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Health risks of leafy vegetable *Alternanthera philoxeroides* (Alligator weed) rich in phytochemicals and minerals

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Abstract

Alternanthera philoxeroides (alligator weed) grows abundantly in polluted Peri-urban Greater Hyderabad, India. It is collected at no cost and sold in the market as a leafy vegetable in the name of "Ceylon Spinach". The plant accumulates iron (Fe), manganese (Mn), cadmium (Cd), lead (Pb) and zinc (Zn) in roots and leaves. Soil samples were analyzed for pH, EC, available nitrogen (N), phosphorus (P) and potassium (K) and showed significant metal concentrations of Pb, Mn and Zn, which varied from one location to another. The metal accumulation order in the plants is root>leaf>stem in all the studied sites. The results revealed that the massive roots of alligator weed are effective in the bioconcentrating Fe, Mn, Zn, Pb and Cd, although the plant parts are rich in nutraceuticals like phenolics and antioxidants. Therefore, low income community prefers to consume it as vegetable. However, its consumption as a leafy vegetable can cause health risks.

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Introduction

Vegetables play a key role in human diet. They are rich source of carbohydrates, fibres, vitamins and minerals which are important for human health care. *Alternanthera philoxeroides* (alligator weed) is a low cost leafy vegetable as well one of the worst aquatic weeds in Telangana, India. It spreads rapidly, more so in polluted habitats, posing economic and environment impacts. It is collected and sold in the local markets on a large scale. It is found abundantly in polluted swamps, lakes, drainage, urban waterways etc. The plant proximate composition is N-free extract 36.6%, crude protein 25.9%, crude fibre 22.3%, ash 10.5% and fat 4.7%, and minerals like Na 0.76%, K 2.33% and Ca 0.41%, alkaloids, polyphenols etc (1). Non-essential amino acids like glutamic acid (20.86%), serine (8.28%), aspartic acid (7.82%), and arginine (6.52%) are abundant whereas essential amino acids such as leucine (4.3%), isoleucine (4.24%), lysine (3.88%), etc. are meagre and 24% of total nitrogen available in the plant body which indicate the plant is a good source of diet (2). It also contains glycosides, flavonoids, saponins and tannins (3) and has water extractable phytochemicals of medicinal importance. The total phenolic content (TPC) and trolox equivalent antioxidant capacity (TEAC) of alligator weed and the contents were 0.56±0.03 mg GAE/g FW and 0.14±0.00 µmol TE/g FW, respectively (4). It has great potential for phytoremediation (5,19,20). Hence, the aim of the present study is to highlight possible health risks for consuming this collected leafy vegetable in Peri-urban Greater Hyderabad.

Material and Methods

Study area

Hyderabad, the capital of Telangana state, is the fourth most populous city in India and popularly known as the 'Pearl City of India'. It is located on the Deccan Plateau (**Fig.**

