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Phytoremediation of Textile Industry Effluent using Aquatic Macrophytes

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Abstract
Present study deals with a laboratory experiment on the usage of Salvinia molesta, Pistia stratiotes and Azolla pinnata in the removal of some heavy metals from ETCO Denim Pvt Ltd, Bijapur Company. It was observed that Pistia stratiotes removed more percentage of Nitrates, Salvinia molesta exhibited maximum percentage reduction for Manganese and Azolla pinnata was able to remove Sulphate from the effluent. The experimental study showed that these plants are suitable for effective removal of heavy metals.

***Keywords**: Heavy metals, Phytoremediation, Aquatic macrophytes*

Introduction

Pollution can be defined in several ways. Water pollution occurs when energy and other materials are released into water. It includes all of the waste materials that cannot be naturally broken down by water. In other words, anything that is added to the water, above and beyond its capacity to break it down, is pollution. In certain circumstances pollution can be caused by nature itself, such as when water flows through soils having high acidity and human actions are responsible for the pollutants that enter the water (Kenneth M. Vigil, 2003).

Textile industry is one of the largest industries in the world and different fibres such as cotton, silk, wool as well as synthetic fibres are all pre-treated, processed, colored and after treatment use large amount of water and a variety of chemicals. The heavy metals are important environmental pollutants and many of them are toxic even at very low concentration. Industrial pollutants, heavy metals, in contrast with organic material cannot be degraded or accumulate in water, soil, bottom sediment and living organisms. In textile industrial effluent, metals are produced during dyeing process, which usually contributes chromium, lead, zinc and copper.

Currently, the textile effluents are treated by physico-chemical methods that are often quite expensive. In addition these methods do not generally degrade the pollutants and cause an accumulation of the dye as sludge creating disposal problem (Robinson *et al*., 1997). Also these methods are extremely costly.

Phytoremediation is a method to remove pollutants from the environment, heavy metals from soil, wastewater and sludge by using plants. Macrophytes are aquatic plants that grow in/or near water and can be classified as emergent, submerged or floating plants. Studies have been done to investigating the capabilities of some macrophytes to remove different concentration of heavy metals, in the role as biomonitors of environmental metal levels (Mishra *et al.,* 2008) and in their ability as biological filters of the aquatic environment.

The objectives of the present study is to investigate the feasibility of using aquatic plants for treating textile industrial effluent and to know the physico chemical characteristics of raw textile industrial effluent before and after being treated with aquatic plants. Also, to know the percentage reduction of physico-chemical characteristics of the textile effluent.

Materials and methods

The methodology adopted for the present study is as follows:

- Sample collection
- Plant acclimatization for Phytoremediation
- Effluent Analysis before and after the introduction of plants
- Comparative assessment for reduction of parameters

Sample collection:

The textile industry effluent was collected from the ETCO Denim Pvt Ltd, Bijapur before it reached the effluent collection tank and the aquatic macrophytes were collected from different water bodies around the University campus. *Pistia stratiotes was collected* from Lakkavalli pond.

Plant acclimatization for Phytoremediation:

The collected plants were acclimatized in the laboratory model in plastic tubs (3 L) containing tap water for about 7 days. The textile industry effluent was dark blue with pungent odour. This aquatic macropohyte was introduced after acclimatization into the different concentrations of the effluent and left for a period of 5 days after which the effluent was analyzed by removing the plants.

Effluent Analysis before and after the introduction of plants:

The Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Hardness (TH), Total Alkalinity (TA) and Chlorides (Cl) were determined by Titrimetric method. Copper (Cu), Manganese (Mn), Iron (Fe), Nitrate (NO_3^-) and Phosphates (SO_4^{2-}) were determined by Spectrophotometric method for textile effluent according to the Standard methods by APHA (2005) and N. Manivasakam (2008).

Statistical analysis involved the application of conventional statistics; mean value and standard deviations to check the precision of analytical results. The percentages were also established between the parameters and heavy metals of the textile effluent and the plants using SPSS 20 software.

Results and Discussion

The physico-chemical analysis of the raw effluent revealed a high concentration BOD, COD, Total alkalinity (TA), Chloride, Iron and Nitrate. The aquatic macropohytes *Salvinia*, *Pistia* and *Azolla* were introduced into the effluent and left for a period of 5 days after which the effluent was analyzed by removing the plants. The analysis revealed that the concentration of the above mentioned parameters has decreased drastically.

