4. RESULTS

Heavy metal contamination is one of most serious environmental problems that limit plant productivity and threatening human health. Sustainable on-site techniques for remediation of heavy metal contaminated sites include phytoextraction, the use of plants to remove contaminants from soils, sediments or water into harvestable plant biomass. A more efficient performance of several basic biochemical tolerance mechanisms provides an advantage to halophytes with respect to several environmental factors including salt and heavy metals.

Observations on morphology, growth, biochemical constituents, enzymes, physico-chemical and bioaccumulation studies were made at 25 days intervals after 25th, 50th, 75th, 100th and 125th days of transplanting halophytes in the tannery effluent and salt treated soil. The data gathered from periodical observations were processed and statistically analysed and the results are presented in the form of plates, tables and figures.

PHYSICO-CHEMICAL CHARACTERISTICS OF EFFLUENT RELEASED FROM TANNERY INDUSTRY

Analysis of physico-chemical characteristics of the tannery effluent is shown in Table 1. Colour is a qualitative characteristic that
can be used to assess the general condition of wastewater. In the present study, the effluent released from tannery industry was brown in colour and had an offensive odour and turbid in nature. pH was recorded as 10.70, which was above the tolerance limit of 5.5 to 9.0 prescribed by the Bureau of Indian Standards (2009). The higher pH of the effluent indicates the basic nature of the effluent. Total hardness of the tannery effluent in the present study was found 568 mg/l. The higher electrical conductivity value (4.99 dSm$^{-1}$) of the effluent indicates that the discharge of chemicals as cations and anions were higher in the tannery waste water.

The effluent showed a higher level of total dissolved solids (TDS) (3432 mg/l). The value was much greater than the tolerance limits (2100 mg/l) prescribed by Bureau of Indian Standards. Levels of total suspended solids (TSS) found in the effluent (1589 mg/l) were greater than that of the permissible limit (100 mg/l). BOD of tannery effluent was found to 699 mg/l which was higher than that of the BIS limits (30 mg/l). The high BOD levels are indications of the pollution strength of the tannery waste water.

The level of sodium and potassium in the effluent was 89.20 and 8.72 meq/l respectively. The level of chloride in the effluent (54.63 meq/l) was higher than that prescribed by BIS (2009). The cations calcium and magnesium present in the effluent were found at higher levels (9.90 and 10.88 meq/l respectively) compared to BIS limits.
Chromium level in raw effluent was found to 142.40 mg/l. Chromium is the major chemical used in tanning process and hence its discharge in the effluent was found to be higher. Cadmium, copper and zinc in the effluent were 28.20, 78.96 and 212.90 mg/l respectively. All these metals were present in higher concentrations compared to the prescribed limits of BIS (2009).

**PHYSICO-CHEMICAL CHARACTERISTICS OF SOIL TREATED BY SALT AND TANNERY EFFLUENT**

Physico-chemical characteristics of soil treated with salt and tannery effluent are given in the table 2. Soil pH is one of the most influential parameters controlling the conversion of metals from immobile solid phase forms to more mobile form. pH of the salt treated and tannery effluent treated soil was 7.7 and 8.3 respectively. Electrical conductivity from salt treated and tannery effluent treated soil was 4.28 dSm\(^{-1}\) and 5.25 dSm\(^{-1}\) respectively.

Levels of sodium in the salt treated soil were found to 45.88 meq/l and tannery effluent treated soil 48.00 meq/l. Potassium levels in the salt treated soil and tannery effluent treated soil was found to 6.82 meq/l and 7.16 meq/l respectively. Chloride levels in the salt treated and tannery effluent treated soil was 39.00 and 43.00 meq/l respectively. Calcium and magnesium levels in salt treated soil were found to be 7.94 meq/l and 8.13 meq/l respectively. In tannery
effluent treated soil the levels of calcium (8.17 meq/lit) and magnesium (8.88 meq/l) were higher than the salt treated soil.

The metals, chromium, cadmium, copper and zinc were found to 4.80, 5.00, 18.19 and 26.00 mg/kg respectively in salt treated soil. Whereas, the metals level in the tannery effluent treated soil (82.00 mg/kg chromium, 23.88 mg/kg cadmium, 54.90 mg/kg copper and 55.00 mg/kg zinc) were higher than the salt treated soil.

FIELD VIEW AND MORPHOLOGY

Overall field view (Plate 1) and morphology of halophytes grown in tannery effluent treated soil are given in plates 2, 3, 4 and 5. The results showed that presence of salt and heavy metals from tannery effluent did not show any negative effect on morphology of cultivated halophytes. Instead, halophytes cultivated in tannery effluent treated soil showed high tolerance, higher growth and more biomass when compared to salt treated soil and control (without salt and tannery effluent).

GROWTH AND LEAF CHARACTERISTICS

During 125 days of cultivation, increase in growth characteristics was observed in all the species cultivated in tannery effluent and salt treated soil when compared to control. However,
highest increase was observed during 75-100 days of cultivation period and there after only marginal increase was observed.

Leaf growth traits might serve as a suitable phytoindicators of heavy metal pollution and in the selection of the resistant species. In addition, it decisively determines the biomass and yield of crops. In the present study, plants grown under tannery effluent treated soil showed highest shoot length, leaf number and maximum leaf area when compared to salt treated soil and control (Plates 6, 7, 8, 9, 10, 11, 12 and 13). The length and breadth of the leaves were maximum in tannery effluent treated soil and which might be due to more accumulation of heavy metals and salts.

