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The Role of Catchment Vegetation in Reducing Atmospheric Inputs of Pollutant Aerosols in Ganga River

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Abstract The role of woody perennials in the Ganga river basin in modifying the run-off quality as influenced by atmospheric deposition of pollutant aerosols was investigated. The concentration of seven nutrients and eight metals were measured in atmospheric deposits as well as in run-off water under the influence of five woody perennials. Nutrient retention was recorded maximum for *Bougainvillea spectabilis* ranged from 4.30 % to 33.70 %. Metal retention was recorded highest for *Ficus benghalensis* ranged from 5.15 % to 36.98 %. Although some species showed nutrient enrichment, all the species considered in the study invariably contribute to reduce nutrients and metal concentration in run-off water. Reduction in run off was recorded maximum for *B. spectabilis* (nutrient 6.48 %–40.66 %; metal 7.86 %–22.85 %) and minimum for *Ficus religiosa* (nutrient 1.68 %–27.19 %; metal 6.55 %–31.55 %). The study forms the first report on the use of woody perennials in reducing input of atmospheric pollutants to Ganga river and has relevance in formulating strategies for river basin management.

Keywords Atmospheric deposition · Pollutant aerosols · Metal retention · Ganga river

The rising atmospheric deposition of pollutant aerosols as a result of anthropogenic activities such as fossil fuel burning in urban-industrial areas has become a common phenomenon in many parts of the world. Atmospheric emission coupled with wind action is adding pollutants and nutrients even in areas far away from source oriented sites (Pandey et al. 2009a). During past few decades although some developed countries, have made considerable progress in reducing the amount of air pollutants released from point sources but the control of air pollutants generated by dispersed or non-point sources is still a big challenge. The problem is more acute in developing countries like India where, due to new establishing industries and extensive urban growth, atmospheric loading and deposition of pollutant aerosols is continued to rise.

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 (Pandey et al. 2009a). In river systems, where the mid-stream access of land-borne contaminants is restricted, atmospheric deposition directly add contaminants on to the water surfaces. Thus, despite all efforts to minimize environmental contamination, atmospherically driven pollutants will continue to contaminate ecosystems including surface water resources. Under such conditions, plantation of properly screened plant species in the catchment be able to provide a better substitute for restoration and management of major river systems against air-driven atmospheric pollutants.

Chemicals from atmosphere can stimulate, inhibit or have variable effects on growth and productivity of forest vegetation. Studies have shown stronger dependence of forest maintenance of nutrients derived from atmosphere and even in some ecosystems, atmospheric input of nutrients provide an important mechanism for replacing hydrologic losses as well as losses due to timber extraction (Friedland and Miller 1999). However, the relative importance of such deposition often depends upon site and

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specific nutrient. For instance, N in bulk deposition is equivalent to about 70 % of nitrogen incorporated annually in above ground woody tissues in some temperate hardwood forests (Swank 1984). Woody perennials in the catchment may modify the air-driven input of nutrients and trace elements in the near by water bodies. Relatively less information however, are available on atmospheric input of nutrient and metals elements with modifying influence of woody perennials on catchment run-off.

The present study was conducted from April 2006 to March 2010 near Malviya bridge river site of Varanasi (25° 18′ N latitude and 83° 1′ E longitude) situated in the midst of eastern Gangetic plane of India. The traffic volume of the study area during rush hours is approximately 1,250 vehicles h^{-1}. The climate of the region is tropical monsoonal. The year is divisible in to three distinct seasons, a hot and dry summer (March–June), a humid rainy season (July–October) and a cold winter season (November–February). Mean maximum temperature was observed in June (27.8–40.9°C) and at rare occasions temperature exceeds 44°C. The night time temperature sometimes drops below freezing. The rainy months remained warm and wet, with humidity reaching close to saturation. Wind direction shifts predominantly from westerly and south-westerly in October through April and easterly and north-westerly in remaining months.

The main objective of the study was to characterize the deposition of trace elements and nutrients at a source oriented Ganga river site in Varanasi and to study the role of selected woody perennials in modifying the deposition/run-off quality in the river catchment. The study has relevance since the holy river Ganga is the center of tourist attraction as well as an important source of irrigational and drinking water supply for a major population of the river side towns.

