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RESEARCH ARTICLE

HEAVY METALS PHYTOREMEDIATION POTENTIALITY OF *SUAEDA MARITIMA* (L.) DUMORT. AND *SESUVIUM PORTULACASTRUM* L. FROM INFLUENCE OF TANNERY EFFLUENTS

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ABSTRACT

Heavy metal pollution due to industrial effluents is gaining worldwide attention. Tannery industry is common in many parts of the world and it pollutes groundwater and ecosystems and produce major amount of heavy metals and reduce agricultural crops yield. Phytoremediation of some heavy metals (Pb, Cr, Cd, Cu and Zn) from application of diluted tannery effluents by two halophytes, *Suaeda maritima* (L.) Dumort. and *Sesuvium portulacastrum* L. were observed from the present study. From the results it is noticed that maximum accumulation of heavy metals (Pb, Cr, Cd, Cu and Zn) was observed in *S. maritima* cultivated in tannery effluent treated soil. It is estimated from 1kg dry weight of plant sample, *S. maritima* accumulated 142.10 mg Pb, 75.86 mg Cr, 53.06 mg Cd, 83.26 mg Cu and 103.75 mg Zn followed by *S. portulacastrum* (127.27 mg Pb, 64.60 mg Cr, 46.82 mg Cd, 71.65 mg Cu and 91.64 mg Zn) after 120 DAS cultivation period.

Key words: Tannery effluents, Heavy metals, Halophytes, Phytoremediation.

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INTRODUCTION

Leather tanning industries have cropped up in India over the past three decades. A total number of 2161 tanneries are located in India and spread across the states of Tamil Nadu, West Bengal, Maharashtra, Punjab, Karnataka, Andhra Pradesh, Bihar and Uttar Pradesh. At present more than 568 tanneries are well established in Dindigul, Erode and Vellore districts of Tamil Nadu (Murali and Rajan, 2012). The major metals at these sites are lead (Pb), zinc (Zn), copper (Cu) and cadmium (Cd) and chromium (Cr) (Baskar and Abdul Raheem, 2011). To preserve the natural environment, new methods of remediation using physical, chemical and biological principles are being studied (Cunningham and Berti, 1993 and Basha and Jha, 2008). Some plants have a proven potential for removing the heavy metals from contaminated soil. A great deal of recent studies strongly indicates that halophytic plants could be more suitable for heavy metal extraction mainly from saline soil than glycophytes (Manousaki and Kalogerakis, 2011 and Milić *et al*., 2012). Many halophytes often have high metal tolerance that is strongly linked to traits for salt tolerance (Duarte *et al*., 2013). In this manuscript we have explored the potential for the different concentrations of diluted tannery effluents on *Suaeda maritima* and *Sesuvium portulacastrum* to characterize the heavy metals phytoremediation potential of tannery effluent contaminated soil. In recent years, researchers have undertaken numerous studies on phytoremediation of heavy metal-contaminated saline soils using halophytes (Korzeniowska and Stanislawska- Glubiak, 2015 and Christofilopoulos *et al*., 2016).

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MATERIALS AND METHODS

Plant Material

Two species of fast growing salt marsh halophytic herbs like Suaeda maritima (L.) Dumort. and Sesuvium portulacastrum L. were selected for the characterization and screening for phytoremediation of heavy metals from tannery effluents with special reference for biochemical studies . The experimental site was located at Panampattu Village, Villupuram District of Tamil Nadu, India.

Tannery effluents collection

The raw effluent was collected from the tannery industry situated at Vaniyambadi near Vellore District in clean plastic cans and stored at 4^0C for further studies.

Pot culture experiments

The experiment was conducted in an open-air area with natural light, temperature, and humidity. Red soil and sand (3:1 ratio) free from pebbles and stones were filled in polythene bags.

The seedlings / cuttings from the selected species of similar size were transplanted from the nursery bed and planted at the polythene bags. The experiment comprised of the following three set of treatments with five replicates and average values are reported. Plants were watered for every 2-3 days, depending on the evaporative demand. Plants were harvested for experimental purpose at intervals of 30, 60, 90, 120 days. During each and every sampling day, samples were randomly collected, washed thoroughly with tap water followed by distilled water.

S.no	Treatment	Method
1.	Control	Without any treatment (Plants are irrigated with tap water only)
2	Effluent treatment	30%, 60% and 90% of tannery effluents was treated 250 ml for 4 times with a gap of 7 days intervals.