Effluent Characteristics: The effluent from textile industry was collected and analyzed for DO, BOD, COD, Total Hardness, Total Alkalinity and Chloride. Results are shown in Tables 1,2,3,4,6,7,8 and 9. Raw textile effluent had alkaline pH as bleaching of fibers adds halogen. High concentration BOD could be explained by the fact that desiring step in textile process contributes 50 % increase of BOD load. Biodegradable organic compounds like synthetic and natural polymers in water bodies cause deficiency of dissolved oxygen and found to have a significant impact on aquatic life (Dos Santos *et al.,* 2006).

The concentration of DO is found to be nil in raw effluent. However, after the introduction of plant the concentration of DO was found to increase in both 50% and 25%. It was also observed that the concentration of DO in *Pistia* was 33.83 mg/l in 25% and 56.9 mg/l in 50% raw effluent. However in the experiment using *Azolla* in 25% of effluent DO was found to be 30.06 mg/l and in 50% of effluent it was found to be 42.86 mg/l. Similarly in the tub containing *Salvinia* DO was found to be 27.16 mg/l in 25% and 41.36 mg/l in 50% of the effluent (Tables 4,9 and Fig 1,3). The concentration of BOD and COD decreased with increase in DO concentration (Mahdi Ahmed *et al*., 2007).

Heavy metal concentration: The overall characterization of the effluent revealed that the concentration of Nitrate and Iron was high in effluent. The concentration of Cu, Mn, Fe, NO_3^- and SO_4^{2-} are shown in Tables 11,12,13,14,16,17,18 and 19. It is almost several times higher than the permitted limits (Yasir *et al.,* 2005). Dyeing and printing processes produce effluent containing toxic organic compounds such as phenols, heavy metals like copper, chromium and also impart highly concentrated color. Heavy metals are considered as the most dangerous elemental pollutants and are of particular concern because of their toxicities to human health (Boran and Altinok, 2010).

Percentage reduction of heavy metals: The removal of different metals by the selected aquatic plants is shown in Table 15 and 20. *Pistia* was found to be the most efficient for the removal of selected heavy metals in both 50% and 25% conc. effluent. The present study is in accordance with the work done by Mishra and Tripathi (2008) while working on *Pistia stratiotes, Spirodela polyrrhiza* and *Eichhornia crassipes*. It was observed that there is less removal of Fe and Mn by *Salvinia* in 50% concentration (Table 15), it is supposed to be the most difficult metal to remove from waste water because macrophytes do not require this for any physiological purposes. This induces oxidative stress and alterations in antioxidant enzyme activities (Sharmin *et al.,* 2012). Many studies revealed that heavy metals are not only retained in the roots but transferred to the shoots and deposited in the leaves, at concentrations 100–1000 fold higher than those found in non-hyper accumulating species (Rascio and Izzo, 2012).

There was 100% reduction in both 25% and 50% concentration of the effluent percentage pertaining to copper. The concentration of copper in effluent was negligible at the beginning and was nil after the treatment including that there was a complete uptake of copper by macrophytes. (Table 15, 20 and Fig 6, 8). Standard deviation and mean was calculated for the precision of results. For, the confirmation of variation of parameters and heavy metal concentration from the average. The following parameters DO, BOD, COD, TH, TA & Chloride are 0±8.56, 315.76±31.88, 318.86±26.03, 5.44±0.90, 170.65±12.02 & 274.32±17.0 in 50% effluent and 0±3.34, 199.6±26.59, 104.16±15.79, 2.81±0.53, 84.02±7.56 & 141.0±8.32 in 25% effluent respectively (Table 4 and 9).

Similarly the variation of heavy metals Cu, Mn, Fe, NO_3^- & SO_4^{2-} are 0.0096±0, 4.46±0.84, 10.75±0.50, 44.32±2.00 & 4.05±0.39 in 50% effluent and 0.0077±0, 3±1.27, 5.90±0.18, 18.73±1.02 & 2.03±0.25 in 25 % effluent respectively (Table 14 and 19). A study has also shown that uptake of metals by plants depends upon the bioavailability of metal in the water phase which is depending upon the retention time of metal (Tangahu *et al*., 2011).