Materials and Methods

The atmospheric deposition was collected using particulate collectors. These were made of a 5 L high density polyethylene bottle connected to Teflon funnel of 115 cm^{-2} collection area. All these collection systems were devised with PVC needles on top to avoid bard nesting. Collectors were maintained at a height of 2 m to avoid collection of re-suspended soil particulates. Rain water and run-off water samples were collected on event basis. As soon as the samples were brought to the laboratory, a 50 mL sub-sample of atmospheric deposition collected in the bottle and a 50 mL of sub-sample of the rinsing water were filtered through a cellulose nitrate membrane washed with 5 % HNO_3. Both samples were stored in dark at ambient temperature before analysis.

Ternary acid digestion procedure was followed for extraction of all the metals (Allen et al. 1986). Metals in the filtrate of particulate, leaf samples and run-off water were determined using Atomic Absorption Spectrophotometer (Perkin Elmer Model 2130, USA). 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 readings to calibrate the instrument. Atmospheric deposition, clearfall and run-off waters were analyzed for $SO_4{}^{2-}$, $NO_3{}^-$, $NH_4{}^+$ and $PO_4{}^{3-}$ as described by Pandey and Pandey (2009) and Na^+, K^+, Ca^{2+} and Mg^{2+} using flame photometer. The chemicals used for analysis were Merck analytical grade. Metal and nutrient retention capacity of selected woody perennials (*Bougainvillea spectabilis, Cassia fistula*, *Ficus benghalensis*, *Ficus religiosa* and *Mangifera indica*) growing in the catchment were recorded in terms of percent difference between clearfall and throughfall. All the statistical analyses were done using SPSS 16 programme.

Results and Discussion

Varanasi region witnessed sizably high depositions of $SO_4{}^{2-}$, NO_3^-, $NH_4{}^+$, Ca^{2+}, Mg^+ and $PO_4{}^{3-}$ (Fig. 1). Variations in nutrient ions were significant due to season and chemical species (ANOVA, $p < 0.01$). Depositions of $SO_4{}^{2-}$ (17.20 kg ha^{-1} $year^{-1}$), $NO_3{}^-$ (12.85 kg ha^{-1} $year^{-1}$) and $Mg_2{}^+$ (14.97 kg ha^{-1} $year^{-1}$) appeared almost in similar range. Deposition of Na^+, Ca^{2+} and $NH_4{}^+$ appeared more or less in a similar range (Fig. 1). Atmospheric deposition of K^+ (1.82 kg ha^{-1} $year^{-1}$) remained lowest, although spatial trends were found almost similar for all the nutrient ions studied. On temporal scale, atmospheric deposition for all the nutrient ions remained maximum during winter and minimum during rainy season.

Miller et al. (1993) have reported atmospheric N input of 16.7 kg ha^{-1} $year^{-1}$ at a high elevation forest of Whiteface mountain, New York receiving regional transport of pollutant aerosols. This value is lower than those recorded in this study receiving urban-industrial emissions (21.20 kg ha^{-1} $year^{-1}$ $NO_3{}^-$ + $NH_4{}^+$). Dry deposition of HNO_3 could be a factor contributing to high bulk deposition of $NO_3{}^-$. The climate of this region is characterized by extended period of dryness terminated by a short wet period. Formation of HNO_3 is favoured by high day temperature and light intensity which raise the concentration of OH^+ radicals. The $NO_3{}^-$ particles formed by the reaction of atmospheric HNO_3 with particulates could lead to high deposition of $NO_3{}^-$ at river sites. The bulk deposition of orthophosphate observed in this study remained lower in comparison to all other nutrient ions. Pandey and Pandey (2005) reported relatively lower deposition of P in some remote areas of dry tropics. Atmospheric deposition of Ca^{2+} showed significant positive correlation with Na^+ ($r = 0.86$;