Estimation of plant chromium, cadmium, copper zinc and lead

The plant samples were subjected to dry ashing using 0.5 g of each, and with the aid of a muffle furnace heated to 450°C for 8 hours. The cool ash was transferred to a fume cupboard and 5 ml concentrated HNO_3 and 15 ml concentrated HCl were added. The mixture was heated on a steam bath for 60 minutes. Contents of the beaker were evaporated to dryness followed by the addition of 1 ml concentrated HNO_3 and re evaporated to dryness. One ml concentrated HNO_3 was again added and the solution warmed. Five ml distilled water was added, the resulting solution warmed again and filtered into a 100 ml flask and made up to mark with distilled water. The solution was used for the determination of Cr, Cd, Cu, Pb and Zn using an atomic absorption spectrophotometer (Lindsay and Norvell, 1978).

Estimation of soil chromium, cadmium, copper zinc and lead

Ten gram of air dried soil was taken in a 150 ml conical flask and 20 ml of DTPA extracting (Triehanolamine 14.92 g, 1.967 g of dimethylene trianine penta acetic acid and 1.47 g of calcium chloride were dissolved in 500 ml distilled water. The pH was adjusted to 7.3 using 1:1 N HCl and diluted to 1 litre using distilled water). Each flask was covered with stretchable parafilm and secured upright on a horizontal shaker with a stroke of 8 cm with a speed of 120 cycles/ minute. After 2 hours of shaking, the suspensions were filtered through Whatman No. 42 filter paper. The filtrates were analyzed for available chromium, cadmium, copper, lead and zinc using atomic absorption spectrophotometer with appropriate standards (Lindsay and Norvell, 1978).

Statistical analysis

Each experiment was repeated five times and the mean values and standard deviations were then calculated (Snedecor and Cochran, 1967).

RESULTS

Lead

The level of lead in two halophytes cultivated in tannery effluent treated soil and control are presented in the Table 1. Maximum accumulation was observed in *S. maritima* (Leaf 60.90, stem 49.60 and root 31.60 mg/kg.dr.wt) followed by *S. portulacastrum* (Leaf 54.68, stem 43.88 and root 28.65 mg/kg.dr.wt) in tannery effluent treated soil when compared to control after 120 day cultivation period with 90 % effluent treatment. The minimum accumulation of lead was shown in *S. portulacastrum* in after 30 days cultivation of control plants (Leaf 1.45, stem 1.20 and root 0.78 mg/kg.dr.wt) than equal value in *S. maritima* (Leaf 1.45, stem 1.20 and root 0.78 mg/kg.dr.wt). The highest percentage increase over control potassium accumulation was observed in the leaf of *S. maritima* than in the root and stem (Leaf 97.61%, root 97.53% and stem 97.07%) followed by *S. portulacastrum* (Leaf 97.34%, stem 97.26% and root 97.21%) at 90% of tannery effluent treatment after 120 days of cultivation period. Values shown are mean ±SD for five replicates. In Table 2, it is observed that two halophytes cultivated in tannery effluent and control soil, gradually reduced the soil lead. When compared to control soil, the maximum reduction was achieved in tannery effluent treated soil, *S. maritima* (98.85-17.25 mg/kg.dr.wt (-473.04% reduction) and *S. portulacastrum* (100.00-25.85 mg/kg.dr.wt (-257.01% reduction) -54.4%, *S. monoica* -48.9% and *I. pes-caprae* -41.7%) after 125 days of cultivation.

Chromium

Accumulation of Chromium in the tissues of *S. maritima* and *S. portulacastrum* cultivated in tannery effluent treated soil and control soil are presented in the table 3. Higher chromium content was accumulated in after 120 days, halophytes cultivated in 90% of tannery effluent treated soil where, *S. maritima* accumulated (Leaf 36.98, stem 24.20 and root 14.68 mg/kg.dr.wt) followed by *S. portulacastrum* (Leaf 30.00, stem 21.00 and root 13.60 mg/kg.dr.wt). The minimum accumulation of lead was shown in both the two experimental plants after 30 days cultivation of control plants (Leaf 0.65, stem 0.40 and root 0.20 mg/kg.dr.wt). The highest percentage increase over control potassium accumulation was observed in the root of *S. maritima* than in the stem and leaf (Root 98.63%, stem 98.34% and leaf 98.24%) followed by *S. portulacastrum* (Root 98.52%, stem 98.09% and leaf 97.83%) at 90% of tannery effluent treatment after 120 days of cultivation period. Values shown are mean ±SD for five replicates. From the results (Table 4), it is observed that chromium was considerably decreased in tannery effluent treated soil when compared to control. Highest reduction in chromium was recorded in *S. maritima* cultivated soil, 84.60-24.50 mg/kr.dr.wt (-2435.309% reduction) which was followed by *S. portulacastrum*, 85.18-29.60 mg/kg.dr.wt (-187.77% reduction) after 120 day experimental period at 90% of treatments.

