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Ecosystem sustenance of Upper Ganga Ramsar site through phytoremediation

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ABSTRACT

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Investigations were made to assess the hyper-accumulator plants useful in uptake of heavy metals pollutants from soil and water in wetlands of the Upper Ganga Ramsar site. Fourteen plant species were found useful in phytoremediation of the wetlands of which 10 species were hydrophytic (71.4%) and four terrestrial (28.6%). The free floating *Eichhornia crassipes, Pistia stratiotes* and *Lemna minor* were most useful in detoxification of the water body as they uptake maximum number of heavy metals from water. It is suggested that while clearing off the weeds during wetland management, their controlled populations be retained for unhampered Phytoremediation of wetlands necessary for maintenance of the ecosystem equilibrium.

Key-words: Hyper-accumulator, wetland, phytoremediation, Upper Ganga, Ramsar Site, Uttar Pradesh, India.

INTRODUCTION

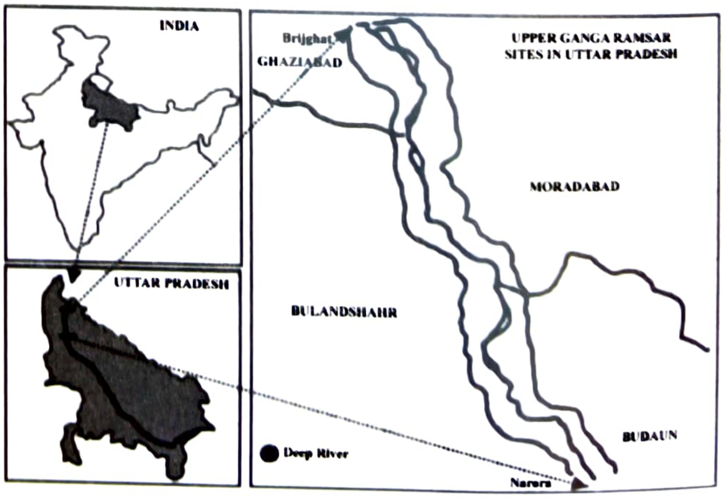
Wetlands, including rivers, lakes, ponds and other water reservoirs, account for *c.* 4% of the earth's ice-free land surface. These versatile, most productive ecosystems with enormous biodiversity act as water resource for primary productivity and livelihood of dependent livestock, flora and fauna while also bringing about carbon sequestration (Allen 1989). Woefully, many wetlands are slowly becoming victims of pollutant influx due to modernization, developmental activities and population pressure and are getting annihilated in the expanding civilization. The Ramsar convention for conservation and sensible use of all wetlands for achieving sustainable development was therefore developed in 1971 at Ramsar, Iran which was amended in 1982 and 1987 with 12 articles. According to this convention, the wise use of wetland is the maintenance of their ecological characters which is achieved through implementation of ecosystem approaches within the context of sustainable development (Sarkar 2011). India became a contracting party of this convention on 1st Feb, 1982 with six wetlands, the number slowly increased to 26, of which the Upper Ganga Ramsar Site (Lat. 28°10'26"-28°47'18"N; Long. 77°07'04"-78°25'57"E) in Uttar Pradesh was included in 2005 as the only riverine Ramsar site of India (Brooks & Robinson 1998, Murthy et al. 2013).

According to the Ramsar classification, there are 42 wetland types which are grouped into three categories, the marine and coastal wetlands, the inland wetlands and the human made wetlands. These are the cradles of biological diversity, providing water and primary productivity for sustenance of biodiversity as they support high concentration of birds, mammals, reptiles amphibians, fishes and invertebrate species while acting as store house of plant genetic material. The 85 km stretch of the Upper Ganga Ramsar Site is an inland river/stream wetland where water surges recurrently during floods from the Ganga river and recedes during dry summer months. The total wetland area covered within 167 km perimeter of the Ramsar site is 11364 ha with pre-monsoon vegetation coverage of 58 ha and post-monsoon 25 ha, and water turbidity being moderate to high. The Ganga river is constantly exposed to several anthropogenic disturbances from human settlements, religious ceremonies and burial practices along its catchments which pose threat to the soil and waters through sewage and trash dumping, industrial effluents, food, human and animal remain disposal, etc. Most hazardous of these are the hydrochloric acids, heavy metals, bleaches, dyes and pesticides (Ebrahimpour & Mushrifah 2008) which percolate through soil into wetlands and river streams. Contaminant accumulation thus creates toxicity, bio-accrual and bottleneck in aquatic food web where phytoplanktons are at bottom and the avian fauna at zenith. Recurrent extraction and elimination or transformation of these pollutants from soil and water, into non-toxic compounds is therefore integral to wetland conservation and sustenance which has direct impact on perpetuation of its endangered fauna.