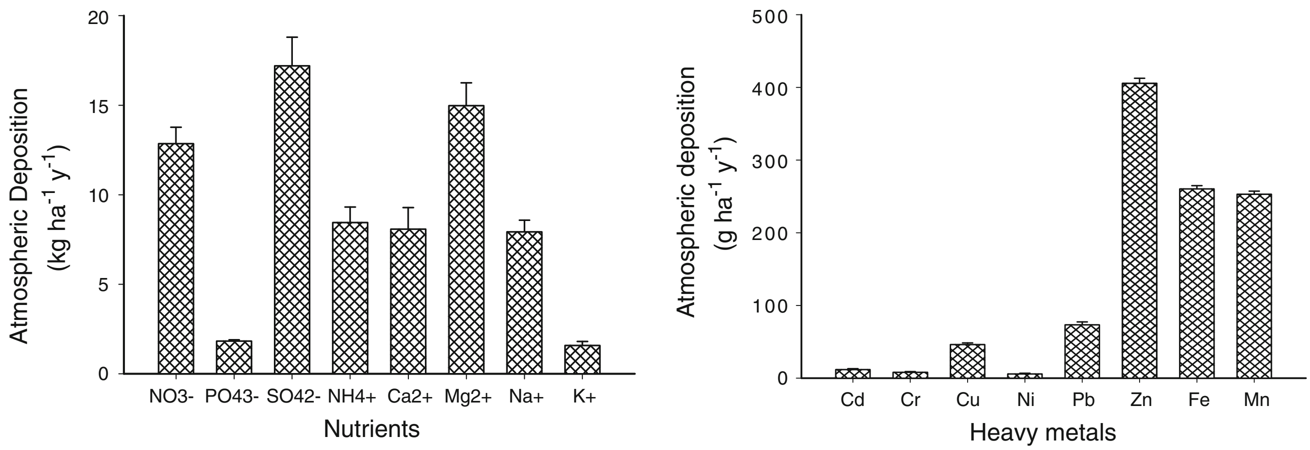

Fig. 1 Atmospheric deposition of nutrients and metals at the study site

$p < 0.01$) and NH_4^+ ($r = 0.86$; $p < 0.01$). PO_4^{3-} also showed significant correlation with K^+ ($r = 0.82$: $p < 0.01$). Correlation coefficients between cations indicated their common source of origin. Values of correlation coefficient between Ca^{2+} and SO_4^{2-} ($p < 0.01$) and between Ca^{2+} and NO_3^- ($p < 0.01$) were also significant.

The values recorded here appeared more than 6 times higher than that reported for non-source oriented northern forested ecosystems (Aber et al. 1989). This suggests that the river site selected in this study is under the strong influence of atmospheric deposition through air-shed. Miller et al. (1993) reported annual N and S input at the rate of 16.7 and 17.5 kg ha^{-1} $year^{-1}$ respectively, at high elevation forest site at Whiteface mountain of New York receiving regional transport of pollutants. Singer et al. (1996) have reported atmospheric bulk deposition of SO_4^{2-}–S to be 14.3 kg ha^{-1} $year^{-1}$ at a forest site on Mt. Carmel. Sickman et al. (2003) have reported nutrient enrichment in remote high elevation lake of the Sierra, Nevada, and California.

Among the eight metals studied, maximum atmospheric deposition was recorded for Zn (405.70 g ha^{-1} $year^{-1}$). Atmospheric deposition appeared minimum for Ni (5.80 g ha^{-1} $year^{-1}$). For Fe and Mn, the atmospheric depositions were also high (Fig. 1). These observations indicate that the region witness high atmospheric loading which results in substantial deposition of Cd, Cr, Fe, Mn, Ni, Pb and Zn. The values recorded in this study are comparable to those observed in earlier studies conducted at source and non-source oriented locations of Indian tropics characterized by similar atmospheric loading (Khillare et al. 2004; Pandey et al. 2009a, 2012). Analysis of variance (ANOVA) indicated significant ($p < 0.01$; $p < 0.001$) variations in the atmospheric deposition of different metals.