Cadmium

The amount of cadmium accumulated by four halophytes cultivated in tannery effluent treated and control soil were shown in table 5. Similar to chromium, the halophytes cultivated in tannery effluent treated soil showed higher accumulation of cadmium, especially in *Suaeda maritima* leaf followed by stem and root (Leaf 24.98, stem 16.88 and root 11.20 mg/kg.dr.wt) than in *S. portulacastrum* (Leaf 21.60, stem 15.22 and root 10.00 mg/kg.dr.wt). The lowest accumulation of lead was shown in both the two experimental plants after 30 days cultivation of control plants (Leaf 0.28, stem 0.20 and root 0.10 mg/kg.dr.wt).

Table 1. Effect of different concentrations of tannery effluents on lead content (mg/kg.dr.wt) on plant samples of *Suaeda maritima* and *Sesuvium portulacastrum*

S.NO	Plants	Concentrations (%)	30 DAS			60 DAS			90 DAS			120 DAS		
			Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
1.	*Suaeda maritima*	Control	1.45± 0.072	1.20± 0.060	0.78± 0.039	1.89± 0.093	1.42± 0.071	0.86± 0.043	3.18± 0.590	2.88± 0.144	1.30± 0.065	4.85± 0.243	3.14± 0.157	1.45± 0.072
		30%	8.88± 0.444	5.90± 0.295	3.50± 0.175	15.33± 0.767	11.26± 0.563	6.66± 0.333	27.89± 1.394	20.88± 1.044	13.88± 0.694	37.65± 1.883	26.85± 1.343	18.90± 0.945
		60%	17.69± 0.885	14.82± 0.741	7.00± 0.350	26.85± 1.342	21.80± 1.090	12.22± 0.611	35.95± 1.798	26.98± 1.349	17.98± 0.899	48.99± 2.449	35.20± 1.760	24.85± 1.243
		90%	25.86± 1.293	19.65± 0.982	11.60± 0.580	36.12± 1.806	28.26± 1.413	18.95± 0.948	46.88± 2.344	35.88± 1.944	22.80± 1.140	60.90± 3.045	49.60± 2.480	31.60± 1.580
2.	*Sesuvium portulacastrum*	Control	1.45± 0.073	1.20± 0.060	0.78± 0.039	1.73± 0.087	1.40± 0.070	0.80± 0.040	2.96± 0.148	2.80± 0.140	1.14± 0.057	4.50± 0.225	3.00± 0.150	1.38± 0.069
		30%	8.80± 0.440	5.50± 0.275	3.30± 0.165	15.00± 0.750	10.88± 0.544	6.22± 0.311	25.87± 1.294	17.68± 0.884	10.90± 0.545	33.66± 1.683	22.82± 1.141	16.82± 0.841
		60%	15.93± 0.796	14.80± 0.740	6.20± 0.310	23.68± 1.184	19.80± 0.990	10.90± 0.545	30.56± 1.528	24.22± 1.211	15.80± 0.790	42.82± 2.141	31.60± 1.683	20.96± 1.048
		90%	24.90± 1.245	18.62± 0.931	10.85± 0.543	32.80± 1.640	25.82± 1.291	16.80± 0.840	40.93± 2.046	31.66± 1.583	20.14± 1.007	54.68± 2.734	43.88± 2.194	28.65± 1.432

Table 2. Effect of different concentrations of tannery effluents on lead content (mg/kg.dr.wt) on soil samples of *Suaeda maritima* and *Sesuvium portulacastrum*

S.NO	Plants	Concentrations (%)	30 DAS	60 DAS	90 DAS	120 DAS
1.	*Suaeda maritima*	Control	14.80 ± 0.740	10.25 ± 0.513	7.88 ± 0.394	4.80 ± 0.240
		30%	28.92 ± 1.446	24.30 ± 1.215	16.19 ± 0.809	11.88 ± 0.594
		60%	60.90 ± 3.045	51.60 ± 2.580	35.62 ± 1.781	20.90 ± 1.045
		90%	98.85 ± 4.947	60.18 ± 3.100	29.63 ± 1.481	17.25 ± 0.863
2.	*Sesuvium portulacastrum*	Control	14.80 ± 0.740	10.90 ± 0.545	8.83 ± 0.441	5.90 ± 0.295
		30%	30.00 ± 1.500	26.65 ± 1.332	18.90 ± 0.945	14.19 ± 0.309
		60%	60.95 ± 3.047	54.60 ± 2.73	38.16 ± 1.908	23.19 ± 1.159
		90%	100.00 ± 5.000	68.65 ± 3.433	36.80 ± 1.840	25.85 ± 1.293