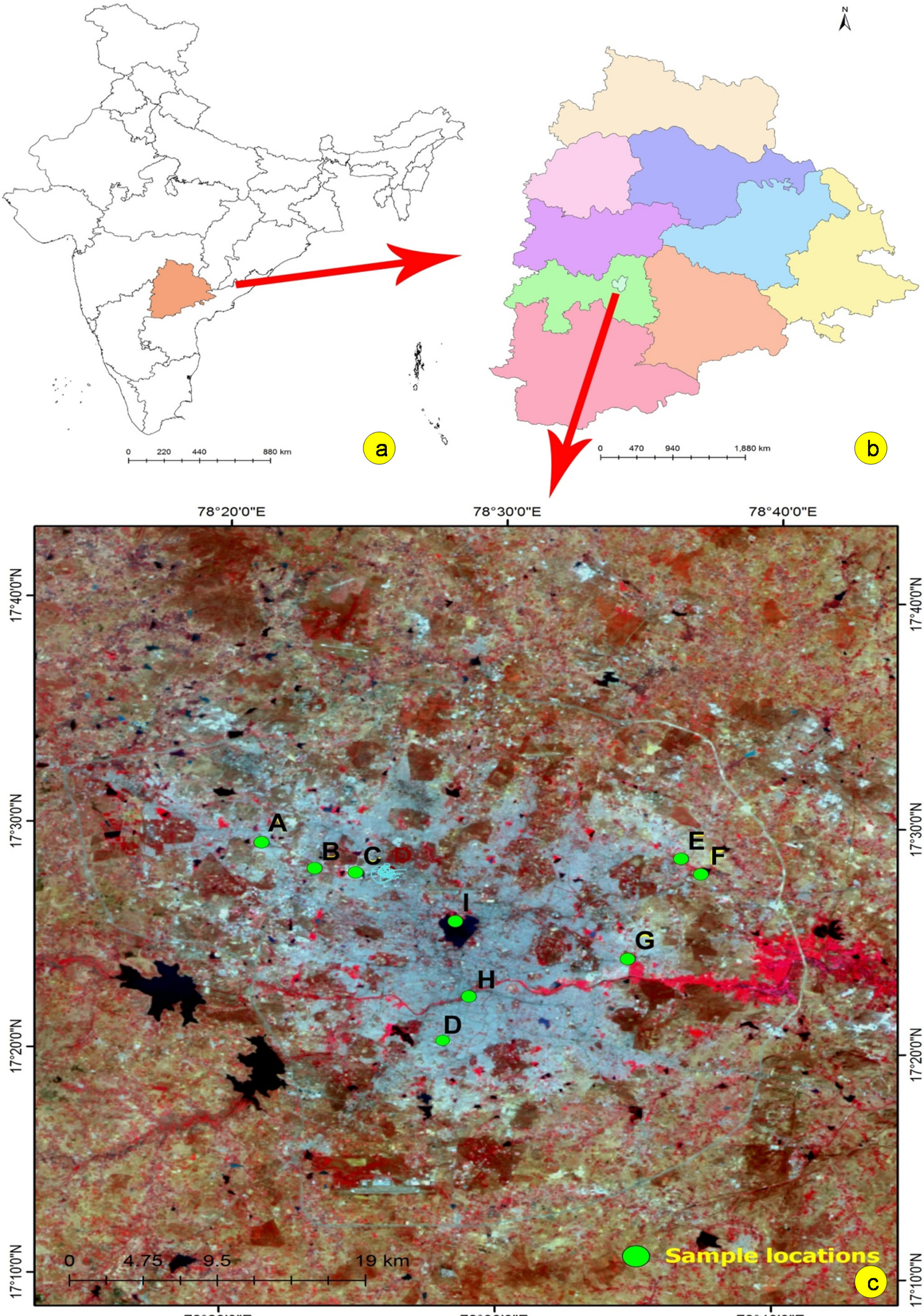

Figure 1. The study area: (a) India; (b) Telangana; (c) Random sampling sites covered in Peri-urban Greater Hyderabad. A. Prakash Nagar; B. Hitech City; C. Mysamma Pond; D. Control (UH); E. Cherlapally; F. Rampally; G. Uppal; H. Musi; and I. Hussain Sagar.

Table 1. Alligator weed associates in different polluted sites of peri-urban Greater Hyderabad

	Site	Geographical co-ordination	Top 3 dominant associated plant taxa
1	Rampally	17°27′55.70″N 78°37′13.34″E	*Eichhornia crassipes, Alternanthera sessilis, Polygonum hydropiper*
2	Musi	17°22′24.43″N 78°28′53.18″E	*Setaria verticillata, Cyperus alopecuroides, Typha domingenesis*
3	Prakash Nagar	17°29′09.28″N 78°21′16.45″E	*Pistia stratiotes, Setaria verticillata, Brachiaria mutica*
4	Uppal	17°24′08.24″N 78°34′36.56″E	*Eichhornia crassipes, Typha domingenesis, Setaria verticillata*
5	Cherlapally	17°28′36.72″N 78°36′29.76″E	*Pistia stratiotes, Eichhornia crassipes, Typha domingenesis*
6	Hussain Sagar	17°25′44.32″N 78°28′20.83″E	*Setaria verticillata, Polygonum hydropiper, Cyperus alopecuroides*
7	Mysamma pond	17°27′51.51″N 78°24′42.57″E	*Eichhornia crassipes, Pistia stratiotes, Typha domingenesis*
8	Hitech City	17°28′01.78″N 78°23′13.47″E	*Eichhornia crassipes, Typha domingenesis, Polygonum hydropiper*
9	Control (UH)	17°27′27.29″N 78°19′07.66″E	*Alternanthera paronychioides, Brachiaria mutica, Ammania baccifera*

UH: University of Hyderabad

1). The annual mean temperature is 26°C though sometimes it exceeds 45°C during summer and the lowest temperature falls to 10°C. The annual average rainfall is of 772 mm. The Greater Hyderabad Municipal Corporation (GHMC) spreads over an area of 650 sq km. There are hundreds of small and large-scale industries like plastic, chemical, dye, agrofertilizer, pesticide units, paint, steel products, beverages and pharmaceutical industries exist in the area. Due to urbanization and the discharge of untreated and partial treated industrial effluents on the other have led to the decline and degradation of the catchment areas of many lakes and their eutrophication.