**Shoot length**

Shoot length of halophytes cultivated in tannery effluent and salt treated soil are presented in Figure 1. Presence of NaCl in both tannery effluent and salt treated soil favoured the increase in shoot length and it is maximum in *I. pes-caprae, S. portulacastrum, S. maritima* and *S. monoica* after 125 days of cultivation when compared to control. Gradual increase in shoot length was observed up to 125 days of cultivation. However, maximum shoot length increase was observed between 75-100 days of cultivation period.
**Total Number of Leaves**

Total number of leaves (Figures 2a and 2b) were higher in *S. maritima* (375.4%) followed by *S. monoica* (290%), *S. portulacastrum* (272.6%) and *I. pes-caprae* (239%) cultivated in tannery effluent treated soil, when compared to salt treated soil [*S. maritima* (280%), *S. monoica* (190%), *S. portulacastrum* (170%) and *I. pes-caprae* (155%)] after 125 days of cultivation when compared to control.

**Leaf area**

Leaf area (Figure 3) increased in all the four species of halophytes cultivated in tannery effluent and salt treated soil. However, in tannery effluent treated soil, the maximum leaf area was observed in *I. pes-caprae* (565.8%) followed by *S. portulacastrum* (520.4%), *S. maritima* (440.4%) and *S. monoica* (375%). In salt treated soil, maximum increase in leaf area was observed in *I. pes-caprae* (510.3%), which was followed by *S. portulacastrum* (475%), *S. maritima* (395.1%) and *S. monoica* (340%) when compared to control.

**Fresh weight**

Results on the application of tannery effluent and salt treated soil on fresh weight of four species of halophytes are given in Figure 4. When compared to salt treated soil and control, tannery effluent treated soil showed maximum increase in fresh weight and it was
higher in *S. maritima* (325.1%) followed by *S. portulacastrum* (305%), *S. monoica* (290%) and *I. pes-caprae* (248%) after 125 days of cultivation.

**Dry weight**

Figure 5, shows the dry weight of the halophytes cultivated under tannery effluent and salt treated soil after 125 days of cultivation. Similar to fresh weight, highest dry weight was observed in effluent treated soil and it was maximum in *S. maritima* (325.05%) followed by *S. portulacastrum* (304.9%), *S. monoica* (279.9%) and *I. pes-caprae* (247.78%) when compared to salt treated soil and control after 125 days of cultivation.

**LEAF ANATOMY**

In the present study, leaf anatomy of four species of halophytes showed typical to that of C₃ species. The leaf thickness was much reduced in control plants, when compared to salt and tannery effluent treated halophytes (Plates 14, 15, 16 and 17). Spongy and palisade parenchyma cell size were enlarged higher in tannery effluent than halophytes cultivated in salt treated. The length and breadth of parenchyma cells were also increased in tannery effluent and salt treated soil cultivated plants, when compared to control plants.
In the present study, it was also observed that four halophytes accumulated large quantities of heavy metals and salts in their enlarged leaf tissues, which was distributed inside the plasmalemma and vascular bundle. These metals and salts appear to be sequestered in the well-developed vacuoles which could be a good reservoir for heavy metals.

**Mesophyll Thickness**

In the present study the mesophyll thickness was increased maximum in tannery effluent treated plants when compared to salt treated and control plants (Table 3). The highest mesophyll thickness (259.5 µm) was observed in *S. portulacastrum* treated under tannery effluent when compared to salt treated soil (196.8 µm) followed by *S. maritima* (216.9 µm in tannery effluent and 179.8 µm in salt treated soil), *S. monoica* (152.6 µm in tannery effluent and 146.9 µm in salt treated soil) and *I. pes-caprae* (139.6 µm in tannery effluent and 122.8µm in salt treated soil) after 125 days of cultivation.

**BIOCHEMICAL ANALYSIS**

**Total Chlorophyll**

Changes in the chlorophyll content in the leaves of four species of halophytes cultivated in tannery effluent and salt treated soil are given in Figure 6. The highest value of chlorophyll content was
observed in *S. maritima* (215%) followed by *S. monoica* (180.3%), *S. portulacastrum* (170%) and *I. pes-caprae* (167%) cultivated in tannery effluent treated soil. In salt treated soil, about 170% increase in chlorophyll content was observed in *S. maritima* followed by *S. monoica* (147.61%), *S. portulacastrum* (145%) and *I. pes-caprae* (143.87%). However, control plants showed only a marginal increase in chlorophyll content.

**Soluble Protein**

Maximum increase in biochemical parameters observed between 75 to 100 days development period. Changes in the soluble protein content of the leaves in four species of halophytes cultivated in tannery effluent and salt treated soil are given in Figure 7. When compared to salt treated and control plants, the plants cultivated in tannery effluent treated soil showed higher protein content in *S. maritima* (202.1%) followed by *S. monoica* (181.6%), *S. portulacastrum* (168.7%) and *I. pes-caprae* (144.7%) after 125 days of cultivation.

**Total Phenol**

The results on total phenol content of halophytes cultivated in tannery effluent and salt treated soil are given in Figure 8. In tannery effluent treated soil, the highest phenol content was noticed in
I. pes-caprae (350%), which was followed by S. maritima (210%), S. monoica (199%) and S. portulacastrum (185%). In salt treated soil, the phenol content was higher in I. pes-caprae (320%) than in S. maritima (187.3%), S. monoica (169%) and S. portulacastrum (160%). However, control plants showed only a marginal increase in phenol content after 125 days of cultivation.

**Proline**

When compared to control and salt treated soil, proline content (Figure 9) increased in four species of halophytes cultivated in tannery effluent treated soil and the highest proline content was observed in S. maritima (389.5%), which is followed by S. monoica (297.70%), S. portulacastrum (260%) and I. pes-caprae (240%) after 125 days of cultivation.

