

Evaluation of Bioaccumulation Factor (BAF), Bioconcentration Factor (BCF), Translocation Factor (TF) and Metal Enrichment Factor (MEF) Abilities of Aquatic Macrophyte Species Exposed to Metal Contaminated Wastewater

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ABSTRACT: Wastewaters receiving aquatic bodies are quite complex in terms of pollutants, the transport and interactions with heavy metals. This complexity is primarily due to high variability of pollutants, contaminants and related parameters. The macrophytes are plausible bio-indicators of the pollution load and level of metals within the aquatic systems than the wastewater or sediment analyses.

The potential ability of aquatic macrophytes in natural water bodies receiving municipal sewage from Solapur city was assessed. Data from the studies on macrophytes exposed to a mixed test bath of metals and examined to know their potentialities to accumulate heavy metals for judging their suitability for phytoremediation technology were used. Potentialities for metal absorption, accumulation, magnification and enrichment were assessed. It was found that these abilities were dependent on the plant species and metal types. The data was received from the studies conducted from June 2014 to June 2018 with the macrophyte species *Eichhornia crassipes*, *Eichhornia azurea*, *Salvinia molesta*, *Salvinia auriculata*, *Pistia stratiotes*, and *Ipomoea aquatic* from the group of floating macrophytes, *Potamogeton crispus*, *Potamogeton perfoliatus*, *Potamogeton pectinatus*, *Potamogeton perfoliatus*, *Sagittaria sagittifolia* L. and *Colocasia esculenta* from the group of Submerged macrophytes and Emergent macrophytes: *Cyperus esculentus*, *Cyperus rotundus*, *Typha domingensis*, *Phragmites*, *Cyperus longus*, *Cyperus alopecuroides*, *Typha angustifolia*, *Typha latifolia*, *Iris pseudacorus*. *Cyperus esculentus*, *Cyperus rotundus*, *Typha domingensis*, *Phragmites australis*, *Cyperus alopecuroides*, *Cyperus longus*, *Typha angustifolia* L., *Typha latifolia* and *Iris pseudacorus* from the group of Emergent macrophytes.

KEYWORDS: Aquatic macrophytes, Bioaccumulation Factor, Bio-concentration Factor, Translocation Factor, Metal Enrichment Factor, Heavy metals; Plant potentials, Phytoremediation, Sewage Pollution.

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I. INTRODUCTION

Heavy metals are widespread and common pollutants of great environmental concern due to their non-degradable, toxic and persistent nature. They have serious ecological ramifications as they can enter in food chains and food webs [1]. They cause damages to the human health by disturbing growth, development, reducing haemoglobin, creating cancer, damaging the organs and nervous system, sometimes severe death [2, 3]. There is common belief that the living organisms require some heavy metals traces of metals like iron, zinc, cobalt, manganese, copper and strontium. But in their excessive levels are harmful to organisms. The metals like Lead, Cadmium, Chromium, Mercury, Arsenic, and Antimony are non-essential heavy metals [4,5]. The Bio-concentration factor of plant is most important plant feature in phytoremediation process. It gives an idea about the uptake potential for the metals, their mobilization into plant tissues, and storages in the aerial plant biomass [6]. Most of the aquatic plants have potential to uptake heavy metals, extract in large concentrations into their roots, transport and Translocate them to aerial parts [7]. The ecological tolerance aquatic plant species depends on different environmental factors like specific habit conditions, metal concentrations and water chemistry of aquatic habitats [8]. It is necessary to identify the suitable macrophytes or plants to absorb the greatest amount of these elements [9]. Most of the aquatic plants including the macrophyte species show different behaviors in terms of their ability to accumulate metal in their roots, stems and/or leaves. Therefore, The assessment of potentials of aquatic plants using Bioconcentration factor (BCF), Bioaccumulation factor (BAF), Metal Enrichment factor (MEF) and Metal Translocation Factor (MTF) are useful as they help to select the plants to employ in phytoremediation process to be used in many locations and in the wastewater sites [10, 11].

Some researchers [12,13] have studied the heavy metal accumulation and pointed out that environmental pollution caused by toxic metals has increased dramatically in recent years. The accumulation of heavy metals in various plants from anthropogenic sources like sewage and wastewaters has attracted the attention of researchers on inorganic pollution and has established plants as passive biomonitors [14, 15]. Number of plant species including macrophytes has been used for biological monitoring and remediation of metal pollution as these species have a tendency to assimilate metals from their surrounding environment [16]. Bioaccumulation factor and bioconcentration factor (BCF) are the important parameters used in environmental toxicology and risk assessment [17] and these both factors are traditionally used by scientific regulatory agencies [18]. The BCFs are generally standardized indicators and are based on laboratory-based bioaccumulation observations [19]. BAFs are used in the determination of the degree of intake and component storage of toxic compounds like metals in both, the plants and animals [18-19]. Some of the researchers [20, 21, 22 and 23] have pointed out that the ability of plants in phytoremediation has commonly been characterized by the metal translocation factors (MTF). Establishing metal enrichment factor (MEF) is an alternative method used to characterize the degree of anthropogenic pollution [24, 25] which is also attracting the researchers in recent period.

Water is an essential natural resource for all forms of life including human beings. For the human society, it is an important natural resource for economic development of agriculture, industry and other societal needs and various needful facilities. Most of water resources are under the threat of increasing pollution stress. These water sources not only supply water for human needs but also receive wastewaters discharged from various human activities [26]. Most of the aquatic ecosystems in the world are facing the pollution problems and are under increasing stress resulted from due to the effects of the rapidly growing population, technological development, urbanization and different activities of economic growth which cause aquatic species to disappear at an alarming rates [27]. Heavy metal contaminated water is the major environmental problem in most of these areas. Many times is due to the discharge of wastewater from industries, trade centers and runoff from mining sites in untreated or partially treated forms. They drastically affect not only the health of human being but also the fauna and flora from the natural ecosystems including anthropogenic agro-ecosystems. Most of the available conventional wastewater methods are very expensive, laborious and energy intensive. They don't provide the efficient treatments to reduce the desirable pollutants and do not achieve acceptable results. Phytoremediation is one of the suitable option which can serve as an ecological alternative to the conventional mechanized treatment systems and thus it has gained increased attention of scientific and industrial communities in recent years. Since last decade, it is emerging as an alternative sustainable, cheaper and simple technology for efficient

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treatments of wastewaters. Being the cost effective and environment friendly technology as the phytoremediation technology uses suitable plants for the removal of heavy metals from wastewater and it renders them harmless [28]. Phytoremediation treatment is an integrated multidisciplinary approach for the treatment of contaminated wastewaters from the different sources. It provides a great potential to treat such polluted wastewaters in wetland systems using aquatic macrophytes. Therefore, the assessment of the potentials of these macrophytes for the screening them to prefer in the treatment technologies efficiently and effectively to meet the treatment needs has become essential and find out the bioaccumulation bio-concentration, enrichment and metal translocation potentials of these macrophytes. The present studies are the efforts to make such assessment. The task in the present investigation was to calculate the BCF, BAF, MEF and MTF to assess the tolerance categories developed by the macrophyte species and to evaluate their potential for phytoremediation process.