Pistia stratiotes

Pistia was found to reduce the dark blue colour of the effluent to light colour. There was a considerable decline in COD, Total Hardness, Total Alkalinity and Chloride in 25% concentration of the effluent as compared to 50% (Table 4, 9 and Fig 1, 3). *Pistia* showed percentage reduction of the following parameters BOD, COD, TH, TA & Chloride are 13.62, 8.22, 17.06, 77.28 & 47.74 in 25% effluent, and in 50% effluent 40.18, 4.33, 32.24, 77.17 & 53.85 respectively. There was a decreased in concentration of heavy metals Mn, Fe, NO_3^- & SO_4^{2-} are 100, 31.43, 56.64 & 59.83 in 25% effluent, then in 50% effluent 44.02, 14.04, 72.76 & 66.63 respectively (Table 5,10,15,20 and Fig 2,4,6,8). A similar observation has been reported by Egbet Selvin Rose (1998) on *Lemna minor* and Jebansean (1997) on *Eichhornia crassipes.*

Pistia has got the wonderful capacity of removal of heavy metals as well. Again it was observed that the removal was more in 25% concentration than in 50% (Table 14, 19 and Fig 5, 7). Our observations had similarity with the work carried out on heavy metal removal from waste water by water lettuce (Selvapathy, 1997) and phytoremediation on Zn using *Spirodela* (Rolli, 2007).

Azolla pinnata

Azolla was found to be a rather delicate plant and started to decompose, after being introduced into the effluent irrespective of its concentration. There was a slight change in the colour of effluent at the end of the study period. As in *Pistia*, the concentration of the parameters analyzed (BOD, COD, TH, TA and Cl) were found to decrease sharply in 25% effluent concentration as compared to 50% (Table 4,9 and Fig 1,3). Egbert Selwin Rose (1998) has made a similar observation working on *Lemna minor*. *Azolla* showed highest percentage reduction of BOD (40.26% and 59.70%) and Sulphate (84.42% and 85.37%) in both 25% and 50% concentration of the effluent respectively (Table 5,10,15,20 and Fig 2,4,6,8).

Salvinia molesta

Salvinia was observed to be a free-floating aquatic macrophyte, its wide distribution, faster growth rate and close relation with other water ferns, including *Azolla* and *Lemna*, make it a potential for phytoremediation (Banerjee and Sarker, 1997; Wolff *et al*., 2009). Color removal of textile effluent was also observed at the end of the study period. There was a considerable decline in percentage of BOD, COD, TH, TA & Chloride are 27.75, 38.52, 54.14, 60.47 & 56.62 in 25% effluent and 45.46, 2.35, 64.59, 63.61 & 51.28 in 50% effluent respectively.

Similarly there was a reduction in following heavy metals Mn, Fe, NO_3^- & SO_4^{2-} are 73.33, 29.00, 50.04 & 75.90 in 25% effluent and 7.46, 5.08, 66.34 & 80.69 in 50% effluent respectively.

Parameters of textile effluent before and after treatment at 50% concentration

Table 1- trail 1

Parameters	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
DO	0.0	40.0	56.0	42.0
BOD	310.0	170.0	188.0	124.0
COD	320.0	312.0	304.0	264.0
TH	4.784	1.400	2.800	2.520
TA	171.36	62.00	38.60	50.00
Chloride	274.71	134.88	127.25	101.80

Table 2- trail 2

Parameters	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
DO	0.0	42.1	58.3	43.5
BOD	317.4	173.1	188.9	128.6
COD	319.1	311.8	307.4	263.5
TH	5.85	2.25	4.25	3.65
TA	170.63	62.74	37.69	50.91
Chloride	273.75	132.58	126.50	100.74

Table 3- trail 3

Parameters	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
DO	0.0	42.0	56.4	43.1
BOD	319.9	173.5	189.7	129.1
COD	317.5	310.3	303.7	262.8
TH	5.69	2.13	4.01	3.25
TA	169.98	61.52	37.80	48.73
Chloride	274.51	133.47	126.00	101.35

Table 4: Average and standard deviation of textile effluent parameters at 50% concentration

Parameters	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)	Stdev
DO	0	41.36667	56.9	42.86667	±8.568048
BOD	315.7667	172.2	188.8667	127.2333	±31.88118
COD	318.8667	311.3667	305.0333	263.4333	±26.03934
TH	5.441333	1.926667	3.686667	3.14	±0.900798
TA	170.6567	62.08667	38.03	49.88	±12.02878
Chloride	274.3233	133.6433	126.5833	101.2967	±17.00764