**Glycinebetaine**

The data on the changes in the glycinebetaine content in response to halophytes cultivated in tannery effluent and salt treated soil are given in Figure 10. Maximum glycinebetaine content was observed in S. maritima (261.9%) followed by S. monoica (226%), S. portulacastrum (181.81%) and I. pes-caprae (176%) cultivated in tannery effluent treated soil when compared to salt treated soil and control.
ENZYMES

Catalase

When compared to salt treated and control plants, there was considerable increase in the catalase activity in four halophytes cultivated in tannery effluent treated soil and the results are presented in Figure 11. Nearly, 235%, 220%, 178% and 167% increase in catalase activity was observed in *S. maritima*, *S. portulacastrum*, *S. monoica* and *I. pes-caprae* when compared to salt treated and control plants.

Peroxidase

Similar to catalase activity, *S. maritima*, *S. portulacastrum*, *S. monoica* and *I. pes-caprae* showed highest peroxidase activity (345%, 310%, 210% and 192% respectively) when compared to salt treated and control plants after 125 days of cultivation (Figure 12).

Polyphenoloxidase

When compared to salt treated and control plants, enhanced polyphenoloxidase activity was observed in *I. pes-caprae* (240%) followed by *S. maritima* (219%), *S. portulacastrum* (209%) and *S. monoica* (191%) after 125 days of cultivation (Figure 13).
IONS AND MINERAL NUTRIENTS IN SOIL

Sodium

From the results (Figure 14) it is noticed that halophytes cultivated in tannery effluent and salt treated soil decreased the amount of sodium from the soil. Maximum reduction was observed after seventy five days of cultivation period. In tannery effluent treated soil, maximum reduction in sodium was observed in *S. maritima* (-82.2%) followed by *S. portulacastrum* (-79.1%), *S. monoica* (-71.8%) and *I. pes-caprae* (-58.3%) when compared to salt treated soil [*S. maritima* (-73.8%) followed by *S. portulacastrum* (-69.4%), *S. monoica* (-60.7%) and *I. pes-caprae* (-49.8%)].

Potassium

The amount of potassium was markedly reduced in halophytes cultivated in tannery effluent and salt treated soil and the results are presented in Figure 15. In effluent treated soil maximum reduction is observed in *S. maritima* (-59.4%) which is followed by *S. portulacastrum* (-52.5%), *S. monoica* (-42.7%) and *I. pes-caprae* (-37.1%) after 125 days of cultivation when compared to salt treated plants.
**Chloride**

Results of the study also indicated that chloride was reduced in halophytes cultivated in tannery effluent and salt treated soil and the results are presented in Figure 16. The highest reduction in chloride was observed in *S. maritima* cultivated soil (-69.7%) followed by *S. portulacastrum* (-62.7%), *S. monoica* (-58.8%), and *I. pes-caprae* (-48.8%) after 125 days of cultivation in tannery effluent soil when compared to salt treated soil.

**Calcium**

Similar to other ions, calcium content also decreased considerably in *S. maritima* (-62.7%), *S. portulacastrum* (-55.9%), *S. monoica* (-49.8%) and *I. pes-caprae* (-40.0%) cultivated in tannery effluent treated soil when compared to salt treated soil (Figure 17).

**Magnesium**

From the results it is revealed that in tannery effluent treated soil, magnesium (Figure 18) was reduced maximum in *S. maritima* (-62.8%) cultivated soil which was followed by *S. portulacastrum* (-57.2%), *S. monoica* (-40.3%) and *I. pes-caprae* (-33.5%) after 125 days of cultivation when compared to salt treated soil.
SODIUM ABSORPTION RATIO (SAR)

Sodium absorption ratio in halophytes cultivated in tannery effluent and salt treated soil is presented in the Fig. 19. SAR was reduced maximum from 16.443 to 6.010 meq/lit (63.40% reduction) in *S. maritima* cultivated in tannery effluent treated soil followed by *S. portulacastrum* from 16.443 to 6.550 meq/lit (60.10% reduction), *S. monoica* from 16.443 to 7.700 meq/lit (53.10% reduction) and *I. pes-caprae* from 16.443 to 9.300 meq/lit (43.44% reduction) when compared to salt treated soil.

ION AND MINERAL NUTRIENTS IN PLANT SAMPLES

Sodium

Figures 20a, 20b and 20c, show the accumulation of sodium in leaf, stem and root of the four halophytes cultivated in tannery effluent and salt treated soil. Leaves accumulated higher sodium when compared to stem and root in tannery effluent treated soil and maximum accumulation is observed in *S. maritima* (Leaf 437.5%, stem 325.7% and root 143.3%) which is followed by *S. portulacastrum* (Leaf 402.6%, stem 297.4% and root 130.3%), *S. monoica* (Leaf 350.2%, stem 250.9% and root 112%) and *I. pes-caprae* (Leaf 249%, stem 206% and root 99.6%) when compared to salt treated soil maximum accumulation is found in *S. maritima* (Leaf 380%, stem 290% and root 130%) which was followed by *S. portulacastrum* (Leaf 350%, stem
261% and root 118%), **S. monoica** (Leaf 304.96%, stem 220% and root 101%) and **I. pes-caprae** (Leaf 215%, stem 180% and root 90%).

**Potassium**

Figures 21a, 21b and 21c, show the accumulation of potassium in leaf, stem and root of halophytes cultivated in tannery effluent and salt treated soil. Higher accumulation was observed in the leaves of **S. maritima** than in the stem and root (Leaf 224.2%, stem 171.2% and root 120.9%) followed by **S. portulacastrum** (Leaf 210.6%, stem 181.4% and root 107.8%), **S. monoica** (Leaf 176.6%, stem 146% and root 87%) and **I. pes-caprae** (Leaf 142.8%, stem 122.6% and root 72.18%) cultivated in tannery effluent treated soil when compared to salt treated soil.