Nutrient and metal retention capacity varied significantly depending on the chemical species as well as on plant species (Tables 1, 2). Retention of most of the nutrient ions remained high for *B. spectabilis* and *F. benghalensis. B. spectabilis* retained 16.88, 33.70 and 29.48 % of K^+, Ca^{2+} and Mg^{2+} through canopy interception and foliar absorption and for *F. benghalensis,* percent retention was 9.92, 33.31 and 30.84 % respectively for the same. Nutrient retention was found to be lowest for *F. religiosa.* In general, for most of the nutrient ions, especially NO_3^-, NH_4^+, SO_4^{2-}, Na^+ and K^+, nutrient retention remained insignificantly small, the values remained below their respective coefficient of variation. Even for most of the nutrient ion, except PO_4^{3-} throughfalls were characterized by nutrient enrichment (values marked with negative sign in the Table 1) instead of retention. Unlike nutrient ions however, none of the plant species showed throughfall enrichment for metals. With few exceptions, metal retention remained highest for Cu for most of the plant species considered in this study. The metal retention for Cu were 19.47, 19.46, 32.42, 14.85 and 27.20 % respectively for *M. indica, F. religiosa, F. benghalensis, C. fistula* and *B. spetabilis* (Table 2). With respect to plant species, with a few exceptions, metal retention remained highest for *F. benghalensis* followed by *M. indica, B. spectabilis, F. religiosa* and *C. fistula.* Among all plants selected, none of the plants showed metal leaching.

The canopy interception and foliar absorption of nutrients often depends upon specific nutrient and plant species. For instance, N in bulk deposition, equivalent to about 70 percent of nitrogen incorporated annually in above ground woody tissues in some temperate hardwood forests (Swank 1984). Atmospheric deposition of nutrients and trace elements in many part of our country has been shown to be very high leading to sizably high accumulation in terrestrial vegetation and soil (Singh and Agrawal 2005; Pandey et al. 2009b) as well as raised productivity of aquatic ecosystems (Pandey and Pandey 2005). This has particular relevance

Table 1 Percent nutrient retention capacity of selected woody perennials growing in the catchment of Ganga river

Nutrients	*B. spectabilis*	*C. fistula*	*F. benghalensis*	*F. religiosa*	*M. indica*
PO_4^{3-}	18.15 ± 1.030	10.50 ± 0.560	23.20 ± 5.300	15.90 ± 0.850	16.56 ± 0.890
NO_3^-	15.25 ± 0.850	8.05 ± 0.430	8.56 ± 0.460	−30.72 ± 1.660	6.50 ± 0.350
NH_4^+	6.81 ± 0.390	−1.58 ± 0.080	3.36 ± 0.180	−6.04 ± 0.320	1.59 ± 0.090
SO_4^{2-}	6.60 ± 0.360	−0.06 ± 0.003	8.28 ± 0.450	1.48 ± 0.080	3.66 ± 0.200
Na^+	4.39 ± 0.240	−3.12 ± 0.170	−11.48 ± 0.620	−11.06 ± 0.600	−2.50 ± 0.130
K^+	16.88 ± 0.910	11.95 ± 0.630	9.92 ± 0.550	−5.80 ± 0.310	17.37 ± 0.230
Ca^{2+}	33.70 ± 1.810	9.92 ± 0.530	33.31 ± 1.790	0.03 ± 0.0020	14.98 ± 0.810
Mg^{2+}	29.48 ± 1.640	−1.46 ± 0.080	30.84 ± 1.660	−8.48 ± 0.460	20.05 ± 1.080

Values marked with negative sign indicate nutrient leaching and those with no sign indicate nutrient retention

Values are mean (n = 16) ± 1SE

Table 2 Percent metal retention capacity of selected woody perennials growing in the catchment of Ganga river

Metal	*B. spectabilis*	*C. fistula*	*F. benghalensis*	*F. religiosa*	*M. indica*
Cd	14.37 ± 0.77	7.65 ± 0.41	3.94 ± 0.21	6.79 ± 0.36	15.33 ± 0.82
Cr	12.56 ± 0.67	6.82 ± 0.37	22.39 ± 1.20	21.36 ± 1.13	26.73 ± 1.43
Cu	27.2 ± 1.46	14.85 ± 0.79	32.42 ± 1.74	19.46 ± 1.04	19.47 ± 1.04
Ni	7.89 ± 0.42	7.7 ± 0.41	23.57 ± 1.26	3.62 ± 0.20	1.20 ± 0.06
Pb	16.92 ± 0.89	8.55 ± 0.46	5.41 ± 0.29	10.11 ± 0.54	18.93 ± 1.00
Zn	21.75 ± 1.17	12.72 ± 0.71	33.21 ± 1.78	28.22 ± 1.49	28.82 ± 1.54
Fe	7.86 ± 0.42	2.84 ± 0.15	23.07 ± 1.24	5.82 ± 0.32	12.07 ± 0.64
Mn	22.85 ± 1.27	12.45 ± 0.68	23.85 ± 1.28	7.27 ± 0.39	11.95 ± 0.60

Values are mean (n = 16) ± 1SE

for dry tropical regions where removal of nutrients by leaching remains very slow. Under such condition, atmospheric deposition could shorten the time of nutrient saturation leading to accelerated release and addition of such chemical species to down-stream water bodies. Relatively less information however, is available on coupling of atmospheric nutrient and trace elements with woody perennials with particular reference to their retention and enrichment and consequently low or high inputs to downstream water bodies through run-off water.