Extensive field trips were conducted to document the spread of alligator weed in the contaminated areas of Peri-urban Greater Hyderabad during October to December of 2015. The vegetation was surveyed by laying a total of 92 quadrats (1 × 1 m) and the associated species of alligator weed were recorded in all the selected sites. The plant and soils samples were collected from eight selected contaminated sites where the local people are collecting the alligator weed for consumption (as leafy vegetable), namely, Rampally, Musi, Prakash Nagar, Uppal, Cherlapally, Hussain Sagar, Mysamma pond and Hitech City and the control site from University of Hyderabad [UH] (**Table 1**).

The Alligator weed

Alternanthera philoxeroides (Martius) Grisebach of Amaranthaceae, is a highly proliferic alien weed, popularly known as 'alligator or pig weed' and native to South America. Its occurrence was reported for the first time in India from West Bengal and Bihar (6) and in a short span of five decades, it was widely spread in 16 states of India, namely, Andhra Pradesh, Assam, Bihar, Delhi, Jammu & Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Punjab, Tamil Nadu, Telangana, Tripura, West Bengal and Andaman-Nicobar Islands in aquatic, semi-aquatic and terrestrial, natural and polluted ecosystems (7, 8). It is a perennial, stoloniferous herb with decumbent stem and with massive root system at the nodes. Mature plants form thick interwoven dense mats throughout the water body. In recent times, it is one of the noxious weeds and widely spread polluted areas of Greater Hyderabad, Warangal in particular and Telangana in general. It is sold in the market as "Ceylon Spinach".

Collection of samples

The plant and soil samples collected from the polluted areas of Peri-urban Hyderabad were labelled site-wise. The soil samples were collected after removing 10 cm depth of the top soil and litter, and dried well for a week. The soil samples were ground and riddled using 1000 μm stainless steel sieve. Soil pH and electrical conductivity were determined using digital pH meter 7007 and digital conductivity meter 9009 at 1:2 soil to double-deionised water (DDW) ratio. The composition of soil samples was estimated for available nitrogen by Kjeldahl method, phosphorus by Olsen's method and potassium by Flame photometer (9, 10). Plant samples collected from nine different localities (University of Hyderabad campus is control)

Table 2. Physico-chemical characteristics of selected contaminated sites of peri-urban Greater Hyderabad

Location	pH	EC (dS m^{-1})	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Metal concentration in soil (mg kg^{-1})				
						Cd	Pb	Mn	Zn	Fe
Rampally	8.69	0.44	429.8	185.04	190.0	0	96.26±6.575	146.8±1.24	41.6±0.2	4753±19.45
Musi	7.33	0.76	74.45	15.03	134.5	2.5±1.75	159.25±4.25	252.8±0.88	449.2±1	5550±24
Prakash Nagar	7.77	0.23	514.9	158.36	161.5	0	61.25±5.375	121.6±0.68	71.6±0.84	5465±2.5
Uppal	7.06	3.40	78.26	40.01	280.5	54.75±0.3	226.25±8.375	269.2±4.12	692.4±2.6	5845±9
Cherlapally	8.29	0.30	269.78	279.22	124.5	0	88.5±10.45	156±9.4	72±1.48	5605±13.5
Hussain Sagar	7.61	0.22	61.04	11.66	172.0	0	34.25±8.825	280.4±2.2	114±2.16	5870±11.5
Mysamma pond	8.55	1.31	146.2	125.86	156.5	0	230.75±6.75	110.8±1.56	60.8±1.72	5245±18.5
Hitech City	7.54	1.44	99.1	71.7	186.0	0	52.75±1.5	357.6±2.52	120.4±0.28	5750±6
Control (UH)	6.72	0.54	1230.0	930.0	60.0	0	0	173.6±0.56	156.8±0.08	5870±0.5

were washed thoroughly and rinsed with deionised water. The washed plant material was separated as of roots, stems and leaves, and cut into small pieces of 1-2 cm length and kept in hot oven at 70°C for 4-5 days to obtain constant weight. The well dried materials were ground using FS Ana mill (A11BS62, IKA). Powdered soil and plant samples of each (0.1 gm) were digested using nitric acid and perchloric acid (3:1 *v/v*) and the residues were filtered with Whatman filter papers and diluted with DDW to 25 ml. Different heavy metal concentrations were analyzed using atomic absorption spectrometer (AAS: PerkinElmer A400 model). Standard reference materials were used for calibration and computation of metals.