Many plants, mainly the aquatic macrophytes, are known for effective bio-absorption and bio-accumulation of soluble and bio-available contaminants from water through roots in floating forms and general body surface in submerged and anchored hydrophytes (Brooks & Robinson 1998). These hyperaccumulator plant species are characterized by their vigorous growth and high tolerance for contaminants as well as for altered pH and they help in uptake, disintegration and release of the pollutants into the atmosphere. The members of family Poaceae are most ideal hyperaccumulators due to their fibrous rooting system which stabilize the soil and provide a large surface area for root soil contact. Besides these over 500 other plant species belonging to Asteraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Fabaceae, Lamiaceae, Poaceae, Violaceae and Euphorbiaceae which generally grow on metalliferous soils are capable of accumulating massive amounts of heavy metals in their tissues without exhibiting symptoms of toxicity. All these plants are very useful components of the wetland ecosystem as they provide uninterrupted service in natural management of these wetlands. However during management practices, they are often removed inadvertently which leads to pollutant retention and accumulation in the water body causing deleterious effects on the wetlands. The present investigation was therefore made to record the potential heavy metal accumulator plant species of the Upper Ganga Ramsar Site which effectively extract pollutants from soil and/or water, and establish their functional potential in phytoremediation and protection of this Ramsar site from degradation.

MATERIAL AND METHODS

The study area: The holy Ganga river rises at 7,010 m in Gangotri, Uttar Kashi District, Uttarakhand, on southern slopes of the Himalayan range and flows through Uttarakhand, Uttar Pradesh, Bihar and West Bengal covering 2,525 km before it joins the Bay of Bengal. The entire river stretch of Ramsar site, from Brijghat to Narora (Text-figure 1) has a total water spread area of about 26,590 ha. It is shallow with only intermittent small stretches of deep-water pools and reservoirs upstream barrages. Its banks are sandy and muddy, but with significantly rich biodiversity and religious importance and are embanked with boulders



Text-figure 1. Map showing upper Ganga Ramsar Site in Uttar Pradesh, India.

which check erosion. Its depth varies from 300 cm to 362 cm in wet season and from 50 cm to 150 cm in dry season and transparency ranges between 3 and 5 cm during monsoon season. Irregular water flow from the reservoirs in the upper reaches and inconsistent rainfall in the area are responsible for the irregular flow of the Ganga River. The discharge record from the barrages shows a regular fluctuation in the water level causing disturbance to the natural habitat of different aquatic animals. The entire region has rich biodiversity which includes a rich assemblage of phytoplanktons, zooplanktons, fishes, reptiles and birds including many red listed species of these and about 450 species of plants, both aquatic and terrestrial.

The wetlands are used for irrigation, fishing, pilgrimage, mass religious bathing and post-cremation activity. Its surrounding areas are used for agriculture, grazing, nesting and basking ground for turtles and crocodiles. Protected areas within this Ramsar site are wanting, for *in situ* conservation of the endangered species.

Major disturbances and threats: All the ways from Brijghat to Narora, most of the ghats have religious importance and are important for tourism, livestock grazing and hydro-electric power generation. Pilgrims use the river water for holy bath, cremation and post-cremation and ritual activities. As a result the river is exposed to various threats of pollution, soil erosion, domestic sewage disposal, industrial waste discharge, unspecified agricultural runoff, over-fishing and all factors augmented by population pressure, urban development, expansion of settlements, pesticide/herbicide and fertilizer sprays in agricultural fields, river bank erosion and fluctuation in water-level.