Table 3. Effect of different concentrations of tannery effluents on chromium content (mg/kg.dr.wt) on plant samples of *Suaeda maritima* and *Sesuvium portulacastrum*

S.NO	Plants	Concentrations (%)	30 DAS			60 DAS			90 DAS			120 DAS		
			Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
1.	*Suaeda maritima*	Control	0.65± 0.033	0.40± 0.020	0.20± 0.010	1.12± 0.036	0.72± 0.021	0.42± 0.043	1.23± 0.061	0.98± 0.049	0.76± 0.038	1.56± 0.078	1.10± 0.055	0.88± 0.044
		30%	3.56± 0.178	2.22± 0.111	0.90± 0.045	10.18± 0.509	6.62± 0.331	3.00± 0.150	1.562± 0.781	10.00± 0.500	6.22± 0.311	19.66± 0.983	14.22± 0.711	9.18± 0.459
		60%	7.85± 0.393	4.00± 0.200	3.00± 0.150	16.22± 0.811	9.26± 0.463	6.28± 0.314	20.52± 1.026	12.28± 0.614	9.00± 0.450	26.88± 1.344	18.72± 0.936	12.88± 0.644
		90%	12.68± 0.674	8.66± 0.433	5.28± 0.264	21.53± 1.077	13.30± 0.665	8.42± 0.421	29.66± 1.483	16.29± 0.814	11.60± 0.580	36.98± 1.849	24.20± 1.210	14.68± 0.734
2.	*Sesuvium portulacastrum*	Control	0.65± 0.033	0.40± 0.020	0.20± 0.010	1.10± 0.055	0.70± 0.035	0.40± 0.020	1.15± 0.057	0.86± 0.043	0.72± 0.036	1.39± 0.070	1.00± 0.050	0.80± 0.040
		30%	3.50± 0.113	2.20± 0.110	0.82± 0.041	10.22± 0.511	5.88± 0.294	2.88± 0.144	14.26± 0.713	8.00± 0.400	6.00± 0.300	17.65± 0.882	12.22± 0.611	8.40± 0.420
		60%	7.00± 0.350	3.90± 0.195	3.00± 0.150	15.00± 0.750	9.00± 0.450	6.00± 0.300	17.62± 0.881	11.44± 0.411	8.22± 0.411	22.23± 1.112	16.19± 0.810	11.40± 0.570
		90%	12.00± 0.600	8.50± 0.425	5.20± 0.260	20.52± 1.026	12.00± 0.600	8.00± 0.400	27.68± 1.384	13.66± 0.683	11.00± 0.550	30.00± 1.500	21.00± 1.050	13.60± 0.680

Table 4. Effect of different concentrations of tannery effluents on chromium content (mg/kg.dr.wt) on soil samples of *Suaeda maritima* and *Sesuvium portulacastrum*

S.NO	Plants	Concentrations (%)	30 DAS	60 DAS	90 DAS	120 DAS
1.	*Suaeda maritima*	Control	5.60 ± 0.280	4.00 ± 0.200	3.76 ± 0.188	2.20 ± 0.110
		30%	24.65 ± 1.233	20.18 ± 1.009	16.19 ± 0.810	10.88 ± 0.544
		60%	52.68 ± 2.634	40.66 ± 2.008	30.18 ± 1.509	22.60 ± 1.130
		90%	84.60 ± 4.230	60.05 ± 3.002	42.18 ± 2.109	24.50 ± 1.225
2.	*Sesuvium portulacastrum*	Control	5.80 ± 0.290	4.40 ± 0.220	4.00 ± 0.200	2.68 ± 0.134
		30%	25.00 ± 1.250	22.85 ± 1.143	17.66 ± 0.883	13.18 ± 0.654
		60%	55.00 ± 2.750	45.65 ± 2.282	35.17 ± 1.766	28.65 ± 1.433
		90%	85.18 ± 4.259	46.19 ± 2.309	32.85 ± 1.643	29.60 ± 1.480