II. EXPERIMENTAL METHODS

A. SCIENTIFIC CLASSIFICATIONS OF PLANTS STUDIED

Floating-leaved and Free-floating plants, Emergent plants and Submerged plants were studied during the experimental investigations. The emergent plants are the macrophyte plants which grow in water but which pierces the surface so that they are partially in air. Collectively, such plants are referred as emergent vegetation. Floating-leaved macrophytes are those whose root systems have attached to the substrate or bottom of the body of water and the leaves that float on the water surface. Submerged macrophytes completely grow under the water with their root attached to the substrate or may be without any root system. Free-floating macrophytes are those aquatic plants which are found suspended on water surface with their roots not attached to any substrate or sediment or bottom of water body. Scientific details of their identification are as below;

Floating macrophytes:

1. *Eichhornia crassipes*: It is nothing but the common water hyacinth. *Eichhornia crassipes* is its binomial name. It belongs to the kingdom plantae with subkingdom tracheobionta in vascular plants and superdivision of spermatophyte due to seeds of plant. It is a flowering plant from Magnoliophyta division with class Liliopsida as it is monocotyledon of subclass Liliidae with Liliidae order from family Pontederiaceae having Genus *Eichhornia* Kunth.
2. *Eichhornia azurea*: The common name of *Eichhornia azurea* is Anchored water hyacinth. This is a plant of kingdom plantae with clade Angiosperms, monocots and commelinids with order commelinales of family Pontederiaceae having genus *Eichhornia* and species *E.azurea*. *Eichhornia azurea* is its binomial name.
3. *Salvinia molesta*: *Salvinia molesta* is the binomial name. Commonly, it is known as giant salvinia. It is a fern that floats on pond surfaces. It is a plant from kingdom plantae having class polypodiopsida with order salviales from family salvinaceae of genus *Salvinia* and species *S.molesta*.
4. *Salvinia auriculata*: *Salvinia auriculata* is the binomial name of the plant belonging to the species *S.auriculata* of genus *salvinia* of family Salvinaceae of order salviales belonging to class polypodiopsida of kingdom plantae.
5. *Pistia stratiotes*: It is commonly known as Pistia with binomial name *Pistia stratiotes*. It belongs to the plantae kingdom of clade angiosperms, monocots having order Alismatales of family Araceae with subfamily Aroideae, Tribe Pistieae with genus *pistia* and species *P.stratiotes*.
6. *Ipomoea aquatic*: It is a macrophytic plant of Plantae kingdom, clade Angiosperms, Eudicots of clade Asterids with order Solanales of family Convolvulaceae having genus *Ipomea* and species *I.aquatic* and *Ipomoea aquatic* as its binomial name.

Submerged macrophytes:

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1. *Potamogeton crispus*: *Potamogeton crispus* is a binomial name of macrophyte which belongs to the Kingdom plantae, clade Angiosperms, monocots having order Alismatales from family Potamogetonaceae of genus Potamogeton with species P.crispus.
2. *Potamogeton perfoliatus*: This plant belongs to kingdom Plantae, Clade-Angiosperms, monocots, having order-Alismatales belonging to family-Potamogetonaceae of genus Potamogeton with Potamogeton perfoliatus as species name and binomial name.
3. *Potamogeton pectinata*: This is commonly known with its binomial name as Stuckenia pectinata and its synonyme is *Potamogeton pectinata*. It is a macrophyte of Kindom-Plantae, Angiosperms of monocot having order-Alismatales from family-Potamogetonaceae having genus-Stuckenia and species-S.pectinata.
4. *Sagittaria sagittifolia* L.: Arrowhead is a common name to this macrophyte. It belongs to kingdom-Plantae, Clade-Angiosperms, monocots and has order-Alismatales with family-Alismataceae, genus-Sagittaria and species name as S.sagitiifolia. Its binomial name is *Sagittaria sagittifolia*.
5. *Colocasia esculenta* : This plant belongs to the kingdom-planae, clade-Angiosperms with family-Araceae of genus-Colocasia and species C.esculenta. Its binomial name is *Colocasia esculenta*.

Submerged macrophytes:

6. *Potamogeton crispus*: *Potamogeton crispus* is a binomial name of macrophyte which belongs to the Kingdom plantae, clade Angiosperms, monocots having order Alismatales from family Potamogetonaceae of genus Potamogeton with species P.crispus.
7. *Potamogeton perfoliatus*: This plant belongs to kingdom Plantae, Clade-Angiosperms, monocots, having order-Alismatales belonging to family-Potamogetonaceae of genus Potamogeton with Potamogeton perfoliatus as species name and binomial name.
8. *Potamogeton pectinata*: This is commonly known with its binomial name as Stuckenia pectinata and its synonyme is *Potamogeton pectinata*. It is a macrophyte of Kindom-Plantae, Angiosperms of monocot having order-Alismatales from family-Potamogetonaceae having genus-Stuckenia and species-S.pectinata.
9. *Sagittaria sagittifolia* L.: Arrowhead is a common name to this macrophyte. It belongs to kingdom-Plantae, Clade-Angiosperms, monocots and has order-Alismatales with family-Alismataceae, genus-Sagittaria and species name as S.sagitiifolia. Its binomial name is *Sagittaria sagittifolia*.
10. *Colocasia esculenta* : This plant belongs to the kingdom-planae, clade-Angiosperms with family-Araceae of genus-Colocasia and species C.esculenta. Its binomial name is *Colocasia esculenta*.

Emergent macrophytes:

1. *Cyperus esculentus*: *Cyperus esculentus* is commonly known as Chufa sedge and binomially, *Cyperus esculentus* L. It belongs to the kingdom-Plantae, clade Angiosperms, monocots, and commelinids with order-Poales, family-Cyperaceae, genus-Cyperus and species-C.esculentus.
2. *Cyperus rotundus*: *Cyperus rotundus* is commonly known as coco-grass. Its binomial name is *Cyperus esculentus* L. It belongs to kingdom-Plantae with Clade-Angiosperms, monocots, commelinids having order-Poales from Cyperaceae family with Cyperus genus and C.rotundus as species.
3. *Typha domingensis*: *Typha domingensis* Pers is the binomial name of it. It belongs to the Plantae kingdom, clade-Angiosperms, monocots and commelinids having order Poales from Typhaceae family and Typha genus and T.domingensis as the name of this species.
4. *Phragmites*: *Phragmites* is common name to the macrophyte having binomial name *Phragmites australis*. *Phragmites* belongs to Plantae kingdom with clade Angiosperms, monocots and commelinids and order-Poales with Poaceae family, subfamily-Arundinoideae having genus-*Phragmites adans.*
5. *Cyperus longus*: *Cyperus longus* is commonly known as Galingale. It belongs to Plantae kingdom with clade Angiosperms, monocots and Commelinids with order-Poales, family-Cyperaceae and genus *Cyperus* and classified as C.longus L. species.
6. *Cyperus alopecuroides*: *Cyperus alopecuroides* is commonly known by the same name. It belongs to kingdom-Plantae, Clade Angiosperms, monocots and commelinids with Cyperaceae family, genus-*Cyperus* and has the species name C.alopecuroides. Its binomial name is *Cyperus alopecuroides* [Rottb.](#)

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7. *Typha angustifolia*: Narrowleaf cattail has the binomial name *Typha angustifolia* L. It belongs to the kingdom Plantae, clade Angiosperms, monocots and commelinids with order-Poales, family Typhaceae having genus *Typha* and species name *T.angustifolia*.
8. *Typha latifolia*: *Typha latifolia* shows male flower spike when it gets matured and female flower spike beneath it in both the immature and mature stages. It belongs to Plantae kingdom with clade Angiosperms, monocots and commelinids. It belongs to the order Poales, Typhaceae family with *Typha* genus and *T.latifolia* species.
9. *Iris pseudacorus*: Yellow iris is known as *iris pseudacorus*. It belongs to Plantae kingdom with unranked angiosperms, monocots in the order Asparagales, family-Irideae, subfamily-Iridoideae with genus *Iris*, subgenus *Limniris* and species *I.pseudacorus*.