Table 5: Percentage reduction of textile effluent parameters in 50% concentration

Parameters	Salvinia (%)	Pistia (%)	Azolla (%)
DO	_	_	_
BOD	45.466	40.187	59.706
COD	2.352	4.338	17.384
TH	64.592	32.246	49.293
TA	63.618	77.175	70.771
Chloride	51.282	53.856	63.073

DO- Dissolved oxygen, BOD- Biological Oxygen Demand, COD- Chemical Oxygen Demand, TH- Total Hardness, TA- Total Alkalinity, STDEV- Standard Deviation.

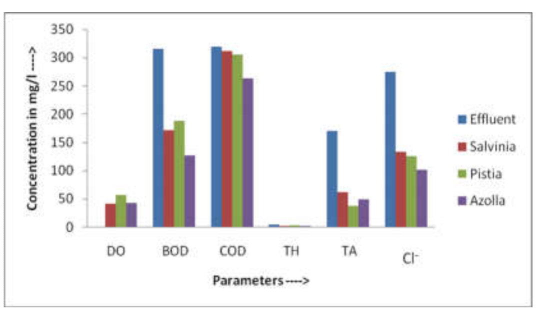

Fig 1. Average of textile effluent parameters in 50% concentration.

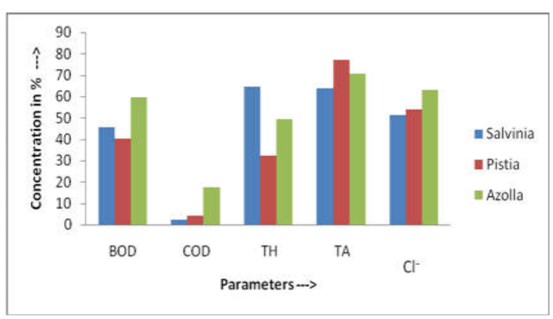

Fig 2. Percentage reduction of textile effluent parameters in 50% concentration.

Parameters of textile effluent before and after treatment at 25% concentration

Table 6- trail 1

Parameters	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
DO	0.0	26.0	30.0	28.0
BOD	200.0	148.0	196.0	152.0
COD	104.0	64.0	96.0	80.0
TH	1.88	1.32	1.80	1.52
TA	84.26	33.0	19.6	30.0
Chloride	141.16	61.08	76.35	63.62

Table 7- trail 2

Parameters	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
DO	0.0	28.4	36.3	30.5
BOD	199.1	142.1	160.3	102.5
COD	103.9	63.8	95.7	81.2
TH	3.25	1.50	2.65	1.70
TA	83.63	32.79	18.70	31.41
Chloride	141.16	61.59	76.07	63.11

Table 8- TRAIL 3

Parameters	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
DO	0.0	27.1	35.2	31.7
BOD	199.7	142.5	160.9	103.2
COD	104.6	64.3	95.1	80.8
TH	3.31	1.05	2.55	1.50
TA	84.17	33.84	18.96	31.45
Chloride	140.69	60.82	77.10	63.03

Table 9: Average and standard deviation of textile effluent parameters at 25% concentration

Parameters	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)	Stdev
DO	0	27.16667	33.83333	30.06667	±3.342706
BOD	199.6	144.2	172.4	119.2333	±26.59973
COD	104.1667	64.03333	95.6	80.66667	±15.79096
TH	2.813333	1.29	2.333333	1.573333	±0.539509
TA	84.02	33.21	19.08667	30.95333	±7.587035
Chloride	141.0033	61.16333	76.50667	63.25333	±8.32103

Table 10: Percentage reduction of textile effluent parameters in 25% concentration

Parameters	Salvinia (%)	Pistia (%)	Azolla (%)
DO	_	_	_
BOD	27.755	13.627	40.263
COD	38.528	8.224	22.560
TH	54.146	17.061	44.075
TA	60.473	77.283	63.159
Chloride	56.622	45.741	55.140

DO- Dissolved oxygen, BOD- Biological Oxygen Demand, COD- Chemical Oxygen Demand, TH- Total Hardness, TA- Total Alkalinity, STDEV- Standard Deviation.