Table 5. Effect of different concentrations of tannery effluents on cadmium content (mg/kg.dr.wt) on plant samples of *Suaeda maritima* and *Sesuvium portulacastrum*

S.NO	Plants	Concentrations (%)	30 DAS			60 DAS			90 DAS			120 DAS		
			Leaf	**Stem**	**Root**	**Leaf**	**Stem**	**Root**	**Leaf**	**Stem**	**Root**	**Leaf**	**Stem**	**Root**
1.	*Suaeda maritima*	Control	0.28± 0.014	0.20± 0.010	0.10± 0.005	0.36± 0.018	0.28± 0.014	0.18± 0.009	0.48± 0.024	0.30± 0.015	0.24± 0.012	0.60± 0.030	0.40± 0.020	0.30± 0.015
		30%	1.88± 0.094	1.22± 0.061	1.00± 0.050	4.68± 0.234	2.43± 0.122	1.50± 0.075	8.62± 0.431	4.00± 0.200	2.22± 0.111	10.65± 0.533	7.48± 0.374	5.00± 0.250
		60%	3.00± 0.150	1.90± 0.095	1.28± 0.064	8.00± 0.400	4.22± 0.211	2.80± 0.140	12.62± 0.631	6.90± 0.345	4.80± 0.240	19.22± 0.961	10.40± 0.520	6.22± 0.311
		90%	7.22± 0.361	4.00± 0.200	2.20± 0.110	14.58± 0.729	6.88± 0.344	4.42± 0.211	20.29± 1.015	11.20± 0.560	7.00± 0.350	24.98± 1.249	16.88± 0.844	11.20± 0.560
2.	*Sesuvium portulacastrum*	Control	0.28± 0.014	0.20± 0.010	0.10± 0.005	0.340± 0.017	0.24± 0.012	0.16± 0.008	0.042± 0.021	0.28± 0.014	0.20± 0.010	0.54± 0.027	0.36± 0.018	0.28± 0.014
		30%	1.86± 0.093	1.20± 0.060	1.00± 0.050	4.50± 0.225	2.30± 0.115	1.40± 0.070	8.00± 0.400	3.80± 0.190	2.00± 0.100	10.22± 0.511	6.90± 0.345	4.50± 0.225
		60%	2.90± 0.145	1.90± 0.095	1.20± 0.060	7.80± 0.390	4.00± 0.200	2.60± 0.130	11.40± 0.570	6.00± 0.300	4.40± 0.220	16.22± 0.811	9.20± 0.460	6.00± 0.300
		90%	7.00± 0.350	4.00± 0.200	2.20± 0.110	14.00± 0.700	6.00± 0.300	4.00± 0.200	17.28± 0.864	9.90± 0.495	6.50± 0.325	21.60± 1.080	15.22± 0.761	10.00± 0.500

Table 6. Effect of different concentrations of tannery effluents on cadmium content (mg/kg.dr.wt) on soil samples of *Suaeda maritima* and *Sesuvium portulacastrum*

S.NO	Plants	Concentrations (%)	30 DAS	60 DAS	90 DAS	120 DAS
1.	*Suaeda maritima*	Control	2.80 ± 0.140	2.20 ± 0.110	1.50 ± 0.075	1.00 ± 0.050
		30%	14.18 ± 0.709	10.19 ± 0.510	8.00 ± 0.400	7.20 ± 0.360
		60%	38.00 ± 1.900	30.62 ± 1.531	25.88 ± 1.294	16.15 ± 0.808
		90%	63.60 ± 3.180	44.50 ± 2.225	22.18 ± 1.109	16.18 ± 0.809
2.	*Sesuvium portulacastrum*	Control	3.00 ± 0.150	2.30 ± 0.115	1.72 ± 0.086	1.32 ± 0.066
		30%	15.00 ± 0.750	12.22 ± 0.611	9.00 ± 0.450	8.10 ± 0.405
		60%	40.02 ± 2.001	33.60 ± 1.680	29.65 ± 1.483	20.18 ± 1.009
		90%	64.00 ± 3.200	46.88 ± 2.3445	25.85 ± 1.293	19.18 ± 0.959

Table 7. Effect of different concentrations of tannery effluents on copper content (mg/kg.dr.wt) on plant samples of *Suaeda maritima* and *Sesuvium portulacastrum*