III.EXPERIMENTAL BASELINE METHODOLOGY

The data on the metal absorption capacities was selected which is based on the survey undertaken to measure heavy metal contents of various aquatic plant species available in four major water tanks located in and around Solapur city as well as the municipal sewage at Degaon-adjointing area of Solapur, Maharashtra. In these areas, the sewage is perennially available in ponds as well as it is used to irrigate the fodder-grass in nearby fields after receiving the agricultural runoff water from nearby fields occasionally. In the earlier studies, the samples of aquatic plant species which are dominant in these regions were selected which included the water hyacinth (*Eichhornia crassipes*), duck weed (*Lemna gibba*), coontail (*Ceratophyllum demersum*), curly leaf pond weed (*Potamogeton crispus*), cattail (*Typha domingensis*), common reed (*Phragmites australis*), matsedge (*Cyprus alopecuroide*), nutesedge (*Cyprus longus*) and barnyardgrass (*Echinochloa stagninum*). The identified macrophytes [29] were exposed to the metal-mixed synthetic wastewater test bath of 100 ppm each metal salts like $\text{CuSO}_4 \cdot 8\text{H}_2\text{O}$, PbO , $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, $\text{CdSO}_4 \cdot 8\text{H}_2\text{O}$ and $\text{NH}_4\text{SO}_4 \cdot \text{NiSO}_4 \cdot 6\text{H}_2\text{O}$ etc. for atleast one month after acclimatization processes and the examined for their potentialities to accumulate heavy metals using the different methods from authentic internet sources of research publications owing to suitability and availability of facilities for analysis including methods such as Cobalt by cobaltous pyridine method as described by Nicolaysen [30], Iron (Fe) by Dichromate method, Zinc (Zn) by EDTA Complexometry-Back Titration method [31], Manganese (Mn) by Volhard's method, Copper (Cu) by Sodium Thiosulphate titration method with confirmation by Spectrophotometric method [32], Lead (Pb) by EDTA Complexometric method, Manganese (Mn) by Periodate Oxidation Method, Chromium by with Diphenylcarbazide Spectrophotometric method [33] Cd by spectrophotometric method [34], Chromium (Cr) by Diphenylcarbazide Method [35], Cobalt (Co) by colorimetric method [36] as described in the vast literature as described elsewhere [37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55] for judging their suitability for phytoremediation technology. The detailed results are reported elsewhere [56] and the data are assessed for the calculation of different factors in the present paper.

There are various types of pollutants in the wastewaters from various sources such as industrial discharges, trade effluents, municipal sewage which enter the water sources. Among these organic and inorganic pollutants, most of these can cause danger directly on the lives of most aquatic organisms and human life by entering the food chain due to their accumulation potentials. The presences of elevated levels of the trace metals in plant tissues have detrimental toxic effects on the animals, especially on the consumption. For instance, the zinc and copper are trace metals those are needed in minute quantities for the healthy growth. Though are essential for plant growth as well as animal and human nutrition, but at elevated concentrations they can lead to phyto-toxicity and zoo-toxicity [57].

Bioaccumulation, bioconcentration, enrichment and transfer are some of such terms scientifically referred to express these potentials of plants. Bioaccumulation is the intake of a chemical substance and its concentration in the organism by the all possible means of intake including contact, respiration and ingestion. In other words, bioaccumulation is the capacity of a substance like metal to build up in the tissues of organisms either through direct exposure to the growth environment that includes wastewater, water, air, and soil or through the consumption of food [58].

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Bioconcentration is the intake and retention of a toxic substance like metal in an organism entirely by respiration from its growth environment like water in aquatic ecosystems or from air in terrestrial ones. It leads to the process of Biomagnification that occurs when the toxic chemical is passed up through the food chain to higher trophic levels, such that in predators and gets exceeded than the concentration to be expected, where this equilibrium prevails between an organism and its environment [59]. In simple words, bio-concentration is the increase in the progressive concentration of a typically toxic chemical in the tissues of an organism which may magnify its concentration through food chain. Enrichment factor (EF) is the degree of metal transfer from growth media like wastewater or water to plant organs. Translocation factor (TF) is the transfer of accumulated metals from roots to leaves in plants. The present study aimed to determine Bioaccumulation Factor (BAF), Bio-concentration Factor (BCF), Enrichment Factor (EF) and Translocation Factor (TF) using the available data published by the group of researchers associated with the present authors [56].

The mobility potentials of macrophytes for the heavy metals from the polluted growth media into the roots of the plants and the ability to accumulate in different parts, translocate the metals from roots to the harvestable aerial part and potential to enrich by metal were evaluated respectively by means of the bioconcentration factor (BCF), bioaccumulation factor (BAF), the metal translocation factor (MTF) and the metal enrichment factor (MEF) to assess the feasibility of the macrophytes for phytoremediation to provide insight for the use of native macrophyte plants to remediate metal contaminated sites.

The Bioaccumulation factor (BAF) was calculated according to the following equation :

$$\begin{aligned} \text{BAF}_{\text{Metal}} &= \frac{\text{[Metal content in aerial parts]}}{\text{[Metal Concentration in Source]}} \\ &= C_{\text{AP}}/C_{\text{WW}} \end{aligned}$$

Where $\text{BAF}_{\text{Metal}}$ stands for bioaccumulation factor for a specified metal, C_{AP} represents specific Metal Concentration in aerial parts expressed in mg/kg and C_{WW} represents Metal Concentration in growth environment-source like wastewater expressed in mg/kg.

The bioconcentration factor was calculated according to the following equation [60]

$$\text{B.C.F} = \frac{\text{Conc. of element in plant}}{\text{Conc. of element in water}}$$

For a specific metal, the bioconcentration of a specified metal is calculated using the following equation;

$$\begin{aligned} \text{BCF}_{\text{Metal}} &= \frac{\text{[Metal Concentration in root]}}{\text{[Metal Concentration in Source]}} \\ &= C_{\text{R}}/C_{\text{WW}} \end{aligned}$$

Where $\text{BCF}_{\text{Metal}}$ stands for bio-concentration factor for a specified metal, C_{R} represents specified Metal Concentration in root expressed in mg/kg and C_{WW} represents Metal Concentration in growth environment-source like wastewater expressed in mg/kg.