Field surveys and specimen collection: Surveys were conducted under the MoEFCc-BSI project on Floristic Diversity of Upper Ganga Ramsar Site (Text-figure 1), during the years 2012-14 for studies on floristic diversity of the region. Plant samples were collected from the wetlands within precincts of the Ramsar site regions, identified and analyzed for their heavy metal content and concentration. All the plant material oven dried at 75ºC, ground to a fine powder and the homogenous samples weighed, digested and analyzed for their heavy metal contents by inductivity coupled plasma optical emission spectrometry using Perkin Elmer Model Optima 5300 DV spectrometer (Allen 1989) and the values were estimated with the help of standard run. Plants with high concentration of heavy metals were categorized as accumulators while those with lower concentrations were excluders.

RESULTS AND DISCUSSION

Heavy metal accumulator plant species: As many as 14 plant species were found to absorb heavy metal traces (Tables 1, 2) of which 12 species (85.7%) were effective in extracting lead (Pb), nine species (64.3%) extracted zinc (Zn) and copper (Cu) whereas eight species (57.1%) extracted cadmium (Cd). Arsenic (As) was extracted by seven species (50%), chromium (Cr) by 6 species (42.8%), mercury (Hg) by 5 species (35.7%), nickel (Ni) by 4 species (28.5%) and silver (Ag) and iron (Fe) by a single species each (7.1% each).

Aquatic heavy metal accumulator species: Among the aquatic species useful in extraction of heavy metals from water, the fast growing weeds *Eichhornia crassipes* was most effective in detoxification of water body as they extracted nine heavy metal toxins - Pb, Cd, Cr, Cu, Zn, As, Hg, Ni and Fe. This was followed by *Pistia stratiotes* which extracted eight elements Pb, Cd, Ag, Cu, Zn, As, Hg and Ni respectively, implying that these are most promising phytoremediation plants and are expected to play significant role in wetland water purification and are therefore essential for sustenance of the aquifer including its floral, faunal as well as phytoplankton community. These species are very fast growing and spreading hence they tend to cover the entire water surface which usually becomes problematic when it chokes the water surface. However, considering their detoxification property, presence of these two species to a certain extent is essential for wetland sustenance. Scattered patches of their population are therefore necessary to be retained under controlled conditions, during clearing operations. The utility of *Pistia stratiotes* for its metal extraction capacity and water detoxification confirms its role as a phytoremediating plant species paving way to future utility of the plant in wetlands phytoremediation. The

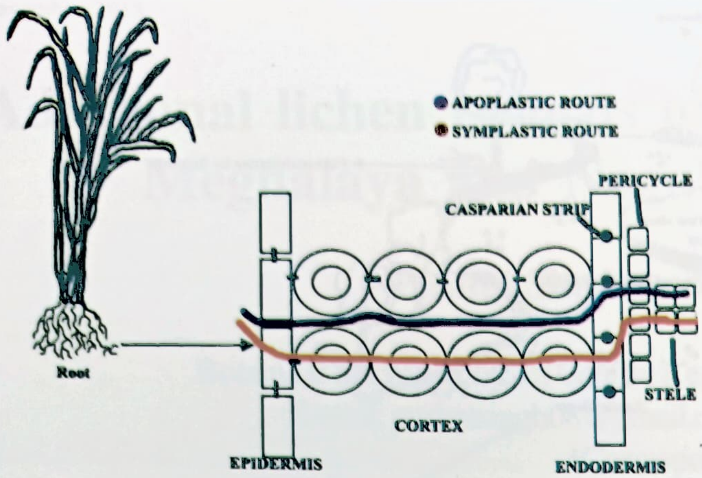
Table 1. Hyperaccumulator plant species useful in phytoremediation.