**Chloride**

Similar to potassium, maximum chloride accumulation (Figures 22a, 22b and 22c) was observed in **S. maritima** (Leaf 379.3%, stem 325.05% and root 164.8%) which was followed by **S. portulacastrum** (Leaf 335.5%, stem 300.5% and root 156.8%), **S. monoica** (Leaf 265.1%, stem 213.6% and root 120.8%) and **I. pes-caprae** (Leaf 219.8, stem 169.3% and root 99.5%) cultivated in tannery effluent treated soil than salt treated soil.
**Calcium**

The plants cultivated in tannery effluent treated soil accumulated higher calcium when compared to salt treated soil (Figures 23a, 23b and 23c 1 and 23c 2). The maximum accumulation is observed in leaves and followed by stem and root in all the plants. The highest accumulation is observed in *S. maritima* (Leaf 177.7%, stem 127.4% and root 99.1%) followed by *S. portulacastrum* (Leaf 166.1% stem 116.2% and root 88.9%), *S. monoica* (Leaf 154.5%, stem 105% and root 77.8%) and *I. pes-caprae* (Leaf 132%, stem 94.1% and root 52.2%) when compared to salt treated soil after 125 days of cultivation.

**Magnesium**

Halophytes cultivated in tannery effluent treated soil especially, leaves accumulated more magnesium when compared to salt treated soil (Figures 24a, 24b and 24c). The maximum accumulation was observed in *S. maritima* (Leaf 191.2%, stem 150.5% and root 74.5%) followed by *S. portulacastrum* (Leaf 178.6% stem 139.3% and root 86%), *S. monoica* (Leaf 149.4%, stem 105.2% and root 57.3%) and *I. pes-caprae* (Leaf 122%, stem 94% and root 50.7%) in tannery effluent treated soil when compared to salt treated soil.
HEAVY METALS - SOIL

Chromium

From the results (Figure 25), it is observed that chromium was considerably decreased in tannery effluent treated soil when compared to salt treated soil. Highest reduction in chromium was recorded in *S. maritima* cultivated soil (-63.5%) which was followed by *S. portulacastrum* (-52.1%), *S. monoica* (-43.9%) and *I. pes-caprae* (-40.8%). Similarly reduction was also noticed in salt treated soil and *S. maritima* recorded -54.1% reduction followed by *S. portulacastrum* (-50.2%), *S. monoica* (-40.6%) and *I. pes-caprae* (-38.5%).

Cadmium

The results shows that halophytes cultivated in tannery effluent soil declined the soil cadmium level (Figure 26) and maximum reduction was observed in *S. maritima* (-54.7%) followed by *S. portulacastrum* (-51.8%), *S. monoica* (-49.3%) and *I. pes-caprae* (-32.9%) when compared to salt treated soil [*S. maritima* (-46%), *S. portulacastrum* (-42%), *S. monoica* (-34%) and *I. pes-caprae* (-24%)] after 125 days of cultivation.

Copper

From Figure 27, it is observed that four halophytes cultivated in tannery effluent and salt treated soil, reduced the soil copper. When
compared to salt treated soil, the maximum reduction was achieved in tannery effluent treated soil (S. maritima -59.7%, S. portulacastrum -54.4%, S. monoica -48.9% and I. pes-caprae -41.7%) after 125 days of cultivation.

**Zinc**

The level of zinc in the soil declined in both the treatments (Figure 28). Maximum reduction is observed in S. maritima (-52.7%) followed by S. portulacastrum (-47.4%), S. monoica (-42.9%) and I. pes-caprae (-37.6%) after 125 days of cultivation in tannery effluent treated soil when compared to salt treated soil [S. maritima (-40.3%), S. portulacastrum (-36.5%), S. monoica (-31.1%) and I. pes-caprae (-25.7%)].

**HEAVY METALS - PLANTS**

**Chromium**

Bioaccumulation of Chromium in the tissues of four halophytes cultivated in tannery effluent and salt treated soil are presented in the Figure 29. Higher chromium content was accumulated in halophytes cultivated in tannery effluent treated soil where, S. maritima accumulated 1165.5% of chromium followed by S. portulacastrum (1115.1%), S. monoica (892.4%) and I. pes-caprae (742.2%) when
compared to salt treated soil [S. *maritima* (5.26%), *S. portulacastrum* (4.8%), *S. monoica* (3.88%) and *I. pes-caprae* (3.05%)] after 125 days of cultivation.

**Cadmium**

Figure 30, represents the amount of cadmium accumulated by four halophytes cultivated in tannery effluent treated and salt treated soil. Similar to chromium, the halophytes cultivated in tannery effluent treated soil showed higher accumulation of cadmium, especially *Suaeda maritima* showed the maximum accumulation of cadmium content (1298.9%) followed by *S. portulacastrum* (1155.6%), *S. monoica* (980.2%) and *I. pes-caprae* (701.3%) after 125 days of cultivation.

**Copper**

The level of copper in four halophytes cultivated in tannery effluent and salt treated soil are presented in the Figure 31. Maximum accumulation was observed in *S. maritima* (1011.2%) followed by *S. portulacastrum* (891.5%) *S. monoica* (734.2%) and *I. pes-caprae* (543.5%) in tannery effluent treated soil when compared to salt treated soil.

**Zinc**

The experimental data revealed that higher accumulation of zinc is found in halophytes cultivated in tannery effluent treated soil when compared to salt treated soil (Figure 32). Maximum accumulation was
found in *S. maritima* (664.7%) followed by *S. portulacastrum* (601%), *S. monoica* (508%) and *I. pes-caprae* (473%) when compared to salt treated soil [*S. maritima* (66.6%), *S. portulacastrum* (58%), *S. monoica* (46.4%) and *I. pes-caprae* (34%)] after 125 days of cultivation.