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$$\begin{aligned} \text{MEF}_{\text{Metal}} &= \frac{[\text{Metal content in only shoot}]}{[\text{Metal Concentration in Source}]} \\ &= C_{\text{OS}}/C_{\text{ww}} \end{aligned}$$

Where $\text{MEF}_{\text{Metal}}$ stands for specific metal enrichment factor, C_{OS} represents specified Metal content in only shoot expressed in mg/kg and C_{ww} represents Metal Concentration in growth environment-sources like wastewater expressed in mg/kg.

$$\begin{aligned} \text{MTF}_{\text{Metal}} &= \frac{[\text{Metal Content in only shoot}]}{[\text{Metal Concentration in root}]} \\ &= C_{\text{OS}}/C_{\text{R}} \end{aligned}$$

Where $\text{MTF}_{\text{Metal}}$ stands for specific metal translocation factor, C_s represents Metal content in aerial parts expressed in mg/kg and C_r represents Metal Concentration in root expressed in mg/kg. It is also called as shoot-root quotient and may be denoted as TF in general.

IV. RESULTS AND DISCUSSION

Many heavy metals reach to the toxic levels when their concentrations become bio-magnified through the food chains and food webs. These processes have attracted the attention of many scientists, researchers which warranted a focus on development of the suitable methods for removing the metallic pollutants from the environment. Phytoremediation of heavy metals is an innovative eco-friendly innovative method for removing these toxic metals from aquatic bodies. The present investigation has been conducted to know the potentialities of aquatic plants to absorb various metals like Cd, Cr, Co, Cu, Fe, Ni, Pb and Zn using by means of macrophytes growing in wastewater from Solapur city of western region in Maharashtra. These macrophyte species belong to various families, and are floating, submerged or emergent types. They are abundantly available in the Solapur region naturally. As concluded from referred vast literature [61, 62, 63, 64] these plants have a relatively high ability to absorb, concentrate, translocations and enrichments of metals. Uptake of one of these metals by any plant is generally highly correlated with the uptake of the other plants. Their roots tend to absorb more metals than their stems, which in turn absorb more metals than the shoot or stem and leaves. Aerial parts have in total more metal contents as these include roots, stem or sometimes referred as shoot and leaves. The concentrations of heavy metals are always in higher levels in the plants grown in any polluted environment than their levels in their surrounding water or wastewater. This is also true that the concentration of trace metals in aquatic environment depends on many factors such as wastewater discharge, quantity, frequency of discharge, seasonal variations in quantitative and qualitative abundance of of macrophytes and pollution load [65].

Nine of the heavy metals (Cd, Cr, Cu, co, Fe, Ni, Pb and Zn) has been discussed in the present study which is based on the measured levels of these pollutants in the studied macrophytes and synthetic wastewater used for the studies for the macrophyte species *Eichhornia crassipes*, *Eichhornia azurea*, *Salvinia molesta*, *Salvinia auriculata*, *Pistia stratiotes* and *Ipomoea aquatic* from the group of floating macrophytes, *Potamogeton crispus*, *Potamogeton pectinatus*, *Potamogeton perfoliatus*, *Sagittaria sagittifolia L.* and *Colocasia esculenta* from the group of Submerged macrophytes and *Cyperus esculentus*, *Cyperous rotundus*, *Typha domingensis*, *Phragmites australies*, *Cyprus alopecnroide*, *Cyperus longus*, *Typha angustifolia L.*, *Typha lotifolia* and *Iris pseudacorus* from the group of Emergent macrophytes. The results evaluated in terms of Bioaccumulation Factor, Bioconcentration Factor, Translocation Factor and Enrichment Factor for these nine metals are presented in Table 1, 2 and 3 as per their respective categories of floating, emergent and submerged respectively.

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Table 1: Bioaccumulation Factor (BAF), Bioconcentration Factor (BCF), Translocation Factor (TF) and Metal Enrichment Factor (MEF) of floating macrophyte species

Macrophyte species	Metal	Conc in root in $\mu\text{g/g}$ (C_R)	Conc in shoots in $\mu\text{g/g}$ (C_S)	Conc in Aerial parts in $\mu\text{g/g}$ (C_{AP})	BCF = (C_R/C_{WW})	BAF = (C_{AP}/C_{WW})	MEF = (C_{OS}/C_{WW})	MTF = (C_{OS}/C_R)
<i>Eichhornia crassipes</i>	Cd	7.5	1.2	8.7	0.075	0.084	0.16	0.012
	Cr	27.5	5.62	33.12	0.275	0.3312	0.0562	0.2044
	Co	38.6	12.3	50.9	0.386	0.509	0.123	0.319
	Cu	18.4	6.8	25.3	0.184	0.252	0.068	0.37
	Fe	1134.6	198.1	1332.7	11.346	13.327	1.981	0.175
	Mn	343	151	494	3.43	4.94	1.51	0.44
	Ni	732	345	1077	7.32	10.77	3.45	0.471
	Pb	27.7	12.3	40	0.277	0.4	0.123	0.444
Zn	184	59	243	1.84	2.43	0.59	0.321	
<i>Eichhornia azurea</i>	Cd	8.95	4.19	13.14	0.0895	0.134	0.019	0.468
	Cr	11.9	5.45	17.35	0.0119	0.174	0.1735	0.374
	Co	2.98	0.93	3.91	0.298	0.039	0.009	0.312
	Cu	14.4	11.25	25.65	0.144	0.257	0.011	0.781
	Fe	2413	1276	3689	24.13	36.89	12.76	0.528
	Mn	876	794	1670	8.76	16.70	7.94	0.906
	Ni	7.96	5.34	13.3	0.0796	0.133	0.0534	0.671
	Pb	6.33	2.91	9.24	0.063	0.092	0.029	0.460
Zn	212	94.4	306.4	2.12	3.064	0.944	0.445	
<i>Salvinia molesta</i>	Cd	0.24	0.11	0.35	0.003	0.004	0.001	0.005
	Cr	2.20	1.05	3.25	0.022	0.033	0.011	0.477
	Co	4.1	2.03	6.13	0.041	0.061	0.020	0.496
	Cu	2.21	1.5	3.71	0.022	0.037	0.015	0.679
	Fe	59	32	91	0.590	0.91	0.320	0.542
	Mn	64.2	32.4	96.6	0.642	0.966	3.24	5.047
	Ni	84.2	60.8	145	0.842	1.45	0.608	0.722
	Pb	3.85	2.96	6.81	0.039	0.068	0.03	0.769
Zn	24.0	14.3	38.3	0.240	0.383	0.143	0.596	
<i>Salvinia auriculata</i>	Cd	0.2	0.15	0.35	0.002	0.004	0.002	0.75
	Cr	22	6.9	28.9	0.22	0.289	0.069	0.314
	Co	17.4	2.41	19.81	0.174	0.198	0.024	0.139
	Cu	10.2	7.9	18.1	0.102	0.181	0.079	0.775
	Fe	14759	7103	21862	14.759	218.62	71.03	0.481
	Mn	12561	1394	13956	125.61	139.56	13.94	0.111
	Ni	4.09	2.98	7.07	0.041	0.071	0.03	0.729
	Pb	23.6	4.14	27.73	0.236	0.277	0.041	0.175
Zn	128	47.9	175.9	1.28	1.759	0.479	0.371	
<i>Pistia</i>	Cd	23.9	12.7	36.6	0.239	0.366	0.127	0.531