The throughfall enrichment effects of plant leaves have also been reported in other studies including the Silent Valley forest in south India (Rao et al. 1995) and subtropical montane moist forest on Ailao Mountains, China (Liu et al. 2002). Woody plants with full leaf condition often increase dry fall input. Potassium is the element that is most affected by canopy exchange. Ca^{2+} and Mg^{2+} are less affected by canopy exchange in comparison to K^+ (Zimmermann et al. 2002). Throughfall enrichment can be major pathway in nutrient cycling in natural ecosystems especially for those areas where direct anthropogenic flushing of nutrient is almost negligible. Furthermore, the above canopy air environment also affects the water balance of surrounding area. Through evapo-transpiration, it adds moisture to the air. This effect on the local humidity may be small, but similar to the water body, it may increase the humidity within and down wind of catchment vegetation (Tabacchi et al. 2000). This phenomenon may provide a trap/sink for atmospheric aerosols, contributing to throughfall enrichment of nutrients. Studies indicated that deposition of sulphates, under the canopy can be 1.5–6 times greater than rates outside the forest (Potter et al. 1991).

Some nutrients are more efficiently absorbed by leaves. For example, foliar absorption of Fe, Mn and Cu may be more efficient than absorption through soil. Uptake by plant leaves is more efficient when nutrient solution remains on the leaf as a thin film. Massive evaporation by river may increase humidity in its near catchment areas which may provide formation for thin films on leaf-surfaces and/or reduce accumulation of salts on leaves. Although contrasting reports available, some plant species are efficient accumulator of certain nutrient elements, especially when available in excess. For instance, black poplar trees (*Populus nigra* L.) can take up more than 50 % of artificial fertilization rates as high as 400 kg N ha^{-1} $year^{-1}$, whereas they assimilate only 16 kg N ha^{-1} $year^{-1}$ in natural conditions (Cole 1991). Similarly, a Carolina poplar (*Populus xcanadensis*) is an efficient nitrogen filter, as it is able to store large amounts of nitrogen in its root (O'Neill and Gordon 1994).

The plants considered in this study trapped and absorbed metal ions more efficiently than the rate of leaching or foliar secretion of such elements. In fact, many plants have the ability to store elements/ions in specialized sub-cellular organs such as vacuoles in order to minimize the cellular toxicity. Accumulation of toxic metal ions has been well established for higher plant species (Pandey et al. 2009b). This mechanism probably is the major contributor of increasing retention of metal elements in catchment vegetation.

Our data indicate that although some plant species contributes to throughfall enrichment through foliar leaching of nutrient ions, catchment vegetation invariably reduce transport of nutrients and metals through run-off (Tables 3, 4). Canopy induced increase in metal/nutrient percolation/infiltration to soil seemed to have contributed to reduced concentration of metals in run-off water. All the five plant species considered in this study invariably contributed to reducing nutrients and metals in run-off water. Reductions of both, nutrients and metals appeared more effective during low rainfall in comparison to heavy rainfall events. In general, this modifying influence was maximum for *B. spectabilis* and minimum for *F. religiosa* for nutrients (Table 3) and for metals it was maximum for *F. benghalensis* and minimum for *C. fistula*. Reduction of nutrient ions in run-off remained highest for PO_4^{3-} in all plant species, wherein PO_4^{3-} in run-off reduced by 34.20, 27.19, 36.90, 18.35 and 34.20 % under the influence of *M. indica, F. religiosa, F. benghalensis,* C. *fistula* and *B. spectabillis* respectively. For metals, the run-off reduction remained maximum for Cu and the respective reduction in run-off under these species were 26.02, 31.35, 36.98, 21.54 and 32.97 % (Table 4).