**ELECTRICAL CONDUCTIVITY (EC) IN TANNERY EFFLUENT AND SALT TREATED SOIL AND HALOPHYTES**

In the present study, soil EC reduced from 5.25 to 1.73 dSm\(^{-1}\) in *S. maritima* cultivated in tannery effluent treated soil and from 4.28 to 1.65 dSm\(^{-1}\) in salt treated soil (Figure 33). Correspondingly, plant EC was increased from 4.38 to 9.98 dSm\(^{-1}\) in tannery effluent treated soil and from 4.30 to 9.78 dSm\(^{-1}\) in salt treated soil in plant samples (Figure 34).

In *S. portulacastrum* cultivated soil, the EC was reduced from 5.25 to 1.82 dSm\(^{-1}\) in tannery effluent treated soil and from 4.28 to 1.78 dSm\(^{-1}\) in salt treated soil. While in the plant sample, the EC was increased from 4.34 to 9.53 dSm\(^{-1}\) in tannery effluent treated soil and from 4.22 to 9.12 dSm\(^{-1}\) in salt treated soil.

Similarly in *S. monoica* cultivated soil, the EC reduced from 5.25 to 2.19 dSm\(^{-1}\) in tannery effluent treated soil and from 4.28 to 2.10 dSm\(^{-1}\) in salt treated soil and increased in the plant samples from 4.25 to 8.75 dSm\(^{-1}\) in tannery effluent treated soil and from 4.19 to 8.44 dSm\(^{-1}\) in salt treated soil.
In *I. pes-caprae* cultivated soil, EC reduced from 5.25 to 2.57 dSm\(^{-1}\) in tannery effluent treated soil and from 4.28 to 2.42 dSm\(^{-1}\) in salt treated soil and increased in plant samples from 3.95 to 7.87 dSm\(^{-1}\) in tannery effluent treated soil and from 3.80 to 7.66 dSm\(^{-1}\) in salt treated soil.

**pH IN SOIL AND PLANTS**

Soil pH measurement is useful because it is a predictor of various chemical activities within the soil. As such, it is also a useful tool in making management decisions concerning the type of plants suitable for location and possible need to modify soil pH.

In the present study, it is revealed that cultivation of halophytes considerably decreased the pH in tannery effluent than salt treated soil after 125 days of cultivation (Figure 35). Soil pH declined from 8.3 to 6.8 (18% reduction) in tannery effluent treated soil and from 7.7 to 6.5 (15.5% reduction) in salt treated soil in *S. maritima* cultivated soil.

In *S. portulacastrum* soil, the pH declined from 8.3 to 6.96 (16.1% reduction) in tannery effluent treated soil and from 7.7 to 6.65 (13.6% reduction) in salt treated soil followed by *S. monica* 8.3 to 7.10 (14.4% reduction) in effluent treated soil and 7.7 to 6.85 (11.03% reduction) in salt treated soil and in *I. pes-caprae* from 8.3 to 7.35 (11.4% reduction) in tannery effluent treated soil and from 7.7 to 6.91 (10.2% reduction) in salt treated soil.
Correspondingly, plant pH (Figure 36) increased from 6.90 to 9.90 (43.4%) in tannery effluent treated soil and from 6.70 to 9.30 (38.8%) in salt treated soil in *S. maritima* followed by *S. portulacastrum* from 6.82 to 9.60 (40.7%) in tannery effluent treated soil and from 6.60 to 9.10 (37.8%) in salt treated soil, *S. monoica* from 6.80 to 9.40 (38.20%) in effluent treated soil and from 6.57 to 8.90 (35.4%) in salt treated soil and *I. pes-caprae* from 6.65 to 9.10 (36.8%) in tannery effluent treated soil and from salt 6.40 to 8.60 (34.3%) in salt treated soil after 125 days of cultivation.

**ACCUMULATION OF NaCl IN HALOPHYTES**

From the results, it is clearly revealed that the four halophytes cultivated under tannery effluent and salt treated soil considerably decreased the soil salinity by absorbing high amounts of the sodium and chloride from soil. However, maximum accumulation of NaCl was observed in halophytes cultivated in tannery effluent treated soil. It is estimated from 1g dry weight of plant sample, *S. maritima* accumulated 286.96 mg NaCl followed by *S. portulacastrum* 226.21 mg NaCl, *S. monoica* 194.83 mg NaCl and *I. pes-caprae* 158.81 mg NaCl (Figure 37).
In salt treated soil, *S. maritima* accumulated 261.27 mg NaCl, followed by *S. portulacastrum* 224.01 mg NaCl, *S. monoica* 181.58 mg NaCl and *I. pes-caprae* 145.81 mg NaCl after 125 days of cultivation (Fig. 37).

**ACCUMULATION OF HEAVY METALS IN HALOPHYTES**

From the data, (Figure 38) it is noticed that maximum accumulation of heavy metals (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 52.90 mg Cr, 25.88 mg Cd, 39.45 mg Cu and 78.00 mg Zn followed by *S. portulacastrum* (49.82 mg Cr, 22.10 mg Cd, 35.1 mg Cu and 70.10 mg Zn), *S. monoica* (40.89 mg Cr, 17.50 mg Cd, 29.2 mg Cu and 60.20 mg Zn) and *I. pes-caprae* (33.16 mg Cr, 12.10 mg Cd, 22.46 g Cu and 57.90 mg Zn).