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<i>stratiotes</i>	Cr	22.8	13.3	36.1	0.228	0.361	0.133	0.583
	Co	8.64	2.13	10.77	0.086	0.108	0.021	0.247
	Cu	16.46	10.96	27.42	0.165	0.274	0.11	0.666
	Fe	8634	4768	13402	86.34	134.02	47.68	0.552
	Mn	3321	957	4278	33.21	42.78	9.57	0.288
	Ni	6.11	4.93	11.04	0.061	0.11	0.493	0.807
	Pb	10.3	6.32	16.62	0.103	0.166	0.632	0.614
	Zn	253	173	426	2.53	4.26	1.73	0.684
<i>Ipomoea aquatic</i>	Cd	12.6	6.4	26.8	0.126	0.268	0.064	0.508
	Cr	42.1	19.7	93.4	0.421	0.934	0.197	0.468
	Co	52.7	34.2	128.5	0.527	1.285	0.342	0.649
	Cu	105	64.5	253.8	1.105	2.538	0.645	0.614
	Fe	3287	1182	6642	32.87	66.42	11.82	0.360
	Mn	503	313	1239	5.03	12.39	3.13	0.622
	Ni	64.1	47.3	163.5	0.641	1.635	0.473	0.738
	Pb	7.64	4.21	18.04	0.076	0.180	0.042	0.55
	Zn	210	103	478	2.1	4.78	1.03	0.490

The *Eichhornia crassipes* was capable to absorb and accumulate more Fe than the other metals whereas, least absorption of almost all metals was recorded in the *Ipomoea aquatic* macrophyte. The overall absorption of Fe was higher in almost all the plants tested from among the floating macrophytes. Relatively, less absorption of Cd and Co was noticed. Therefore, the factors studied show that the *Eichhornia crassipes* has higher potential of absorptions and hence it is more useful for phytoremediation among the floating macrophytes.

Table 2: Bioaccumulation Factor (BAF), Bioconcentration Factor (BCF), Translocation Factor (TF) and Metal Enrichment Factor (MEF) of submerged macrophyte species

Macrophyte species	Metal	Conc in root in $\mu\text{g/g}$ (C_R)	Conc in shoots in $\mu\text{g/g}$ (C_S)	Conc in Aerial parts in $\mu\text{g/g}$ (C_{AP})	BCF = (C_R/C_{WW})	BAF = (C_{AP}/C_{WW})	MEF = (C_{OS}/C_{WW})	MTF = (C_{OS}/C_R)
<i>Potamogeton Crispus</i>	Cd	0.42	0.09	0.51	0.004	0.005	0.001	0.214
	Cr	64.8	23.7	88.5	0.648	0.885	0.237	0.366
	Co	9.3	5.4	14.7	0.093	0.147	0.054	0.581
	Cu	3.09	2.33	5.42	0.003	0.054	0.023	0.754
	Fe	1255	853	2108	12.55	21.08	8.53	0.68
	Mn	145	96	241	1.45	2.41	0.96	0.662
	Ni	354	135	489	3.54	4.89	1.35	0.381
	Pb	13.27	4.63	17.9	0.133	0.179	0.046	0.349
	Zn	41.01	2.41	43.42	0.41	0.434	0.024	0.059
<i>Potamogeton pectinata</i>	Cd	1.23	0.62	1.85	0.012	0.019	0.006	0.504
	Cr	4.4	2.7	7.1	0.044	0.071	0.027	0.614
	Co	8.4	3.6	12	0.084	0.12	0.036	0.429
	Cu	18.53	4.54	23.07	0.185	0.231	0.045	0.245

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	Fe	123	86	209	1.23	2.09	0.86	0.699
	Mn	23.21	5.49	28.7	0.232	0.287	0.055	0.237
	Ni	41.93	9.51	51.44	0.419	0.514	0.095	0.227
	Pb	19.34	6.42	25.76	0.193	0.258	0.064	0.332
	Zn	174	26.7	200.7	1.74	2.007	0.267	0.154
<i>Potamogeton perfoliatus</i>	Cd	2.97	1.33	4.3	0.03	0.043	0.013	0.448
	Cr	3.12	1.44	4.56	0.031	0.046	0.014	0.462
	Co	8.32	5.22	13.54	0.083	0.135	0.052	0.627
	Cu	16.22	7.23	23.45	0.162	0.235	0.072	0.446
	Fe	56.2	22.6	78.8	0.562	0.788	0.226	0.402
	Mn	368	137	505	3.68	5.05	1.37	0.372
	Ni	28.05	7.52	35.57	0.281	0.356	0.075	0.268
	Pb	15.24	5.35	20.59	0.152	0.206	0.054	0.351
	Zn	394	142	536	3.94	5.36	1.42	0.36
<i>Sagittaria sagittifolia</i> L.	Cd	18.53	4.94	23.47	0.185	0.235	0.049	0.267
	Cr	16.32	8.15	24.47	0.163	0.245	0.082	0.499
	Co	17.26	9.75	27.01	0.173	0.27	0.098	0.565
	Cu	15.41	11.12	26.53	0.154	0.265	0.111	0.722
	Fe	560	322	882	5.60	8.82	3.22	0.575
	Mn	194	123	317	1.94	3.17	1.23	0.634
	Ni	72.4	42.5	114.9	0.724	0.425	1.15	0.587
	Pb	50.36	27.12	86.48	0.504	0.865	0.271	0.539
	Zn	312	145	457	3.12	4.57	1.45	0.465
<i>Colocasia Esculenta</i>	Cd	33.2	21.4	54.6	0.332	0.546	0.214	0.645
	Cr	63.2	42.6	105.8	0.632	1.058	0.426	0.674
	Co	97.4	72.6	170	0.974	1.70	0.726	0.745
	Cu	92.6	63.2	155.8	0.926	1.558	0.632	0.683
	Fe	11965	7332	19997	119.65	199.97	73.32	0.613
	Mn	297	185	482	2.97	4.82	1.85	0.623
	Ni	67.2	44.5	111.7	0.672	1.117	0.445	0.663
	Pb	11.03	6.96	17.99	0.110	0.18	0.07	0.631
	Zn	203	127	330	2.03	3.30	1.27	0.626

The contents in terms of different factors presented in Table 2 reflects that the submerged macrophytes are also having considerable potential for metal remediation as envisaged from the concerned factors reflecting that they also can be used for phytoremediation of metal contaminated water or wastewaters.

Emergent macrophyte plants are relatively easier to monitor the process of phytoremediation in the shallow water or wastewater treatment sites. Their harvesting after maturity is easier. These plants also have great potential to remediate the heavy metals from the contaminated sites. The evaluation of potentials of emergent macrophytes reveals that they can be suitable employed for the removal of metals studied. Plants like *Cyperus esculentus* and *Cyperus rotundus* are common all over the Maharashtra region and hence easily available to employ for the treatment process. Their potentials revealed from Table 3 reflect their usefulness for remediating the metals from contaminated water and wastewaters. Therefore, they are suitable candidates for in-situ treatment processes in the surface flow channels.