S.NO	Plants	Concentrations (%)	30 DAS			60 DAS			90 DAS			120 DAS		
			Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
1.	*Suaeda maritima*	Control	1.24± 0.012	1.00± 0.050	0.70± 0.035	2.11± 0.105	1.42± 0.071	0.90± 0.045	2.99± 0.149	2.00± 0.100	0.98± 0.049	4.86± 0.243	2.90± 0.145	1.22± 0.061
		30%	4.00± 0.200	2.20± 0.110	1.90± 0.095	7.98± 0.399	3.90± 0.195	2.40± 0.120	14.88± 0.744	8.88± 0.444	6.22± 0.311	18.66± 0.933	11.66± 0.583	9.00± 0.450
		60%	8.22± 0.411	4.42± 0.221	2.43± 0.122	16.96± 0.848	9.00± 0.450	6.40± 0.320	20.88± 1.044	13.22± 0.611	10.00± 0.500	27.66± 1.383	18.90± 0.945	13.30± 0.665
		90%	14.88± 0.744	9.00± 0.450	6.28± 0.314	21.66± 1.083	14.40± 0.720	12.40± 0.620	28.82± 1.441	18.90± 0.945	14.88± 0.744	38.76± 1.938	24.60± 1.230	19.90± 0.995
2.	*Sesuvium portulacastrum*	Control	1.24± 0.062	0.90± 0.045	0.68± 0.034	2.00± 0.100	1.40± 0.070	0.84± 0.042	2.50± 0.125	1.80± 0.090	0.90± 0.045	4.42± 0.221	2.00± 0.100	1.20± 0.060
		30%	3.96± 0.198	2.20± 0.110	1.70± 0.085	7.00± 0.350	3.70± 0.185	2.22± 0.111	12.22± 0.611	8.00± 0.400	6.00± 0.300	16.98± 0.849	10.90± 0.545	7.92± 0.396
		60%	8.00± 0.400	4.40± 0.220	2.20± 0.110	14.32± 0.716	8.22± 0.411	6.00± 0.300	17.68± 0.884	12.10± 0.605	8.22± 0.441	26.66± 1.333	16.90± 0.845	11.65± 0.583
		90%	13.22± 0.661	9.00± 0.450	6.00± 0.300	18.82± 0.941	14.00± 0.700	11.22± 0.561	26.00± 1.300	16.22± 0.811	12.40± 0.620	33.22± 1.661	20.80± 1.040	17.63± 0.882

Table 8. Effect of different concentrations of tannery effluents on copper content (mg/kg.dr.wt) on soil samples of *Suaeda maritima* and *Sesuvium portulacastrum*

S.NO	Plants	Concentrations (%)	30 DAS	60 DAS	90 DAS	120 DAS
1.	*Suaeda maritima*	Control	11.90 ± 0.595	9.65 ± 0.483	6.00 ± 0.300	4.65 ± 0.233
		30%	20.00 ± 1.000	18.55 ± 0.927	15.90 ± 0.795	11.00 ± 0.550
		60%	46.80 ± 2.325	40.00 ± 2.000	30.00 ± 1.500	21.65 ± 1.083
		90%	96.60 ± 4.830	62.88 ± 3.100	36.90 ± 1.845	20.58 ± 1.029
2.	*Sesuvium portulacastrum*	Control	12.00 ± 0.600	10.00 ± 0.500	6.50 ± 0.325	5.50 ± 0.275
		30%	21.00 ± 1.050	20.00 ± 1.000	16.90 ± 0.845	13.80 ± 0.690
		60%	48.00 ± 2.400	43.44 ± 2.172	35.60 ± 1.780	25.80 ± 1.290
		90%	97.00 ± 4.850	44.85 ± 2.243	38.90 ± 1.945	25.66 ± 1.283

Table 9. Effect of different concentrations of tannery effluents on zinc content (mg/kg.dr.wt) on plant samples of *Suaeda maritima* and *Sesuvium portulacastrum*