All the data are presented as mean (n=3) ± standard deviation (SD). One-way ANOVA, Tukey's and Dunnett's multiple comparison tests were employed to assess the significant differences in metal concentrations in the plant parts of alligator weed from different sites, comparing multiple sites with the control site (α=0.05). The correlation analysis was performed on pH, EC, N, P, K and the heavy metals present in soils of contaminated areas of Peri-urban Hyderabad to assess the relationship of element content from similar sources. It was carried out using Pearson correlation co-efficient through the statistical software SPSS 16.0 for windows.

Metal bioconcentration and translocation factors

The heavy metals transported from soil to roots, stems/ branches and leaves were evaluated using translocation factor (TF) and bioconcentration factor (BCF) (11).

Results

The soil pH of different sites ranged from 7.06 to 8.69 and the EC was from 0.22 to 3.40 dS m^{-1}. The alkaline nature of the soils is due to the presence of OH^- ions (12). Soil showed high N and P that ranged up to 514.9 to 61.04 mg kg^{-1} and 279.22 to 11.66 mg kg^{-1}, respectively. Highest nitrogen content is because of leaching of pesticides and fertilizers from nearby agricultural and industrial areas. Deposition of abundant phosphorous at the bottom of the sediments and its adsorption to metallic oxides was also one of the main reactions (13). Higher availability of K was stretched up to 280.5 to 124.5 mg kg^{-1}. The lower availability of N and P, and higher availability of K was found in control when compared to the polluted soils (**Table 2**).

Metal concentration in the selected contaminated sites was ordered as Fe (5870±11.5 to 4753±19.45 mg kg^{-1}) > Zn (692.4±2. to 41.6±0.2 6 mg kg^{-1}) > Mn (357.6±2.5 to 110.8±1.5 mg kg^{-1}) > Pb (230.75±6.75 to 34.25±8.825 mg kg^{-1}) > Cd (54.75±0.3 to 2.5±1.75 mg kg^{-1}). Regarding soil characterization of metals except Fe, all the other metals i.e. Pb, Mn and Zn showed significantly higher concentration from one location to another. The concentration of Cd is highest at Uppal (54.75±0.3 mg kg^{-1}) and Mysamma pond contained the highest concentration of Pb (230.75±6.75 mg kg^{-1}) followed by Uppal (226.25±8.375 mg kg^{-1}). The concentration of these metals is greater than the permissible limits suggested by US Environmental Protection Agency (14). Excessive amount of Zn (692.4±2.6 mg kg^{-1}) and Mn (357.6±2.5 mg kg^{-1}) was found in Uppal and Hitech city (**Table 2**). The source of metal contamination is due to domestic waste and industrial effluents released into surrounding water bodies which have been percolating for a long time.

Pearson's correlations of soils are presented in **Table 3**. The pH and EC reading showed the negative correlation (r^2 = -0.50). However, EC showed positive correlation with K (r^2 = 0.83) and negative with N (r^2 = -0.48) and P (r^2 = -0.39). N (r^2 = 0.53) and P (r^2 = 0.73) showed the positive correlation with soil pH. Pb (r^2 = 0.68), Mn (r^2 = 0.37) and Zn (r^2 = 0.77) were positively correlated with the EC, and Fe (r^2 = 0.06) correlated with pH. Fe showed the positive correlation with N (r^2 = 0.13) and P (r^2 = 0.07). The association of Pb and Zn (r^2 = -0.50), Mn and Zn (r^2 = -0.50), Pb and Fe (r^2 = -0.50) and Zn and Fe (r^2 = -0.50) shows the natural occurrence of the metals as part of the anthropogenic activities and weathering processes. It indicates that almost all the sites were contaminated with considerable amount of metals from municipal waste, domestic wastes, untreated effluents from nearby industries and fertilizer application in the nearby fields.