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Table3: Bioaccumulation Factor (BAF), Bioconcentration Factor (BCF), Translocation Factor (TF) and Metal Enrichment Factor (MEF) of emergent macrophyte species

Macrophyte species	Metal	Conc in root in $\mu\text{g/g}$ (C_R)	Conc in shoots in $\mu\text{g/g}$ (C_S)	Conc in Aerial parts in $\mu\text{g/g}$ (C_{AP})	BCF = (C_R/C_{WW})	BAF= (C_{AP}/C_{WW})	MEF = (C_{OS}/C_{WW})	MTF = (C_{OS}/C_R)
<i>Cyperus Esculentus</i>	Cd	66	53	157	0.66	1.57	0.53	0.803
	Cr	524	69	625	5.24	6.05	0.69	0.132
	Co	637	183	911	6.37	9.11	1.83	0.287
	Cu	157	120	365.5	1.57	3.655	1.20	0.764
	Fe	2396	1738	5268	23.96	52.68	17.38	0.725
	Mn	344	196	711	3.44	7.11	1.96	0.570
	Ni	122	76	244	1.22	2.44	0.76	0.623
	Pb	347	59	429	3.47	4.29	0.59	0.170
	Zn	99	54	184	0.99	1.84	0.54	0.545
<i>Cyperus Rotundus</i>	Cd	68	66	192	0.68	1.92	0.66	0.971
	Cr	400	63	505	4.00	5.05	0.63	0.158
	Co	712	312	1108	7.12	3.12	11.08	0.438
	Cu	186	121	390	1.86	3.90	1.21	0.651
	Fe	1623	938	3274	16.23	32.74	9.38	0.578
	Mn	244	136	481	2.44	4.81	1.36	0.558
	Ni	222	127	425	2.22	4.25	1.27	0.572
	Pb	163	89	325	1.63	3.25	0.89	0.546
	Zn	257	97	427	2.57	4.27	0.97	0.377
<i>Typha Domingensis</i>	Cd	5.21	2.86	8.07	0.521	0.807	0.286	0.549
	Cr	41.7	16.4	58.1	0.417	0.581	0.164	0.393
	Co	13.5	4.27	17.77	0.135	0.1787	0.043	0.316
	Cu	138	19.5	157.5	1.38	1.575	0.195	0.141
	Fe	7891	2211	1.0102	7.891	101.02	22.11	0.280
	Mn	243	136	379	2.43	3.79	1.39	0.560
	Ni	548	353	901	5.48	9.01	3.53	0.644
	Pb	14.3	7.28	21.58	0.143	0.216	0.073	0.509
	Zn	236	92	328	2.36	3.28	0.92	0.390
<i>Phragmites Australies</i>	Cd	8.5	2.9	13.9	0.085	0.139	0.029	0.341
	Cr	52	6.5	80.9	0.52	0.809	0.065	0.125
	Co	19.5	1.78	21.81	0.195	0.218	0.0178	0.0913
	Cu	32.1	8.89	46.13	0.321	0.461	0.089	0.277
	Fe	12721	3519	16961	127.21	169.61	35.19	0.277
	Mn	2346	154	2607	23.46	26.07	1.54	0.067
	Ni	401	131	593	4.01	5.93	1.31	0.327
	Pb	14.5	6.22	24.8	0.145	0.248	0.062	0.430
	Zn	252	99.7	434.4	2.52	4.344	0.997	0.396
<i>Cyperus alopecuroides</i>	Cd	2.81	1.42	5.75	0.0281	0.0575	0.014	0.505
	Cr	8.11	1.43	12.66	0.0811	0.127	0.004	0.176

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	Co	NR	NR	NR	NR	NR	NR	NR
	Cu	16.1	5.33	29.63	0.161	0.296	0.0533	0.331
	Fe	2562	832	4740	25.62	47.40	8.32	0.325
	Mn	65	39	157	0.65	1.57	0.39	0.6
	Ni	48	19.8	93.7	0.48	0.937	0.198	0.413
	Pb	12.08	NR	73.31	0.121	0.733	NR	NR
	Zn	143	47.5	253.7	1.43	2.537	0.475	0.332
<i>Cyperus longus</i>	Cd	7.51	4.13	11.64	0.0751	0.116	0.013	0.550
	Cr	52.5	11.66	64.16	0.525	0.642	0.117	0.222
	Co	14.04	3.13	17.17	0.140	0.172	0.031	0.223
	Cu	24.6	14.4	39	0.246	0.39	0.144	0.585
	Fe	11015	1385	12400	110.15	124.00	13.85	0.126
	Mn	189	134	323	1.89	3.23	1.34	0.709
	Ni	87	36	123	0.87	1.23	0.36	0.414
	Pb	22.7	12.9	35.6	0.227	0.356	0.129	0.568
	Zn	137	34	171	1.37	1.71	0.34	0.248
<i>Typha angustifolia</i> L.	Cd	6.2	NR	9.5	0.062	NR	0.095	NR
	Cr	8.6	2.1	14.5	0.086	0.145	0.021	0.244
	Co	15.7	9.3	36.8	0.157	0.368	0.093	0.592
	Cu	24.8	6.1	43.2	0.248	0.432	0.061	0.246
	Fe	9989	1474	13150	99.89	131.50	14.75	0.148
	Mn	1332	921	3427	13.32	34.27	9.21	0.691
	Ni	153	94	370	1.53	3.70	0.94	0.614
	Pb	14.75	6.3	32.66	0.148	0.33	0.063	0.427
	Zn	141	61	216	1.41	2.16	0.61	0.433
<i>Typha latifolia</i>	Cd	6.2	3.7	9.9	0.062	0.099	0.037	0.597
	Cr	8.4	5.1	13.5	0.084	0.135	0.051	0.607
	Co	3.12	2	5.12	0.0312	0.0512	0.02	0.641
	Cu	24	4.3	28.3	0.24	0.283	0.043	0.179
	Fe	42.5	16.3	58.8	0.425	0.588	0.163	0.384
	Mn	194	83.3	277.3	1.94	2.773	0.833	0.429
	Ni	26.2	7.4	33.6	0.262	0.336	0.074	0.282
	Pb	19.3	5.2	24.5	0.193	0.245	0.052	0.269
	Zn	81	14	95	0.81	0.95	0.14	0.173
<i>Iris Pseudacorus</i>	Cd	2.2	0.9	3.1	0.022	0.031	0.009	0.409
	Cr	3.2	1.1	4.3	0.032	0.043	0.011	0.344
	Co	22.1	14.2	36.3	0.221	0.363	0.42	0.643
	Cu	36.4	17.9	54.3	0.364	0.543	0.179	0.492
	Fe	7964	732	8696	79.64	86.96	7.32	0.092
	Mn	643	319	956	6.43	9.56	3.19	0.496
	Ni	164	91	255	1.64	2.55	0.91	0.555
	Pb	21.7	12.7	34.4	0.217	0.344	0.127	0.585
	Zn	12	2	14	0.12	0.14	0.02	0.167

NR stands for Not Reported.