S.NO	Plants	Concentrations (%)	30 DAS			60 DAS			90 DAS			120 DAS		
			Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
1.	*Suaeda maritima*	Control	2.38± 0.119	2.00± 0.100	1.60± 0.080	4.60± 0.230	3.56± 0.178	2.22± 0.111	6.00± 0.300	4.80± 0.240	2.98± 0.149	8.20± 0.410	5.54± 0.277	4.00± 0.200
		30%	8.86± 0.443	5.00± 0.250	4.12± 0.206	14.90± 0.745	9.22± 0.461	6.60± 0.330	24.30± 1.215	16.88± 0.844	12.18± 0.609	30.55± 1.527	21.50± 1.075	14.19± 0.710
		60%	16.88± 0.844	10.44± 0.522	6.18± 0.309	23.90± 1.195	17.92± 0.846	11.85± 0.592	28.88± 1.444	22.68± 1.134	16.88± 0.844	36.90± 1.845	28.22± 1.411	18.90± 0.945
		90%	22.90± 1.145	16.83± 0.841	10.00± 0.500	26.80± 1.340	26.00± 1.300	15.26± 0.763	35.90± 1.795	30.19± 1.509	19.22± 0.961	45.00± 2.250	34.25± 0.713	24.50± 1.225
2.	*Sesuvium portulacastrum*	Control	2.35± 0.118	1.98± 0.099	1.60± 0.080	4.20± 0.210	3.00± 0.150	2.00± 0.100	5.18± 0.259	4.63± 0.232	2.68± 0.134	6.58± 0.329	5.22± 0.261	3.62± 0.181
		30%	8.80± 0.440	5.00± 0.250	4.00± 0.200	12.22± 0.611	9.00± 0.450	6.18± 0.309	21.68± 1.084	14.25± 0.713	10.22± 0.511	26.40± 1.320	20.10± 1.005	12.10± 0.605
		60%	16.00± 0.800	10.07± 0.503	6.12± 0.306	21.60± 1.080	15.80± 0.790	9.90± 0.495	25.90± 1.295	19.40± 0.970	13.27± 0.663	32.80± 1.640	16.91± 0.845	15.00± 0.750
		90%	21.60± 1.080	16.00± 0.800	10.00± 0.500	24.10± 1.205	22.00± 1.100	14.18± 0.709	33.28± 1.664	29.18± 1.459	17.00± 0.850	39.90± 1.995	30.19± 1.509	21.55± 1.077

Table 10. Effect of different concentrations of tannery effluents on zinc content (mg/kg.dr.wt) on soil samples of *Suaeda maritima* and *Sesuvium portulacastrum*

S.NO	Plants	Concentrations (%)	30 DAS	60 DAS	90 DAS	120 DAS
1.	*Suaeda maritima*	Control	20.00 ± 1.000	33.66 ± 1.683	10.00 ± 0.500	5.18 ± 0.259
		30%	33.66 ± 1.683	26.85 ± 1.343	20.18 ± 1.009	16.18 ± 0.809
		60%	76.80 ± 3.825	60.55 ± 3.027	30.18 ± 1.509	22.28 ± 1.114
		90%	126.18 ± 6.309	96.80 ± 4.84	54.80 ± 2.74	27.56 ± 1.378
2.	*Sesuvium portulacastrum*	Control	20.00 ± 1.000	14.18 ± 0709	12.82 ± 0.641	6.00 ± 0.300
		30%	33.85 ± 1.698	27.19 ± 1.359	23.50 ± 1.125	20.50 ± 1.025
		60%	78.85 ± 3.942	66.90 ± 3.345	33.80 ± 1.690	26.85 ± 1.343
		90%	128.00 ± 6.400	99.25 ± 4.963	58.56 ± 2.928	34.00 ± 1.700

The highest percentage increase over control potassium accumulation was observed in the root of *S. maritima* than in the stem and leaf (Root 99.10%, leaf 98.87% and stem 98.81%) followed by *S. portulacastrum* (Root 99.00%, leaf 98.70% and stem 98.66%) at 90% of tannery effluent treatment after 120 days of cultivation period. Values shown are mean ±SD for five replicates. The results shows that halophytes cultivated in tannery effluent soil declined the soil cadmium level (Table 6) and maximum reduction was observed in *S. maritima* 63.60-16.18 mg/kg.dr.wt (-294.93%) followed by *S. portulacastrum* 64.00-19.18 mg/kg.dr.wt (-233.68%) after 120 days of cultivation at 90% effluent level. Values shown are mean ±SD for five replicates.

Copper

The level of copper in two halophytes cultivated in tannery effluent treated soil and control soil are presented in the table 7. Maximum accumulation was observed in *S. maritima* (Leaf 38.756, stem 24.60 and root 19.90 mg/kg.dr.wt) followed by *S. portulacastrum* (Leaf 33.22, stem 20.80 and root 17.63 mg/kg.dr.wt) in tannery effluent treated soil after 120 days of experimental period at 90% effluent treatment when compared control. The maximum percentage increase over control was achieved in tannery effluent treated soil (*S. maritima* 96.80% in leaf, 96.48% in root and 95.93% in stem than in *S. portulacastrum* (Leaf 96.55%, root 96.14 and stem 95.67) after 120 days of cultivation. Values shown are mean ±SD for five replicates. From Figure 8, it is observed that four halophytes cultivated in tannery effluent and control soil, reduced the soil copper. When compared to control soil, the maximum reduction was achieved in tannery effluent treated soil, *S. maritima,* 96.60-20.58 mg/kg.dr.wt (-369.38%) than in *S. portulacastrum,* 97.00-25.66 mg/kg.dr.wt (-278.02%) after 120 days of cultivation. Values shown are mean ±SD for five replicates.