Table 3. Pearson correlations of soils in peri-urban Greater Hyderabad

	pH	EC	N	P	K	Pb	Mn	Zn	Fe
pH	1.00	-0.50	0.53	0.73*	-0.43	-0.05	-0.73*	-0.76*	0.06
EC		1.00	-0.48	-0.39	0.83**	0.68	0.37	0.77*	-0.10
N			1.00	0.70*	-0.20	-0.33	-0.70*	-0.51	0.13
P				1.00	-0.38	-0.16	-0.68	-0.57	0.07
K					1.00	0.35	0.35	0.62	-0.05
Pb						1.00	-0.22	0.58	0.33
Mn							1.00	0.43	-0.54
Zn								1.00	0.24
Fe									1.00

N: Available Nitrogen; P: Available Phosphorus; K: Available Potassium.
*Correlation is significant at $p \leq 0.05$ level (two tailed); **Correlation is significant at $p \leq 0.01$ level (two tailed).

Metal concentration in the Alligator weed

Accumulation of metals in plant parts varies from species to species. The concentration of metal accumulation in all the parts of *A. philoxeroides* was in the order of Fe>Mn>Zn>Pb>Cd (**Table 4**). The general trend of metal accumulation in alligator weed plant in all the selected polluted sites of Peri-urban Hyderabad observed was in the order of root>leaf>stem. Roots are the main site for metal accumulation. This shows metal detoxification within the roots and poor translocation to stems which act as good barrier for defence mechanism.

The concentration of Fe was higher among all the polluted sites and ranged from 4992±8.7 to 84±6.35 mg kg^{-1}. Fe a vital element for plant growth and it becomes toxic under acidic condition and high concentration causes necrosis and tissue injury by converting H_2O_2 to free radicals (15). Cadmium was detected in the soils and plant tissue of Musi and Uppal areas. *A. philoxeroides* can accumulate 44.62 mg/kg of Cd which supports our results 8±0.5 mg kg^{-1} in roots at Uppal (16). The Pb concentration was very high in roots at Rampally (383.25± mg kg^{-1}). High amount of Mn (1870.5±8.05) and Zn (199.5±11.1) was accumulated in underground parts of *A. philoxeroides*. Further, Mn and Zn at high concentration can cause nausea, muscular stiffness, neurological disorders and brain damage (17). The concentration of Pb and Cd were not found in control site (UH) while Mn, Zn and Fe concentrations were found to be 13.5±1.125, 43.5±4.5 and 74.4±0.0006 mg kg^{-1} in roots, 54±0.002, 16.8±0.004 and 21.5±0.0025 mg kg^{-1} in stems and 393.2±0.0068, 53.75±0.0138, and 119±0.031 mg kg^{-1} in leaves, respectively (**Table 5**).

The concentration of these metals in the plant material is greater than the permissible limits suggested by US Environmental Protection Agency (14). The alligator weed also has the ability to accumulate Hg from polluted waters (18). These metals are non-biodegradable and toxic. It clearly indicates that the plant (alligator weed) which sold in the markets has potential to accumulate heavy metals which cause severe health hazards and affect the food chain.

Bioconcentration factor (BCF) and translocation factor (TF)

BCF and TF are important tools to assess the feasibility of plant species for phytoremediation of heavy metals. If the BCF value is more than 1, the plant has phytoremediation potential for heavy metals. The BCF values for Mn and Zn were more than 1 in all the polluted sites. The highest BCF value was found for Mn (16.88) and Zn (3.28) at Mysamma pond. Translocation factor (TF) is the translocation of trace elements from root to shoot and then to leaf. The TF was found highest at Hitech city (0.80) for Pb and the ability of trace elements was in the order of Pb<Cd<Zn<Fe<Mn. Translocation of metals from roots to leaves indicate the ability for the metal removal from contaminated environments. Considering its low TF, high BCF values and ability to accumulate the heavy metals Fe, Zn, Mn, Pb and Cd, thus reveals that the plant body holds trace elements which is cost of living being health.

Associated species

The present study also recorded the twenty nine plant associates of alligator weed by laying 92 quadrats in Peri-urban Greater Hyderabad. Of these, thirteen are indigenous, and sixteen exotics belonging to 27 genera and 20 families of Angiosperms (**Table 6**). The alligator weed turned the most dominant in all the study sites (**Fig. 2a**). Some of these wetland plants such as *Eichhornia crassipes, Pistia stratiotes, Spirodela polyrrhiza, Bacopa monnieri, Ipomoea aquatica* and *Typha domingenesis* are candidates for remediation of toxic metals (19).