S. No.	Species name	Family	Habit	Fl-Fr	Ecology	Trace elements
				A: AQUATIC		
1.	*Azolla pinnata* R.Br.	Azollaceae	Free floating	Sept. – Feb.	In stagnant water bodies near the river.	Pb
2.	*Ceratophyllum demersum* L.	Ceratophyllaceae	Submerged	Oct.-Feb.	In stagnant water bodies near the river.	As, Pb, Zn, Cu
3.	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceaea	Free floating	April-Nov	Densely covering all stagnant water pools and edges of islands and all water boundaries	As, Fe, Cu, Zn, Pb, Cd, Cr, Ni, Hg
4.	*Hydrilla verticilliata* (L.f.) Royle	Hydrocharitaceaea	Submerged	Nov -April	Found in all stagnant water pools.	As, Pb, Zn, Cr
5.	*Ipomaea aquatica* Forssk.	Convolvulaceae	Anchored emergent	Throughout the year	Scattered throughout the river banks.	As, Cd, Pb, Hg, Cu, Zn
6.	*Lemna minor* L.	Lemnaceae	Free floating	June-Nov.	On edges throughout the river banks.	As, Zn, Cu, Hg
7.	*Nelumbo nucifera* Gaertn.	Nymphaeaceae	Anchored floating	June-Oct	Infrequent, in stagnant water pools.	Zn, As, Cu Ni, Pb, Hg.
8.	*Ottelia alismoides* (L.) Pers.	Hydrocharitaceaea	Submerged	Oct-March	In shallow water pools.	Cu
9.	*Pistia stratiotes* L.	Araceae	Free floating	Aug.-Oct	Very infrequent, in stagnant nullas.	As, Pb, Ag, Cd, Cu, Hg, Ni, Zn
10.	*Typha angustifolia* L.	Typhaceae	Anchored emergent	Throughout the year	Frequent in swampy areas	Pb, Cd, Cr, Cu, Zn, Ni
				B: TERRESTRIAL		
11.	*Brassica campestris* L.	Brassicaceae	Terrestrial	Jan.-March	Infrequent, in waste places	Cd, Cr, Pb
12.	*Datura innoxia* Mill.	Solanaceae	Terrestrial	July-Jan.	Infrequent, in deserted places and barren areas.	Cd, Cr, Pb
13.	*Ipomoea carnea* Jacq.	Convolvulaceae	Terrestrial	Throughout the year	Scattered throughout the waste places.	Cd, Cr, Pb
14.	*Solanum nigrum* L.	Solanaceae	Terrestrial	Sept.-Feb.	In catchment regions and along roadsides.	Cd, Pb, Cu, Zn

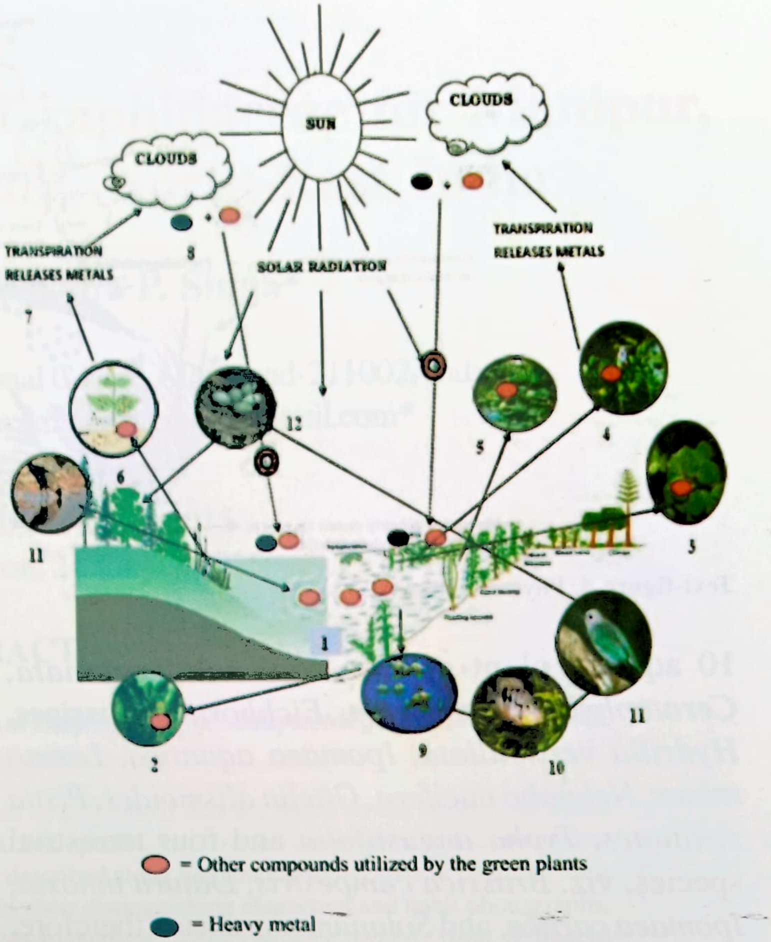
other aquatic plants species, viz. *Ipomaea aquatica*, *Nelumbo nucifera* and *Typha angustifolia* extracted six heavy metals each, e.g. Pb, Cd, Cu, Zn, As, Hg; Pb, Cu, Zn, As, Hg, Ni and Pb, Cd, Cr, Cu, Zn, Ni. *Ceratophyllum demersum, Hydrilla verticilliata* and *Lemna minor* extracted four heavy metals, i.e. Pb, Cu, Zn, As; Pb, Cr, Zn, As and Cu, Zn, As, Hg. *Ottelia alismoides* and *Azolla pinnata* were found to extract only one element each, i.e. Cu and Pd respectively.