In salt treated soil, higher accumulation of heavy metals was observed in *S. maritima* (Cr 4.40 mg, Cd 1.98 mg, Cu 6.89 mg and Zn 17.00 mg) followed by *S. portulacastrum* (Cr 4.30 mg, Cd 1.86 mg, Cu 6.55 mg and Zn 15.80 mg), *S. monoica* (Cr 4.28 mg, Cd 1.70 mg, Cu 6.00 mg and Zn 14.50 mg) and *I. pes-caprae* (Cr 4.05 mg, Cd 1.57 mg, Cu 5.60 mg and Zn 13.40 mg) after 125 days of cultivation.
Table 1. Physico-chemical characteristics of Tannery effluent

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<td>Brown</td>
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<tr>
<td>2.</td>
<td>Odour</td>
<td>Offensive</td>
<td>-</td>
</tr>
<tr>
<td>3.</td>
<td>Turbidity</td>
<td>Turbid</td>
<td>-</td>
</tr>
<tr>
<td>4.</td>
<td>pH</td>
<td>10.70</td>
<td>5.5-9.0</td>
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<tr>
<td>5.</td>
<td>Electrical Conductivity (dSm⁻¹)</td>
<td>4.99</td>
<td>-</td>
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<tr>
<td>6.</td>
<td>Total hardness</td>
<td>568.00</td>
<td>100</td>
</tr>
<tr>
<td>7.</td>
<td>Total dissolved solids (mg/l)</td>
<td>3432.00</td>
<td>2100</td>
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<tr>
<td>8.</td>
<td>Total suspended solids (mg/l)</td>
<td>1589.00</td>
<td>100</td>
</tr>
<tr>
<td>9.</td>
<td>Alkalinity</td>
<td>1350.00</td>
<td>NM</td>
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<tr>
<td>10.</td>
<td>Biological Oxygen Demand</td>
<td>699.00</td>
<td>30</td>
</tr>
<tr>
<td>11.</td>
<td>Sodium (meq/l)</td>
<td>89.20</td>
<td>NM</td>
</tr>
<tr>
<td>12.</td>
<td>Chloride (meq/l)</td>
<td>54.63</td>
<td>NM</td>
</tr>
<tr>
<td>13.</td>
<td>Potassium (meq/l)</td>
<td>8.72</td>
<td>NM</td>
</tr>
<tr>
<td>14.</td>
<td>Calcium (meq/l)</td>
<td>9.90</td>
<td>NM</td>
</tr>
<tr>
<td>15.</td>
<td>Magnesium (meq/l)</td>
<td>10.88</td>
<td>NM</td>
</tr>
<tr>
<td>16.</td>
<td>Chromium (mg/l)</td>
<td>142.40</td>
<td>2.0</td>
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<tr>
<td>17.</td>
<td>Cadmium (mg/l)</td>
<td>28.20</td>
<td>2.0</td>
</tr>
<tr>
<td>18.</td>
<td>Copper (mg/l)</td>
<td>78.96</td>
<td>NM</td>
</tr>
<tr>
<td>19.</td>
<td>Zinc (mg/l)</td>
<td>212.90</td>
<td>1.0</td>
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</tbody>
</table>

NM- Not mentioned
### Table 2. Physio-Chemical characteristics of salt and tannery effluent treated soil after four drenching

<table>
<thead>
<tr>
<th>S.No</th>
<th>Parameters</th>
<th>Salt treated soil</th>
<th>Tannery effluent treated soil</th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>pH</td>
<td>7.7</td>
<td>8.3</td>
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<tr>
<td>2.</td>
<td>Electrical Conductivity (dSm$^{-1}$)</td>
<td>4.28</td>
<td>5.25</td>
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<tr>
<td>3.</td>
<td>Sodium (meq/l)</td>
<td>45.88</td>
<td>48.00</td>
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<tr>
<td>4.</td>
<td>Potassium (meq/l)</td>
<td>6.82</td>
<td>7.16</td>
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<tr>
<td>5.</td>
<td>Chloride (meq/l)</td>
<td>39.00</td>
<td>43.00</td>
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<tr>
<td>6.</td>
<td>Calcium (meq/l)</td>
<td>7.94</td>
<td>8.17</td>
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<tr>
<td>7.</td>
<td>Magnesium (meq/l)</td>
<td>8.13</td>
<td>8.88</td>
</tr>
<tr>
<td>8.</td>
<td>Chromium (mg kg$^{-1}$)</td>
<td>4.80</td>
<td>82.00</td>
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<tr>
<td>9.</td>
<td>Cadmium (mg kg$^{-1}$)</td>
<td>5.00</td>
<td>23.88</td>
</tr>
<tr>
<td>10.</td>
<td>Copper (mg kg$^{-1}$)</td>
<td>18.19</td>
<td>54.90</td>
</tr>
<tr>
<td>11.</td>
<td>Zinc (mg kg$^{-1}$)</td>
<td>26.00</td>
<td>55.00</td>
</tr>
</tbody>
</table>
Table 3. Mesophyll characteristics of *Suaeda maritima*, *Sesuvium portulacastrum*, *Suaeda monoica* and *Ipomoea pes-caprae* cultivated in control, salt and tannery effluent treated soil. The values are mean ± SD of five replicates