Zinc

Table 9, revealed that higher accumulation of zinc is found in halophytes cultivated in tannery effluent treated soil when compared to control soil. Maximum accumulation was observed in *S. maritima* (Leaf 45.00, stem 34.25 and root 24.50 mg/kg.dr.wt) followed by *S. portulacastrum* (Leaf 39.90, stem 30.19 and root 21.55 mg/kg.dr.wt) in tannery effluent treated soil after 120 days of experimental period at 90% effluent treatment when compared control. The highest percentage increase over control was achieved in tannery effluent treated soil (*S. maritima* 94.71% in leaf, 94.16% in stem and 93.46% in root than in *S. portulacastrum* (Leaf 94.11%, stem 93.44 and root 92.57) after 120 days of cultivation at 90%. Values shown are mean ±SD for five replicates. The amount of zinc in the soil gradually declined in both the treatments (Table 10).

Maximum reduction is observed in *S. maritima,* 126.18-27.56 mg/kg.dr.wt (-357.83%) followed by *S. portulacastrum*, 128.00-34.00 mg/kg.dr.wt (-276.47%) after 120 days of cultivation in tannery effluent treated soil when compared to control soil at 90%. Values shown are mean ±SD for five replicates.

DISCUSSION

The present study indicated, after 120 days of cultivation of halophytes at 90% treated with tannery effluent, showed the maximum bioaccumulation of heavy metals. All the heavy metal amounts are significantly increased with increasing concentrations of tannery effluents up to 90%. For instance, soil heavy metals level was gradually declined with the increasing concentrations of tannery effluents. The lowest values are observed in 30% of control plant in both the experimental plants. Metal deposit in the cell walls as a result of binding to pectic compounds could be also considered as an important mechanism for metal detoxification in halophyte species, as demonstrated in *Halimione portulacoides* (Sousa *et al*., 2008). Species used for Phytoremediation study, must not only accumulate higher amounts of the larger element but also have a high growth rate, tolerate the toxic effects of the heavy metals, be adapted to local environment and climate, be resistant to pathogen and pests, be easy to cultivate and repulse herbivores to avoid food chain contamination (Ali *et al*., 2013).

Duarte *et al*. (2013) observed *Halimione portulacoides* is suitable species for Cr(VI) phytoremediation processes through phytoextraction process. Redondo-Gomez (2013) reported that bio-accumulation of metals in roots and tillers of *S. maritima* and *S. densiflora* and described as a feasible method for remediating waters and soils contaminated with heavy metals. Chai *et al*., (2014) have demonstrated that *Suaeda alterniflora* not only endured and sequestrated most heavy metals including Cu, Cd and Pb in belowground parts, but also produced organic acids which chelate with heavy metals to reduce their toxicity. *Suaeda fruticosa* accumulates large amounts of Cd^{2+} and Cu^{2+} in its tissues, especially in roots, suggesting it could be used for decontaminating saline soils polluted by Cd^{2+} and Cu^{2+} (Bankaji *et al*., 2015).

In the present study, maximum accumulation of Pb, Cr, Cd, Cu and Zn content was observed in *Suaeda maritima*, when compared to control followed by *Sesuvium portilacastrum*. The use of halophytes to extract several toxic metals has received increasing attention since a few years (Ghnaya *et al*., 2005; Sousa *et al*., 2008; Ghnaya *et al*., 2007; Lefevre *et al*., 2009, 2010; Redondo-Gomez *et al*., 2011; Milic *et al*., 2012; Chai *et al*., 2014; Rastgoo *et al*., 2014 Korzeniowska and Stanislawska-Glubiak, 2015; Ayyappan *et al*., 2016 and Christofilopoulos *et al*., 2016).

Conclusion

Based on the results from the present phytoremediation study, it is concluded that salt accumulating halophytes *Suaeda maritima* and *Sesuvium portulacastrum* are suggested to be better adapted to cope up with heavy metals stress especially *Suaeda maritima* is highly tolerant to tannery effluents when compared to *Sesuvium portulacastrum*.

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