Terrestrial heavy metal accumulator species: In addition to aquatic plants, the terrestrial species *Solanum nigrum* was found to extract four pollutants - Pb, Cd, Cu and Zn from soil-water interfaces and *Brassica campestris, Datura innoxia, Ipomoea carnea* absorbed three heavy metals each - Pb, Cd, Cr. The plant body of these have high tolerance capacity for these substances and the heavy metal traces extracted from the soil-water interface in waste places where they generally occur, get stored within their cells. While affecting phytoremediation, these species also prevent soil and river bank erosion and help considerably in wetland management.

Mechanism of heavy metal uptake in plants (Text-figure 2)**:** The aquatic plant species transport oxygen through their root parenchyma and lacuna along with water. Their roots solubilize and absorb micronutrients from soil in very low levels, even from nearly insoluble precipitates with the help of plant-produced chelating agents, plant induced pH changes and redox reactions. The ions get attached in extracellular binding domain of trans-membrane transporters which transfer them into the cell. The contaminants thus reach endodermis through epidermis and casparian strips, enter xylem and are transported to the entire plant tissue system in form of sap, reach the shoot system where they get metabolized and are released back in the atmosphere (Shimp 1993). Transport occurs through specialized proteins embedded in the plant cell plasma membrane through ion uptake and translocation involving proton pumps, co-and anti-transporters, and channels involving phytoextraction, phytostabilization, rhizofiltration and phytovolatilization (Erakhrumen & Agbontalor 2007). The roots also exude enzyme which enhance degradation of contaminants in the soil. In addition to



Text-figure 2. Mechanism of heavy metal absorption in plants.



Text-figure 3. Natural phytoremedation in wetland ecosystem.

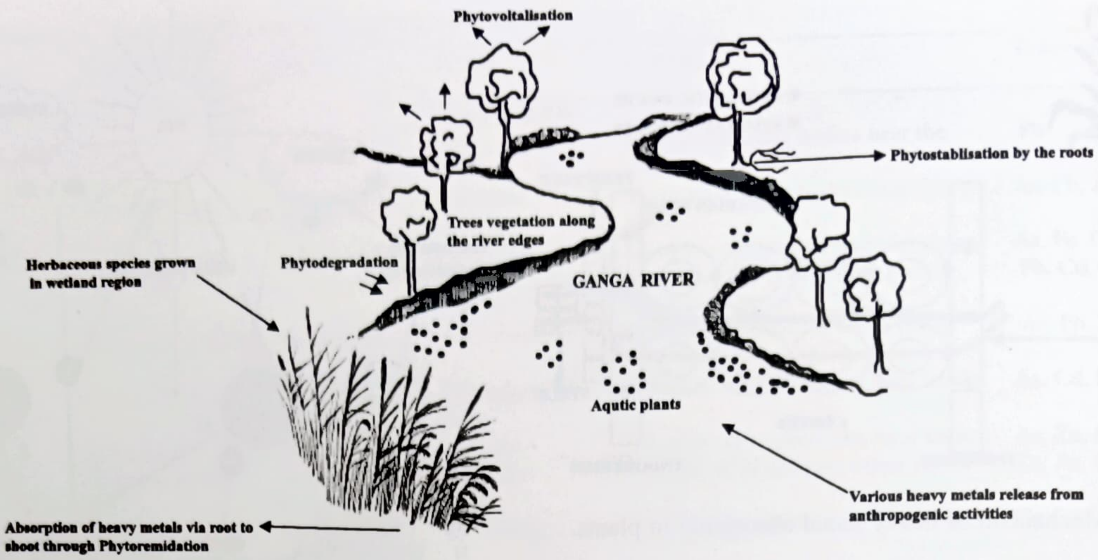
these the passive uptake through micro-pores in root cell walls may also serve as a route into the root for further degradation (Watson et al. 2003).