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A. Bioconcentration Factors (BCF)

An aquatic plant's ability to accumulate metals from growth media water can be estimated using the BAF and concentrate the metal is estimated by using BCF. The enrichment mobility potential of macrophyte is estimated by metal enrichment factor (MTF) and a plant's ability to translocate absorbed metals from the roots to the shoots and aerial parts is measured using the MTF. Therefore, these factors were studied for the selective macrophytes exposed to the metals studied.

Bioconcentration is the process through which the chemical concentrations in the aquatic plant or organism achieves a level which exceeds its level that exists in the growth media like water due to exposure to that chemical concentration in that medium. Bioconcentration is a result of the balance achieved between the rate of exposed for uptake of a chemical substance and its loss or elimination. The extent of bioaccumulation for a chemical substance is expressed in the form of bioconcentration factor (BCF) and is a ratio of chemical concentration in the plant and the growth medium. Following are the observations recorded in the present studies.

I. BCF of floating macrophytes:

- i. *Echhornia crasipes*: Fe>Ni>Mn>Zn>Co>Pb>Cr>Cu>Cd.
- ii. *Echornia azurea*: Fe>Mn>Zn>Co>Cu>Cd>Ni>Pb>Cr.
- iii. *Salvinia Molesta*: Ni>Mn>Fe>Zn>Co>Pb>Cr=Cu>Cd.
- iv. *Salvinia auriculata*: Mn>Fe>Zn>Pb>Cr>Co>Cu>Ni>Cd.
- v. *Pistia stratiotes*: Fe>Mn>Zn>Cd>Cr>Cu>Pb>Co>Ni.
- vi. *Ipomoea aquatic*: Fe>Mn>Zn>Cu>Ni>Co>Cr>Cd>Pb.

II. BCF of submerged macrophytes:

- i. *Potamogeton crispus*: Fe>Ni>Mn>Cr>Zn>Pb>Co>Cd>Cu.
- ii. *Potamogeton pectinatus*: Zn>Fe>Ni>Mn>>Pb>Cu>Co>Cr>Cd.
- iii. *Potamogeton perfoliatus*: Zn>Mn>Fe>Ni>Cu>Pb>Co>Cr>Cd.
- iv. *Sagittaria sagittifolia*: Fe>Zn>Mn>Ni>Pb>Cd>Co>Cr>Cu.
- v. *Colocasia esculenta*: Fe>Mn>Zn>Co>Cu>Ni>Cr>Cd>Pb.

III. BCF of emergent macrophytes:

- i. *Cyperus esculentus*: Fe>Co>Cr>Pb>Mn>Cu>Ni>Zn>Cd.
- ii. *Cyperus rotundus*: Fe>Co>Cr>Zn>Mn>Ni>Cu>Pb>Cd.
- iii. *Typha domingensis*: Fe>Ni>Mn>Zn>Cu>Cd>Cr>Pb>Co.
- iv. *Phragmites australis*: Fe>Mn>Ni>Zn>Cr>Co>Cu>Pb>Cd.
- v. *Cyperus alopecuroides*: Fe>Zn>Mn>Ni>Pb>Cu>Cr>Cd and Co is not reported due to its non-detectable level.
- vi. *Cyperus longus*: Fe>Mn>Zn>Ni>Cr>Cu>Pb>Co>Cd.
- vii. *Typha angustifolia*: Fe>Mn>Ni>Zn>Cu>Co>Pb>Cr>Cd.
- viii. *Typha lotifolia*: Mn>Zn>Fe>Ni>Cu>Pb>Cr>Cd>Co.
- ix. *Iris pseudacorus*: Fe>Mn>Ni>Cu>Co>Pb>Zn>Cr>Cd.

B. Bioaccumulation Factors (BAF)

Bioaccumulation factors (BAF) are generally performed under the laboratory conditions of exposures and hence are different from BCF as BAF does not include the acculation of chemical substances from possible food-chain magnification processes as is in BCF. But, due to the large number and great variety of persistent chemical substances those are to be evaluated and the potential implications of the outcome of the evaluation process for industry, human and ecological health and regulators, there is need to develop a sound methodology to evaluate the chemical substances

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for their bioaccumulation potentials. Following are these potentials observed for the macrophyte plants studied in present evaluation studies.

- I. BAF of floating macrophytes
 - i. Echorhia crasipes: Fe>Ni>Mn>Zn>Co>Pb>Cr>Cu>Cd.
 - ii. Echorhia azurea: Fe>Mn>Zn>Cu>Cr>Cd>Ni>Pb>Co.
 - iii. Salvinia Molesta: Ni>Mn>Fe>Zn>Pb>Co>Cu>Cr>Cd.
 - iv. Salvinia auriculata: Fe>Mn>Zn>Cr>Pb>Co>Cu>Ni>Cd.
 - v. Pistia stratiotes: Fe>Mn>Zn>Cd>Cr>Cu>Pb>Ni>Co.
 - vi. Ipomoea aquatic: Fe>Mn>Zn>Cu>Ni>Co>Cr>Cd>Pb.

- II. BAF of submerged macrophytes:
 - i. Potamogeton crispus: Fe>Ni>Mn>Cr>Zn>Pb>Co>Cu>Cd.
 - ii. Potamogeton pectinatus: Fe>Zn>Ni>Mn>Pb>Cu>Co>Cr>Cd.
 - iii. Potamogeton perfoliatus: Zn>Mn>Fe>Ni>Cu>Pb>Co>Cr>Cd.
 - iv. Sagittaria sagittifolia: Fe>Zn>Mn>Pb>Ni>Co>Cu>Cr>Cd.
 - v. Colocasia esculenta: Fe>Mn>Zn>Co>Cu>Ni>Cr>Cd>Pb.

- III. BAF of emergent macrophytes:
 - i. Cyperus esculentus: Fe>Co>Mn>Cr>Pb>Cu>Ni>Zn>Cd.
 - ii. Cyperus rotundus: Fe>Cr>Mn>Zn>Ni>Cu>Pb>Co>Cd.
 - iii. Typha domingensis: Fe>Ni>Mn>Zn>Cu>Cd>Cr>Pb>Co.
 - iv. Phragmites australis: Fe>Mn>Ni>Zn>Cr>Co>Cu>Pb>Cd.
 - v. Cyperus alopecuroides: Fe>Zn>Mn>Ni>Pb>Cu>Cr>Cd and Co is not reported due to its non-detectable level.
 - vi. Cyperus longus: Fe>Mn>Zn>Ni>Cr>Cu>Pb>Co>Cd.
 - vii. Typha angustifolia: Fe>Mn>Ni>Zn>Cu>Co>Pb>Cr>Cd.
 - viii. Typha latifolia: Mn>Zn>Fe>Ni>Cu>Pb>Cr>Cd>Co.
 - ix. Iris pseudacorus: Fe>Mn>Ni>Cu>Co>Pb>Zn>Cr>Cd.

C. Metal Enrichment Factors (MEF)

Enrichment factor signifies the potential mobility of metal in the macrophytes. The enrichment factor must be higher which means higher metal concentrations in the plant than in the growth media (water for macrophytes), which emphasizes the degree of plant for metal uptake [66, 67].