These observations clearly indicate that with few exceptions, all the five species considered in this study, significantly able to reduce nutrients and metal ions in the run-off, even though some species have contributed to throughfall enrichment of NH_4^+, Na^+ and Mg^{2+}. *B. spectabilis* showed superiority in comparison to all other species except *F. benghalensis,* with respect to nutrient/metal retention as well as their reduction in run-off water due probably to its faster growth in comparison to other

Table 3 Woody perennials growing in the catchment of Ganga river help reducing nutrients in percent run-off water entering into the river

Nutrients	*B. spectabilis*	*C. fistula*	*F. benghalensis*	*F. religiosa*	*M. indica*
PO_4^{3-}	34.20 ± 1.83	18.35 ± 0.98	36.90 ± 1.98	27.19 ± 1.51	34.20 ± 1.80
NO_3^-	26.86 ± 1.44	13.38 ± 0.72	7.16 ± 0.38	4.97 ± 0.27	16.95 ± 0.89
NH_4^+	11.35 ± 0.61	5.45 ± 0.30	1.96 ± 0.11	5.45 ± 0.29	12.35 ± 0.69
SO_4^{2-}	10.97 ± 0.59	3.47 ± 0.19	6.88 ± 0.37	4.90 ± 0.26	11.97 ± 0.64
Na^+	6.48 ± 0.34	3.16 ± 0.17	11.48 ± 0.62	1.68 ± 0.09	18.52 ± 0.97
K^+	20.55 ± 1.10	17.25 ± 0.92	8.52 ± 0.47	9.42 ± 0.50	24.15 ± 1.29
Ca^{2+}	40.66 ± 2.18	15.45 ± 0.82	31.91 ± 1.71	11.90 ± 0.63	26.06 ± 1.42
Mg^{2+}	38.55 ± 2.07	10.56 ± 0.57	29.45 ± 1.62	3.45 ± 0.18	28.48 ± 1.54

Values represent percent reduction in nutrient content in run-off collected under the influence of woody perennials in comparison to those collected from clearfall location near respective species

Values are mean (n = 12) ± 1SE

Table 4 Woody perennials growing in the catchment of Ganga river help reducing metals in percent run-off water entering into the river

Metal	*B. spectabilis*	*C. fistula*	*F. benghalensis*	*F. religiosa*	*M. indica*
Cd	19.46 ± 1.04	11.17 ± 0.60	5.15 ± 0.28	11.91 ± 0.67	16.80 ± 0.90
Cr	20.08 ± 1.08	9.48 ± 0.51	28.48 ± 1.49	23.67 ± 1.27	28.35 ± 1.58
Cu	32.97 ± 1.79	21.54 ± 1.15	36.98 ± 1.98	31.35 ± 1.69	26.02 ± 1.39
Ni	11.87 ± 0.63	11.06 ± 0.59	29.45 ± 1.58	6.55 ± 0.35	1.84 ± 0.09
Pb	21.48 ± 1.15	12.22 ± 0.64	7.26 ± 0.39	13.06 ± 0.70	26.63 ± 1.46
Zn	28.38 ± 1.52	17.15 ± 0.92	35.48 ± 1.91	34.60 ± 1.91	30.48 ± 1.63
Fe	9.81 ± 0.53	4.68 ± 0.25	30.45 ± 1.63	8.57 ± 0.48	15.97 ± 0.90
Mn	10.37 ± 0.54	7.20 ± 0.42	10.86 ± 0.61	8.19 ± 0.44	6.50 ± 0.350

Values represent percent reduction in metal content in run-off collected under the influence of woody perennials in comparison to those collected from clearfall location near respective species

Values are mean (n = 12) ± 1SE

woody perennials considered in this study. Metals may also be taken-up indiscriminately during increased plant demand for resources. Furthermore, canopy influence may promote nutrient/metal concentration in soil layers and thereby reduce nutrient/metal concentration in run-off. It seemed that the coupling of foliar absorption and canopy induced percolation/infiltration to soil layers may be responsible for reduced nutrient/metal concentration of run-off water. This signifies an important contribution of catchment vegetation in reducing nutrient/metal transport to Ganga river. It may however, be noted that this approach will become more effective through removal/filtration of leaf litter before they are finally deposited to the river.

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