<table>
<thead>
<tr>
<th>Name of the species</th>
<th>Mesophyll thickness (µm)</th>
<th>Mesophyll volume (cm³/dm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Suaeda maritima</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>62.5±3.12</td>
<td>6.25 ± 0.31</td>
</tr>
<tr>
<td>S</td>
<td>179.8±8.99</td>
<td>17.98±0.899</td>
</tr>
<tr>
<td>TE</td>
<td>216.9±10.84</td>
<td>21.69±1.08</td>
</tr>
<tr>
<td><em>Sesuvium portulacastrum</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>96.9 ± 4.84</td>
<td>9.69 ± 0.48</td>
</tr>
<tr>
<td>S</td>
<td>196.8±9.84</td>
<td>19.68±0.98</td>
</tr>
<tr>
<td>TE</td>
<td>259.5 ± 12.97</td>
<td>25.95 ± 1.29</td>
</tr>
<tr>
<td><em>Suaeda monoica</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>43.8±2.19</td>
<td>4.38±0.21</td>
</tr>
<tr>
<td>S</td>
<td>146.9±7.34</td>
<td>14.69±0.71</td>
</tr>
<tr>
<td>TE</td>
<td>152.6±7.63</td>
<td>15.26±0.76</td>
</tr>
<tr>
<td><em>Ipomoea pes-caprae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>48.8±2.44</td>
<td>4.88±0.24</td>
</tr>
<tr>
<td>S</td>
<td>122.8±6.14</td>
<td>12.28±0.61</td>
</tr>
<tr>
<td>TE</td>
<td>139.6±6.98</td>
<td>13.96±0.69</td>
</tr>
</tbody>
</table>

C- Control; S- Salt; TE- Tannery Effluent

CD (P=0.05) = 3.609   CD (P=0.05) = 1.923
SED = 7.254           SED = 4.997
Plate 1: Cultivation of *Suaeda maritima*, *Sesuvium portulacastrum*, *Suaeda monoica* and *Ipomoea pes-caprae* in control, salt and tannery effluent treated soil (Field view)
Plate 2: Field view of *Suaeda maritima* treated with tannery effluent after 125 days of cultivation

Plate 3: Field view of *Sesuvium portulacastrum* treated with tannery effluent after 125 days of cultivation
Plate 4: Field view of *Suaeda monoica* treated with tannery effluent after 125 days of cultivation

Plate 5: Field view of *Ipomoea pes-caprae* treated with tannery effluent after 125 days of cultivation
Plate 6: Growth characteristics of *Suaeda maritima* cultivated in control, salt and tannery effluent treated soil

Plate 7: Leaf characteristics of *Suaeda maritima* cultivated in control, salt and tannery effluent treated soil
Plate 8: Growth characteristics of *Sesuvium portulacastrum* cultivated in control, salt and tannery effluent treated soil

Plate 9: Leaf characteristics of *Sesuvium portulacastrum* cultivated in control, salt and tannery effluent treated soil
Plate 10: Growth characteristics of *Suaeda monoica* cultivated in control, salt and tannery effluent treated soil

Plate 11: Leaf characteristics of *Suaeda monoica* cultivated in control, salt and tannery effluent treated soil
Plate 12: Growth characteristics of *Ipomoea pes-caprae* cultivated in control, salt and tannery effluent treated soil

Plate 13: Leaf characteristics of *Ipomoea pes-caprae* cultivated in control, salt and tannery effluent treated soil
Plate 14: Anatomy of leaf characteristics of *Suaeda maritima* cultivated in control, salt and tannery effluent treated soil after 125 days of cultivation.
Plate 15: Anatomy of leaf characteristics of *Sesuvium portulacastrum* cultivated in control, salt and tannery effluent treated soil after 125 days of cultivation
Plate 16: Anatomy of leaf characteristics of *Suaeda monoica* cultivated in control, salt and tannery effluent treated soil after 125 days of cultivation.
Plate 17: Anatomy of leaf characteristics of Ipomoea pes-caprae cultivated in control, salt and tannery effluent treated soil after 125 days of cultivation.
Figure 1: Effect of salt and tannery effluent on shoot length of certain halophytes. Values shown are mean ±SD for five replicate experiments.
Figure 2 (a): Effect of salt and tannery effluent on total number of leaves in *Suaeda maritima* and *Sesuvium portulacastrum*. Values shown are mean ±SD for five replicate experiments.
Figure 2 (b): Effect of salt and tannery effluent on total number of leaves in *Suaeda monoica* and *Ipomoea pes-caprae*. Values shown are mean ±SD for five replicate experiments.
Figure 3: Effect of salt and tannery effluent on total leaf area of certain halophytes. Values shown are mean ±SD for five replicate experiments.
Figure 4: Effect of salt and tannery effluent on fresh weight of certain halophytes. Values shown are mean ±SD for five replicate experiments.
Figure 5: Effect of salt and tannery effluent on dry weight of certain halophytes. Values shown are mean ±SD for five replicate experiments.
Figure 6: Effect of salt and tannery effluent on total chlorophyll content of certain halophytes.

Values shown are mean ±SD for five replicate experiments.
Figure 7: Effect of salt and tannery effluent on soluble protein content of certain halophytes.

Values shown are mean ±SD for five replicate experiments.
Figure 8: Effect of salt and tannery effluent on total phenol content of certain halophytes. Values shown are mean ±SD for five replicate experiments.
Figure 9: Effect of salt and tannery effluent on proline content of certain halophytes. Values shown are mean ±SD for five replicate experiments.
Figure 10: Effect of salt and tannery effluent on glycinebetaine content of certain halophytes.

Values shown are mean ±SD for five replicate experiments.
Figure 11: Effect of salt and tannery effluent on catalase activity of certain halophytes. Values shown are mean ±SD for five replicate experiments.
Figure 12: Effect of salt and tannery effluent on peroxidase activity of certain halophytes. Values shown are mean ±SD for five replicate experiments.
Figure 13: Effect of salt and tannery effluent on polyphenoloxidase activity of certain halophytes.

Values shown are mean ±SD for five replicate experiments.
Figure 14: Effect of salt and tannery effluent on sodium content in soil samples of certain halophytes.

Values shown are mean ± SD for five replicate experiments.