Discussion

Due to abundant availability of alligator weed, the plant is sold in the markets of greater Hyderabad and other erstwhile districts in Telangana State viz., Warangal, Medak, Ranga

Table 4. Total element concentrations (mg kg^{-1}) in roots, stems and leaves of *Alternanthera philoxeroides* in peri-urban Greater Hyderabad

Location	Pb			Mn			Zn			Fe		
	Root	Stem	Leaf	Root	Stem	Leaf	Root	Stem	Leaf	Root	Stem	Leaf
Rampally	383.25±9[a]	24.5±6.925[c]	35.75±4.25[a]	477±0.45[a]	47.5±9.75[a]	90.8±5.76[a]	59±0.75[a]	15.75±0.35[a]	28.8±1.12[c]	4202.5±9.75[a]	135.5±2.925[a]	333.2±7.24[a]
Musi	55.25±10.5[a]	20.5±6.075[d]	41.5±3.75[b]	417.5±0.6[a]	2.25±0.625	208±2.84[b]	117.5±0.85[a]	16.25±2.8[a]	77.6±1.12[a]	1745.5±3.45[a]	84±6.35[a]	188.8±7.04[b]
Prakash Nagar	321±8.1[a]	21.125±0.975[d]	43.5±1.725[b]	298±3.15[a]	12.25±2.925[c]	218.4±3.12[a]	85.5±0.55[a]	29.75±0.375[a]	50.4±0.72[c]	3501±12.1[a]	302±4.475[a]	681.6±66.72[a]
Uppal	143.75±4.575[a]	29.5±2.75[c]	46.25±5.25[c]	243±4.55[a]	3.75±2.095	178±4.84	138.5±1[a]	34.25±0.5[a]	78±0.96[a]	2381.5±11.2[a]	186.75±3.75[a]	649.6±5.12[a]
Cherlapally	64.25±7.125[a]	31.25±9.75[b]	47.5±3.725[c]	718±1.7[a]	39.5±1.175[a]	283.6±3.2[a]	62±0.85[a]	34.25±0.5[a]	36.8±0.76	4992±8.7[a]	428±8.575[a]	597.6±4.6[a]
Hussain Sagar	56.5±6[a]	34.75±17[a]	46±4.25[c]	491±2.25[a]	3.25±0.525	242.4±2.92[a]	158±3.45[a]	48±0.2[a]	73.2±6.8[a]	1615.5±18[a]	111±2.35[a]	224.8±2.64[a]
Mysamma pond	53.25±17.5	36.25±4.75[a]	47.75±1.5[c]	1870.5±8.05[a]	15.75±0.5[b]	318.8±1.48[a]	199.5±11.1[a]	21.75±1.025[a]	45.6±6.16	2062±23.25	100±7.75[a]	171.2±3.08[c]
Hitech City	57.75±12.3	36.5±7.4[b]	40±11[b]	1085.5±5.25[a]	7.5±1.15	2190±17.28[a]	112.4±1[a]	24±0.15[a]	52.4±0.36[a]	2582.5±100.3[a]	87±3[a]	163.2±3.56[c]
Control (UH)	0	0	0	113.5±1.125	43.5±4.5	74.4±0.0006	54±0.002	16.8±0.004	21.5±0.0025	393.2±0.0068	53.75±0.0138	119±0.031

Letters in the columns indicate significant difference at $p<0.05$. [a] = ****; [b] = ***; [c] = **; [d] = *
Values mentioned Mean±SD ($n = 3$)
Holm Sidak Method: alpha = 5.000%

Table 5. Translocation factor (TF) and Bioconcentration factor (BCF) of alligator weed growing in select polluted sites from the study area

