14 ± 9.96	744.69 ± 8.12	1082.49 ± 86.79
Cosmarium sp.	36.15 ± 1.12	327.89 ± 13.14	241.30 ± 14.17	670.98 ± 09.39	2665.13 ± 111.35
Oedogonium sp.	18.97 ± 1.04	456.51 ± 27.35	578.63 ± 18.46	562.43 ± 17.97	1745.87 ± 57.02

L^{-1} Cu solutions for 2 h. Pb accumulation was in order of *Spilanthes* sp. > *P. crispus* > *E. crassipes* > *A. lilacina.* Accumulation of Mn was maximum in *P. crispus* shoot (522.87 μg g^{-1} dw), whereas maximum Cr (70.8 μg g^{-1} dw) and Zn (530.95 μg g^{-1} dw) were found in roots of *C. rotundus*. Bioaccumulation of metal in *E. crassipes* roots from different sites were in order of Cu < Cr < Zn < Pb < Mn indicating that *E. crassipes*, effectively removes appreciable quantities of metals from wastewater, especially at low concentrations. Similar results were also found by Soltan and Rashed (2003). It was shown that content of metals in plants varied from site to site, which was due to existence of distinct microhabitat in the sampling sites (Harding and Whitton 1981), growth conditions of plant, metal availability and content of metal in water. Highest translocation ratio of Cu (2.96) and Pb (2.93) was noted for *P. hydropiper* and lowest for Mn (0.099) in *A. lilacina* (Fig. 1B). Higher value of translocation ratio (>1) signifies that the plant effectively translocate metals from root to the shoot (Baker and Brooks 1989), however, lower value of translocation ratio indicated that specific genera could be used as potential plant for phytostabilization (Shu et al. 2002; Archer and Caiwell 2004).

The correlation coefficient between levels of metal in the water with the amount of metal accumulated by plants at various sites has been shown in Table 3. Significantly high positive correlation was found between Zn, Pb, Cu, Cr and Mn in different plants and levels of these metals in water from different sites. Root of *E. crassipes* of Ramghat and Ganda nala of Jwalapur showed positive correlation for all the metals. *Spilanthes* sp. (Ram ghat), *Colocasia* sp. (Vedvyas ghat) and *Fimbristylis* sp. (Shantikunj) also showed positive correlation for all metals. *P. hydropiper* and *P. crispus* showed positive correlation for Cu, Pb, Zn and Mn. Similar results were also reported by Kim et al. (2003) in *Polygonum thumbergii* plant. In *S. munja* at Akhandsacchidnand ghat, very low correlation was observed in shoot while *Ludwigia* sp. at Dhobi ghat, showed a significant positive correlation for all the metals except Mn. *E. crassipes* of mixing point at Jagjeetpur and Akhandsacchidnand ghat showed negative correlation for Mn and Zn, respectively. Roots of *C. rotundus* (Shamshan ghat) and *A. lilacina* (Mixing point at Jagjeetpur) were negatively correlated with Cu. In shoot tissues the maximum positive correlation was observed in Ganda nala of Jwalapur site in *E. crassipes.*

Plant collected from outlet of Matrisadan (*P. hydropiper)* and Akhandsacchidanand ghat (*S. munja)* represented negative correlation for Cr and Pb in shoot tissues. High positive correlation shown by plants collected from Vedvyas ghat with all metals, except Mn in shoot of *Colocasia* sp. In the Akhandsacchidanand ghat same result was obtained with *E. crassipes* but *S. munja* showed negative correlation with Zn in root tissues and with Cr and Pb in shoot tissues. Plants collected from Vedvyas ghat determined very low positive correlation in shoot with all metals except Zn. In Shamshan ghat (*C. rotundus)* and Dhobi ghat *(Ludwigia* sp. and *E. crassipes)* plants showed the same results with respect to root but in case of shoot negative correlations were obtained with majority of metals. The high correlation between the final metal concentration in the water and the tissue of *E. crassipes, S. munja*, *C. rotundus* and *Ludwigia* sp. emphasizes that removal rates are proportional to metal concentration in the plants.

It is concluded that different groups of algae and aquatic plants are growing nearby various ghats in Ganga water