Both enrichment factor (EF) and translocation factor (TF) are to be considered while evaluating whether a particular macrophyte plant is a metal hyperaccumulator (accumulates >1000mg/Kg metal) for the phytoremediation. It should be comparatively higher [68, 69]. Therefore, there has been a continuing interest in searching for native plants that are tolerant towards heavy metals [70].

The performance of macrophytes studied in terms of MEF was in the following order in present investigation.

- I. MEF of floating macrophytes:
 - i. Echorhia crasipes: Ni>Fe>Mn>Zn>Co>Pb>Cd>Cu>Cr.
 - ii. Echorhia azurea: Fe>Mn>Zn>Cr>Pb>Ni>Cd>Cu>Co.
 - iii. Salvinia Molesta: Mn>Ni>Fe>Zn>Pb>Co>Cu>Cr>Cd.
 - iv. Salvinia auriculata: Fe>Mn>Zn>Cu>Cr>Pb>Ni>Co>Cd.

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- v. Pistia stratiotes: Fe>Mn>Zn>Pb>Ni>Cr>Cd>Cu>Co.
 - vi. Ipomoea aquatic: Fe>Mn>Zn>Cu>Ni>Co>Cr>Cd>Pb.
- II. MEF of submerged macrophytes:
- i. Potamogeton crispus: Fe>Ni>Mn>Cr>Co>Pb>Zn>Cu>Cd.
 - ii. Potamogeton pectinatus: Fe>Zn>Ni>Pb>Mn>Cu>Co>Cr>Cd.
 - iii. Potamogeton perfoliatus: Zn>Mn>Fe>Ni>Cu>Pb>Co>Cr>Cd.
 - iv. Sagitara sagittifolia: Fe>Zn>Mn>Ni>Pb>Cu>Co>Cr>Cd.
 - v. Colocasia esculent: Fe>Mn>Zn>Co>Cu>Ni>Cr>Cd>Pb.
- III. MEF of emergent macrophytes:
- i. Cyperus esculentus: Fe>Mn>Co>Cu>Ni>Cr>Pb>Zn>Cd.
 - ii. Cyperus rotundus: Co>Fe>Mn>Ni>Cu>Zn>Pb>Cd>Cr.
 - iii. Typha domingensis: Fe>Ni>Mn>Zn>Cd>Cu>Cr>Pb>Co.
 - iv. Phragmites australis: Fe>Mn>Ni>Zn>Cu>Cr>Pb>Cd>Co.
 - v. Cyperus alopecuroides: Fe>Zn>Mn>Ni>Cu>Cd>Cr>Pb and Co is not reported due to its non-detectable level.
 - vi. Cyperus longus: Fe>Mn>Zn>Ni>Cu>Pb>Cr>Co>Cd.
 - vii. Typha angustifolia: Fe>Mn>Ni>Zn>Cd>Co>Pb>Cu>Cr.
 - viii. Typha lotifolia: Mn>Fe>Zn>Ni>Pb>Cr>Cu>Cd>Co.
 - ix. Iris pseudacorus: Fe>Mn>Ni>Co>Zn>Cu>Pb>Cr>Cd.

D. Metal translocation factors (MTF)

Metal transfer factors indicated that mobility factor of metals among components in macrophyte plants that has exceeded in roots–stems and the least in stems–inflorescences while in fifty mobility factor for the stems–leaves and roots–stems were the highest and lowest, respectively. High bioconcentration factor (BCF) and low metal transfer factor (MTF) and bioaccumulation factor (BAF) values imply the suitabilities of the use of these macrophytes for phytostabilization of the metals and viceversa.

Plants with both bioconcentration factor and translocation factor having higher values have the potential to be used in phytoextraction. Besides, plants with bioconcentration factors are greater and metal translocation factor are less than that have the potential for phytostabilization [71]. The higher values of metal transfer factor (MTF) indicates an efficient ability to transport metals from roots to shoots and, most likely, the existence of tolerance mechanisms of macrophyte plants to cope with high concentrations of metals [66]. Therefore, the metal transfer factors were evaluated in present studies which are comparatively listed below for the metals studied.

- I. MTF of floating macrophytes:
 - i. Echinornia crasipes: Ni>Pb>Mn>Cu>Zn>Co>Cr>Fe>Cd.
 - ii. Echinornia azurea: Mn>Cu>Ni>Fe>Cd>Pb>Zn>Cr>Co.
 - iii. Salvinia Molesta: Pb>Ni>Cu>Zn>Fe>Mn>Co>Cr>Cd.
 - iv. Salvinia auriculata: Cu>Cd>Ni>Fe>Zn>Cr>Pb>Co>Mn.
 - v. Pistia stratiotes: Ni>Zn>Cu>Pb>Cr>Fe>Cd>Mn>Co.
 - vi. Ipomoea aquatic: Ni>Co>Mn>Cu>Pb>Cd>Zn>Cr>Fe.
- II. MTF of submerged macrophytes:
 - i. Potamogeton crispus: Cu>Fe>Mn>Co>Ni>Cr>Pb>Cd>Zn.

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- ii. Potamogator pectinatus: Fe>Cr>Cd>Co>Pb>Cu>Mn>Ni>Zn.
 - iii. Potamogeton perfoliatus: Co>Cr>Cd>Cu>Fe>Mn>Zn>Pb>Ni.
 - iv. Sagitara sagittifolia: Cu>Mn>Ni>Fe>Co>Pb>Cr>Zn>Cd.
 - v. Colocatia esculent: Co>Cu>Cr>Ni>Cd>Pb>Zn>Mn>Fe.
- III. MTF of emergent macrophytes:
- i. Cyperus esculentus: Cd>Cu>Fe>Ni>Mn>Zn>Co>Pb>Cr.
 - ii. Cyperous rotundus: Cd>Cu>Fe>Ni>Mn>Pb>Co>Zn>Cr.
 - iii. Typha domingenensis: Ni>Mn>Cd>Pb>Cr>Zn>Co>Fe>Cu.
 - iv. Phragmites australis: Pb>Zn>Cd>Ni>Cu>Fe>Cr>Co>Mn.
 - v. Cyperus alopecraide: Mn>Cd>Ni>Zn>Cu>Fe>Cr>Pb and Co is not reported due to its non-detectable level.
 - vi. Cyperous longus: Mn>Cu>Pb>Cd>Ni>Zn>Co>Cr>Fe.
 - vii. Typha angustifolia: Mn>Ni>Co>Zn>Pb>Cu>Cr>Fe>Cd.
 - viii. Typha lotifolia: Co>Cr>Cd>Mn>Fe>Ni>Pb>Cu>Zn.
 - ix. Iris pseudacorus: Co>Pb>Ni>Mn>Cu>Cd>Cr>Zn>Fe.

A vast literature was referred to insure the work done on the lines of scientific data base, methodologies, plants so far studied and reviewed work on the present matter to insure the scientific base of the studied macrophytes [72 to 83] before reaching to the conclusion.

V. CONCLUSION

The present study shows that the macrophyte plants have a wide range of metal accumulation, metal concentration, metal enrichment and metal transfer potentials. These potentials vary from species to species of aquatic macrophytes. The macrophytes having higher potentials in terms of these factors for the specified metal or metals under consideration be preferred for the phytoremediation of contaminated water by that metal or those metals.

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