Sustenance of wetland ecosystem essentially depends on water quality as it is the primary water resource for aquatic flora and fauna, which mobilizes the food web and serves as a fundamental prerequisite for the focus and ingression of migratory bird into the Ramsar site. The present analysis encapsulates that at least 14 perpetually occurring floral constituents of the upper Ganga Ramsar site, with 10 hydrophytic (71.4%) and four terrestrial (28.6%) plant species as listed in Table 1 possessed functional significance in bringing about detoxification of soil and/or water from the wetlands of the upper Ganga ramsar site effecting in incessant phytoremediation of these wetlands. These

Table 2. The heavy metals extracted and released by hyperaccumulator plant species.

S.No.	Plant species, A: Aquatic, B: Terrestrial	Elements phytoremedaiated by the plants										
		Pb	Cd	Cr	Cu	Zn	As	Hg	Ni	Ag	Fe	Total
	A: AQUATIC SPECIES											
1.	*Azolla pinnata* R.Br.	+	-	-	-	-	-	-	-	-	-	1
2.	*Ceratophyllum demersum* L.	+	-	-	+	+	+	-	-	-	-	4
3.	*Eichhornia crassipes* (Mart.) Solms	+	+	+	+	+	+	+	+	-	+	9*
4.	*Hydrilla verticilliata* (L.f.) Royle	+	-	+	-	+	+	-	-	-	-	4
5.	*Ipomoea aquatica* Forssk.	+	+	-	+	+	+	+	-	-	-	6***
6.	*Lemna minor* L.	-	-	-	+	+	+	+	-	-	-	4
7.	*Nelumbo nucifera* Gaertn.	+	-	-	+	+	+	+	+	-	-	6***
8.	*Ottelia alismoides* (L.) Pers.	-	-	-	+	-	-	-	-	-	-	1
9.	*Pistia stratiotes* L.	+	+	-	+	+	+	+	+	+	-	8**
10.	*Typha angustifolia* L.	+	+	+	+	+	-	-	+	-	-	6***
	B: TERRESTRIAL SPECIES											
11.	*Brassica campestris* L.	+	+	+	-	-	-	-	-	-	-	3
12.	*Datura innoxia* Mill.	+	+	+	-	-	-	-	-	-	-	3
13.	*Ipomoea carnea* Jacq.	+	+	+	-	-	-	-	-	-	-	3
14.	*Solanum nigrum* L.	+	+	-	+	+	-	-	-	-	-	4

+ Elements traced by the plants, - element not traced by the plants, * Maximum no of elements removed by the plant, ** Second position for removed element, *** Third position removed the elements



Text-figure 4. Phytoremediation in upper Ganga ecosystem.

10 aquatic plant species, viz. *Azolla pinnata*, *Ceratophyllum demersum*, *Eichhornia crassipes*, *Hydrilla verticilliata*, *Ipomaea aquatica*, *Lemna minor*, *Nelumbo nucifera*, *Ottelia alismoides*, *Pistia stratiotes*, *Typha angustifolia* and four terrestrial species, viz. *Brassica campestris*, *Datura innoxia*, *Ipomaea carnea*, and *Solanum nigrum* are therefore, integral components of wetland ecosystem which help in recurrent water purification round the year due to which eutrophication of water bodies is diminished (Text-figure 3). This increases the longevity of purified water in wetlands useful for thriving of wetland biodiversity. Judicious management of these species populations within the wetlands of the internationally important, only riverine Ramsar site of India, to retain at least small patches of their populations during weed clearing operations, so that their perpetual presence is ensured round the year for unremitting detoxification of these wetlands, is fundamental (Text-figure 4). Although their recurrent clearing is essential when gregarious spread occurs, but this should be done with utmost care to maintain their minimal populations and the cleared out plant material can be digested and recycled to extract the metal components from ash which would also help in preventing dead organic matter accumulation. The present finding is of great utility in wetland management without hampering the natural unremitting Phytoremediation essential for sustenance of the Ramsar site biodiversity in equilibrium and perpetuation of its endangered faunal elements and incessant bird influx.

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