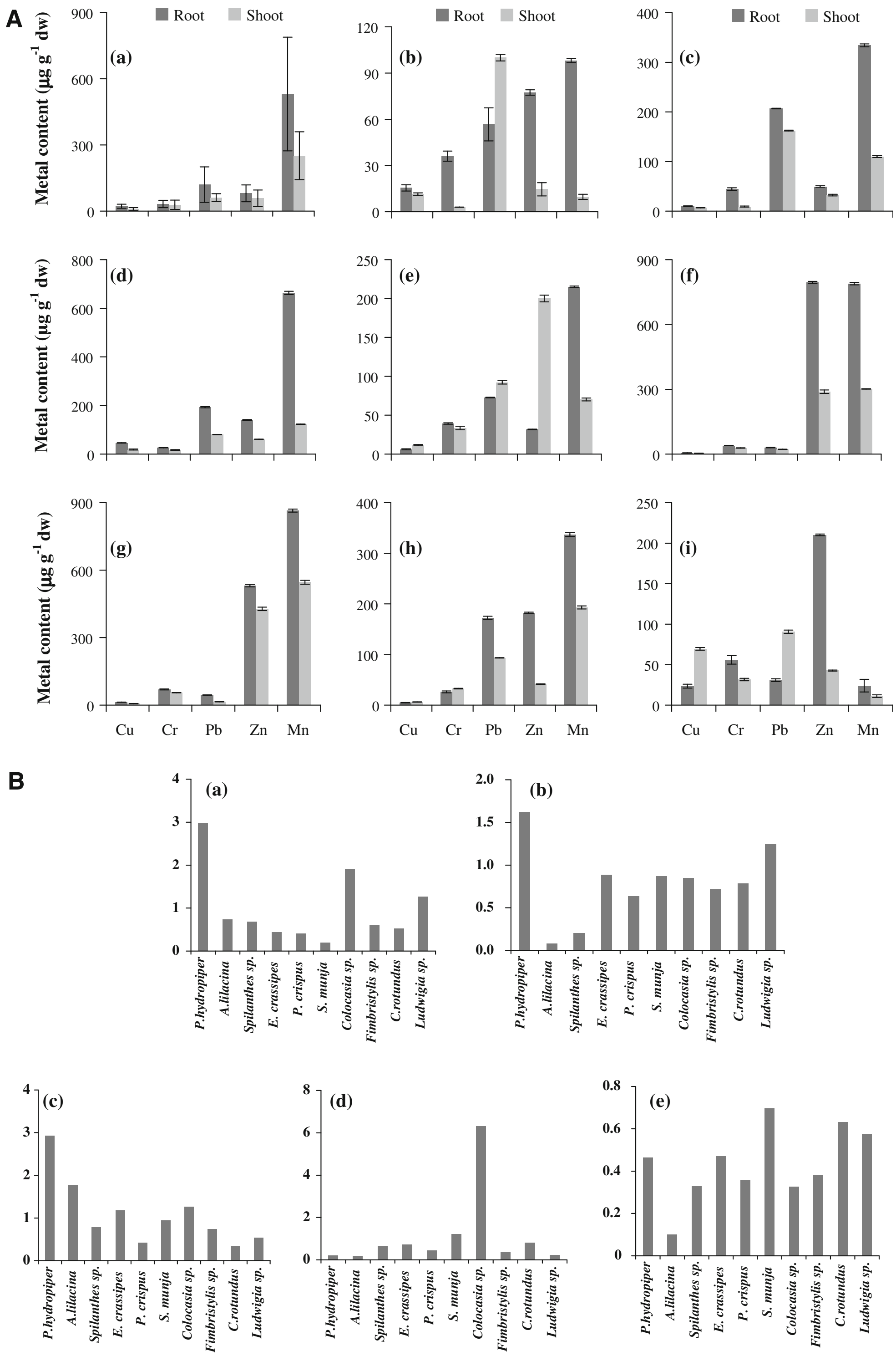

Fig. 1 **A** Metal content (μg g^{-1} dw) in root and shoot of various plants collected from Ganga river at different sites, Haridwar. **a** *E. crassipes*, **b** *A. lilacina*, **c** *Spilanthes* sp., **d** *P. crispus*, **e** *Colocasia* sp., **f** *Fimbristylis* sp., **g** *C. rotundus*, **h** *Ludwigia* sp. **i** *P. hydropiper*. All values are mean ± SD. **B** Translocation ratio of metal **a** Cu, **b** Cr, **c** Pb, **d** Zn, **e** Mn in plants collected from different sites of Haridwar

having metal contamination. Some of these plants and algae were found to accumulate substantial amount of metals like, Cr and Pb in their tissue, which could be used in developing a plant based treatment system involving interdisciplinary approach, mechanical skills and potentials of plants.

Table 3 Correlation between metal content in Ganga water with their accumulation in aquatic plants growing at different ghats

Site	Plants name	Correlation coefficient									
		Cu		Cr		Pb		Zn		Mn	
		Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
Outlet Matrisadan	*P. hydropiper*	0.587	0.452	−0.954	−0.427	0.967	−0.393	0.633	0.381	0.352	0.517
Ram ghat	*Spilanthes* sp.	0.765	−0.328	0.929	0.927	0.939	0.323	0.925	−0.969	0.988	0.999
	E. crassipes	0.889	−0.759	0.657	0.766	0.969	0.322	0.627	−0.436	0.475	0.476
Birla ghat	*P. crispus*	0.730	−0.335	−0.998	0.451	0.922	0.992	0.806	−0.997	0.895	0.837
Akhandsacchi danand ghat	*E. crassipes*	0.999	−0.610	0.936	−0.626	0.959	0.707	−0.916	0.438	0.850	−0.661
	S. munja	0.997	0.699	0.961	−0.963	0.967	−0.802	0.835	0.920	−0.839	0.114
Vedyas ghat	*Colocasia* sp.	0.995	0.924	0.547	0.042	0.662	0.744	0.716	0.397	0.625	−0.962
Shamshan ghat	*C. rotundus*	−0.702	−0.836	0.598	0.700	0.997	0.420	0.679	0.273	0.509	0.888
Dhobi ghat	*E. crassipes*	0.988	−0.970	−0.978	0.996	0.779	0.957	0.843	0.731	−0.989	0.434
	Ludwigia sp.	0.885	0.528	0.637	0.224	0.990	−0.512	0.992	−0.261	0.916	0.689
Mixing point at Jagjeetpur	*A. lilacina*	−0.778	−0.126	−0.903	−0.446	0.851	0.868	0.952	0.674	0.879	0.838
Ganda Nala Jawalapur	*E. crassipes*	0.883	0.937	0.937	0.788	0.966	0.981	0.809	0.611	0.280	0.186
Shantikunj	*Fimbristylis* sp.	0.916	−0.995	0.952	0.968	0.608	0.250	0.453	−0.396	0.590	−0.836

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