Site	Pb				Mn				Zn				Fe			
	TF	BCF_r	BCF_s	BCF_l	TF	BCF_r	BCF_s	BCF_l	TF	BCF_r	BCF_s	BCF_l	TF	BCF_r	BCF_s	BCF_l
Rampally	0.29	0.86	0.25	0.48	0.10	3.25	0.32	0.62	0.27	1.42	0.38	0.69	0.03	0.88	0.03	0.07
Musi	0.37	0.35	0.13	0.26	0.01	1.65	0.01	0.82	0.14	0.26	0.04	0.17	0.28	0.31	0.09	0.03
Prakash Nagar	0.36	0.96	0.34	0.71	0.04	2.45	0.10	1.80	0.35	1.19	0.42	0.70	0.09	0.64	0.06	0.12
Uppal	0.21	0.64	0.13	0.20	0.02	0.90	0.01	0.66	0.25	0.20	0.05	0.11	0.08	0.41	0.03	0.11
Cherlapally	0.49	0.73	0.35	0.54	0.06	4.60	0.25	1.82	0.55	0.86	0.48	0.51	0.09	0.89	0.08	0.11
Hussain Sagar	0.62	0.79	0.49	0.60	0.01	1.75	0.01	0.86	0.30	1.39	0.42	0.64	0.07	0.28	0.02	0.04
Mysamma pond	0.44	0.36	0.16	0.21	0.01	16.88	0.14	2.88	0.11	3.28	0.36	0.75	0.05	0.39	0.02	0.03
Hitech City	0.80	0.87	0.69	0.76	0.01	3.04	0.02	6.12	0.46	0.44	0.20	0.93	0.03	0.45	0.02	0.03
Control (UH)	0.38	0.83	0.00	1.05	0.00	0.00	0.00	0.43	0.78	0.14	0.11	0.37	0.45	0.02	0.01	0.07

TF: Translocation factor; BCF_r: Bioconcentration factor in roots; BCF_s: Bioconcentration factor in stem/branches; BCF_l: Bioconcentration factor in leaves

Table 6. Alligator weed associates in aquatic and terrestrial contaminated ecosystems of peri-urban Greater Hyderabad.

	Associated species	Family	Habit	Popular name	Nativity
1	*Hygrophila auriculata* (Schumach.) Heine	Acanthaceae	Herb	Marsh barbel	Indigenous
2	*Alternanthera paronychioides* A.St.-Hil.	Amaranthaceae	Herb	Smooth chaff flower	Tropical America
3	*Alternanthera sessilis* (L.) R.Br. ex DC.	Amaranthaceae	Herb	Sessile joyweed	Tropical Old World
4	*Lemna aequinoctialis* Welw.	Araceae	Herb	Lesser duckweed	Indigenous
5	*Pistia stratiotes* L.	Araceae	Herb	Water lettuce	Tropical America
6	*Spirodela polyrrhiza* (L.) Schleid.	Araceae	Herb	Greater duckweed	Indigenous
7	*Eclipta prostrata* (L.) L.	Asteraceae	Herb	False daisy/Bhringaraj	Tropical America
8	*Pluchea tomentosa* DC.	Asteraceae	Shrub	Woolly camphor weed	Indigenous
9	*Coldenia procumbens* L.	Boraginaceae	Herb	Creeping coldenia	Indigenous
10	*Cleome chelidonii* L.f.	Cleomaceae	Herb	Celandine spider flower	Indigenous
11	*Commelina benghalensis* L.	Commelinaceae	Herb	Bengal dayflower	Tropical Old World
12	*Ipomoea aquatica* Forssk.	Convolvulaceae	Creeper	Water spinach	Tropical Old World
13	*Merremia aegyptiaca* (L.) Urb.	Convolvulaceae	Creeper	Hairy woodrose	Indigenous
14	*Cyperus alopecuroides* Rottb.	Cyperaceae	Herb	Foxtail sedge/matsedge	Tropical Old World and Australia
15	*Scleria tricuspidata* S.T.Blake	Cyperaceae	Herb	Thunga	Indigenous
16	*Scleria* sp. (ined.)	Cyperaceae	Herb	Thunga	Indigenous
17	*Aeschynomene indica* L.	Fabaceae	Herb	Indian jointvetch	Southeastern North America
18	*Malachra capitata* (L.) L.	Malvaceae	Herb	Brazil jute, Yellow leafbract	Tropical America
19	*Glinus oppositifolius* (L.) Aug.DC.	Molluginaceae	Herb	Indian chickweed	Indigenous
20	*Ludwigia adscendens* (L.) H.Hara	Onagraceae	Herb	Primerose willow	Tropical America
21	*Oxalis corniculata* L.	Oxalidaceae	Herb	Yellow sorrel/sleeping beauty	Europe
22	*Bacopa monnieri* (L.) Wettst.	Plantaginaceae	Herb	Water hyssop/Indian pennywort	Indigenous
23	*Brachiaria mutica* (Forssk.) Stapf	Poaceae	Herb	Para glass/Buffalo grass	Indigenous
24	*Cynodon dactylon* (L.) Pers.	Poaceae	Herb	Devil's/Bermuda grass	Indigenous
25	*Setaria verticillata* (L.) P.Beauv.	Poaceae	Herb	Hooked bristle grass	Europe
26	*Polygonum hydropiper* L.	Polygonaceae	Herb	Water pepper/marsh pepper weed	North Africa
27	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Herb	Water hyacinth	South America
28	*Typha domingenesis* Pers.	Typhaceae	Herb	Southern cattail	Tropical America
29	*Phyla nodiflora* (L.) Greene	Verbenaceae	Herb	Frog fruit plant	South America