Critical difference (p= 0.05) on 125\textsuperscript{th} day salt = 0.53; Effluent= 0.63
Figure 15: Effect of salt and tannery effluent on potassium content in soil samples of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p = 0.05) on 125th day salt = 0.46; Effluent = 0.56
Figure 16: Effect of salt and tannery effluent on chloride content in soil samples of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt= 0.68; Effluent= 0.97
Figure 17: Effect of salt and tannery effluent on calcium content in soil samples of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt = 0.47; Effluent = 0.61
Figure 18: Effect of salt and tannery effluent on magnesium content in soil samples of certain halophytes. Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125\textsuperscript{th} day salt= 0.33; Effluent= 0.79
Figure 19: Effect of salt and tannery effluent on soil sodium absorption ratio of certain halophytes.

Values shown are mean ±SD for five replicate experiments.
Figure 20(a): Effect of salt and tannery effluent on sodium content in leaf of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt= 0.85; Effluent= 0.91
Figure 20(b): Effect of salt and tannery effluent on sodium content in stem of certain halophytes. Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt = 0.75; Effluent = 0.83
Figure 20(c): Effect of salt and tannery effluent on sodium content in root of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt= 0.41; Effluent= 0.47
Figure 21(a): Effect of salt and tannery effluent on potassium content in leaf of certain halophytes.

Values shown are mean ±SD for five replicate experiments.
Figure 21(b): Effect of salt and tannery effluent on potassium content in stem of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt= 0.21; Effluent= 0.29
Figure 21(c): Effect of salt and tannery effluent on potassium content in root of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt= 0.11; Effluent= 0.29
Figure 22(a): Effect of salt and tannery effluent on chloride content in leaf of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p=0.05) on 125th day salt = 0.78; Effluent = 0.81
Figure 22(b): Effect of salt and tannery effluent on chloride content in stem of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt = 0.09; Effluent = 0.18
Figure 22(c): Effect of salt and tannery effluent on chloride content in root of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p = 0.05) on 125\textsuperscript{th} day salt = 0.07; Effluent = 0.13
Figure 23(a): Effect of salt and tannery effluent on calcium content in leaf of certain halophytes. Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt = 0.22; Effluent = 0.29
Figure 23(b): Effect of salt and tannery effluent on calcium content in stem of certain halophytes.

Values shown are mean ±SD for five replicate experiments.
Figure 23(c) 1: Effect of salt and tannery effluent on calcium content in root of *Suaeda maritima* and *Sesuvium portulacastrum*. Values shown are mean ±SD for five replicate experiments.

Critical difference (p = 0.05) on 125\(^{th}\) day salt = 0.040; Effluent = 0.082
Figure 23(c) 2: Effect of salt and tannery effluent on calcium content in root of *Suaeda monoica* and *Ipomoea pes-caprae*. Values shown are mean ±SD for five replicate experiments.

Critical difference (p = 0.05) on 125th day salt = 0.040; Effluent = 0.082
Figure 24(a): Effect of salt and tannery effluent on magnesium content in leaf of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt= 0.03; Effluent= 0.11
Figure 24(b): Effect of salt and tannery effluent on magnesium content in stem of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p = 0.05) on 125th day salt = 0.068; Effluent = 0.081
Figure 24(c): Effect of salt and tannery effluent on magnesium content in root of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p = 0.05) on 125th day salt = 0.10; Effluent = 0.14
Figure 25: Effect of salt and tannery effluent on chromium content in soil samples of certain halophytes.

Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125\textsuperscript{th} day salt= 0.26; Effluent= 0.34
Figure 26: Effect of salt and tannery effluent on cadmium content in soil samples of certain halophytes.

Values shown are mean ±SD for five replicate experiments.
Figure 27: Effect of salt and tannery effluent on copper content in soil samples of certain halophytes.

Values shown are mean ±SD for five replicate experiments.
Figure 28: Effect of salt and tannery effluent on zinc content in soil samples of certain halophytes.

Values shown are mean ±SD for five replicate experiments.
Figure 29: Effect of salt and tannery effluent on chromium content in plant samples of certain halophytes. Values shown are mean ±SD for five replicate experiments.
Figure 30: Effect of salt and tannery effluent on cadmium content in plant samples of certain halophytes. Values shown are mean ±SD for five replicate experiments.
Figure 31: Effect of salt and tannery effluent on copper content in plant samples of certain halophytes. Values shown are mean ±SD for five replicate experiments.

Critical difference ($p = 0.05$) on 125th day salt = 0.082; Effluent = 0.22
Figure 32: Effect of salt and tannery effluent on zinc content in plant samples of certain halophytes.

Values shown are mean ±SD for five replicate experiments.
Figure 33: Effect of salt and tannery effluent on soil EC of certain halophytes. Values shown are mean ±SD for five replicate experiments.

Critical difference (p = 0.05) on 125th day salt = 0.035; Effluent = 0.042
Figure 34: Effect of salt and tannery effluent on plant EC of certain halophytes. Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt= 0.68; Effluent= 0.78
Figure 35: Effect of salt and tannery effluent on soil pH of certain halophytes. Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt = 0.065; Effluent = 0.22
Figure 36: Effect of salt and tannery effluent on plant pH of certain halophytes. Values shown are mean ±SD for five replicate experiments.

Critical difference (p= 0.05) on 125th day salt= 0.22; Effluent= 0.49
Figure 37: Effect of salt and tannery effluent on accumulation of NaCl by certain halophytes after 125 days of cultivation. Values shown are mean ±SD for five replicate experiments.

Critical difference (p = 0.05) on 125th day salt = 0.49; Effluent = 0.68
Figure 38: Effect of salt and tannery effluent on accumulation of heavy metals by certain halophytes after 125 days of cultivation. Values shown are mean ±SD for five replicate experiments.