Figure 2. a). *Alternanthera philoxeroides* (alligator weed) growing luxuriantly on the banks of polluted Hussain Sagar lake. b) Plant sold in local market as "Ceylon spinach" at a low price. c) and d) Local vendors and consumers in the local market. e) Large quantities of collected *Alternanthera philoxeroides* (encircled with broken yellow line) along with other leafy vegetables in the market.

Reddi, Nalgonda, Karimnagar, Khammam, Nizamabad and Mahabubnagar (**Fig. 2b, 2e**). The vendors are picking the green leafy-shoots from contaminated swamp areas and selling it as vegetable (**Fig. 2c, 2d**). Consumption of such produced pose health risks and undisclosed health issues (20). Iron being transition and essential metals, excess of Fe can cause tissue damage due to free radicals and can also activate oncogenes (16). High Mn bioavailability leads to neurological disorders and brain damage while high concentrations of Zn can cause muscular stiffness, loss of appetite, nausea and irritation. Cadmium a non-essential, toxic metal show adverse effects on kidneys, liver, central and peripheral nervous systems (21). High amount of Pb adversely influence the memory power of children, induce hypertension, nephropathy and cardiovascular disease (22). It also reduced the availability of many useful plants for native biota and altered the habitat conditions to facilitate the other invaders. The weed replaces the native wetland plants, restricts water flow in drains and creates favourable habitats for mosquitoes, snails and other insects. The alligator weed can also act as an alternate host and vector for various diseases like encephalitis, malaria, filariasis, yellow and dengue fevers.

Alligator weed alters the decomposition rate of macrophytes and the ecosystem processes which favours the colonization and intrusion of invasive alien species (23). Dense mat population of the weed can also decrease the dissolved oxygen (24) and impact the scenic water bodies (25). It can invade the crop land and reduce the yield of many crops like sweet potato (63%), lettuce (47%), rice (45%), wheat (36%), corn (19%) and carrots (26,28) and also intrude orchards, tea plantations and berry fields and affects the yielding (27). It increases the breeding grounds for mosquitoes, snails and other insects of which impacts on livestock, food production and human health (27, 28). New South Wales (NSW) Government has spent 800,000 US$ to control alligator weed during 2008-2009 (http://weeds.dpi.nsw.gov.au/Weeds/Details/7#TOC). It is highly expensive to eradicate the alligator weed.

Conclusion

Alternanthera philoxeroides, an aquatic macrophyte, is an important source of leafy vegetable, fodder for animals, indicator species of polluted sites and proved to be an effective accumulator of heavy metals Fe, Zn, Mn, Pb and Cd. For its rich and rapid growth, the alligator weed is readily available in the contaminated areas, the local people harvest the leafy-shoots and sell in the local markets of Telangana region, more so in Greater Hyderabad. When it consumed as vegetable by humans and cattle as feed, it can cause serious health hazards and even sometimes leads to death. It spreads easily in aquatic and terrestrial ecosystems, and leads to the biological diversity erosion which favours the intrusion of invasive alien species and these invasive species compete with native rare, endangered and threatened (RET) species. With its dense mat infestation in terrestrial ecosystem, it affects on agricultural crops yield, grazing and human health through the food chain. Though the plant can be treated as a potential candidate to clean-up the polluted environments and has tolerance to grow in contaminated aquatic, semi-aquatic and terrestrial ecosystems, it should be eradicated. The alligator weed is extremely difficult to control once established. Food regulatory authorities should be responsible to reduce its infestation, further spreading and impact on native biota within area. Its eradication is very expensive to newly-formed States like Telangana. Manual control is the effective method to eradicate it. The surveillance of alligator weed suggests that the species should be banned in the vegetable markets, like cat fish and continuous monitoring should be promoted to document its expansion and public awareness campaigns should be taken up by the Government more specifically for its control and to know its impact on native biodiversity and human health. There is an immediate need to go for more surveillance of alligator weed to arrest its further spread and utility.

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Conflict of interest statement

The authors declare there is no conflict of interest.

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