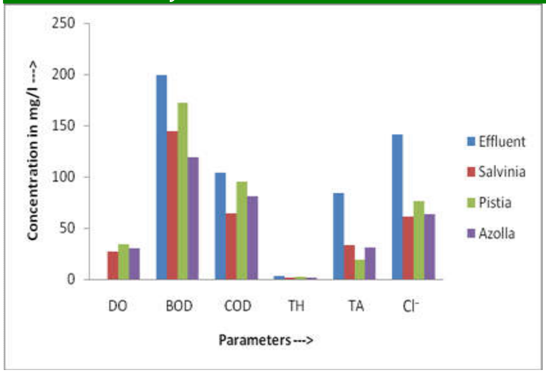

Fig 4. Average of textile effluent parameters at 25% concentration.

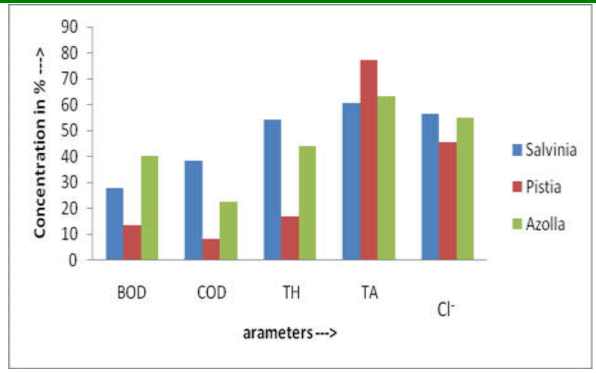

Fig 5. Percentage reduction of textile effluent parameters in 25% concentration

Heavy metals of textile effluent before and after treatment at 50% concentration

Table 11- trail 1

Heavy metals	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
Copper	0.0096	0.0	0.0	0.0
Manganese	4.5	4.3	2.5	3.6
Iron	10.78	10.24	9.44	9.60
Nitrate	46.74	15.10	14.68	20.37
Sulphate	4.00	0.71	1.27	0.54

Table 12- trail 2

Heavy metals	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
Copper	0.0098	0.0	0.0	0.0
Manganese	4.6	4.1	2.7	3.9
Iron	10.81	10.43	9.37	9.50
Nitrate	43.52	14.76	13.28	18.99
Sulphate	4.10	0.85	1.47	0.69

Table 13- trail 3

Heavy metals	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
Copper	0.0096	0.0	0.0	0.0
Manganese	4.3	4.0	2.3	3.5
Iron	10.66	9.94	8.91	9.35
Nitrate	42.70	14.89	8.91	9.35
Sulphate	4.07	0.79	1.32	0.55

Table 14: Average and standard deviation of textile effluent heavy metals at 50% concentration

Heavy metals	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)	Stdev
Copper	0.009667	0	0	0	±0
Manganese	4.466667	4.133333	2.5	3.666667	±0.841295
Iron	10.75	10.20333	9.24	9.483333	±0.500934
Nitrate	44.32	14.91667	12.29	16.23667	±2.009063
Sulphate	4.056667	0.783333	1.353333	0.593333	±0.395517

STDEV- Standard Deviation

Table 15: Percentage reduction of textile effluent heavy metals in 50% concentration

Heavy metals	Salvinia (%)	Pistia (%)	Azolla (%)
Copper	100	100	100
Manganese	7.462	44.029	17.910
Iron	5.085	14.046	11.782
Nitrate	66.343	72.269	63.364
Sulphate	80.690	66.639	85.373

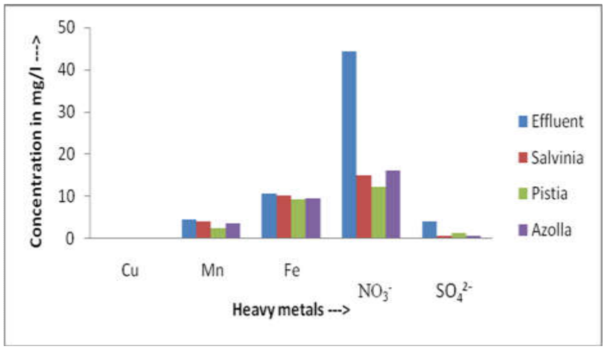

Fig 5. Average of textile effluent heavy metals at 50% concentration

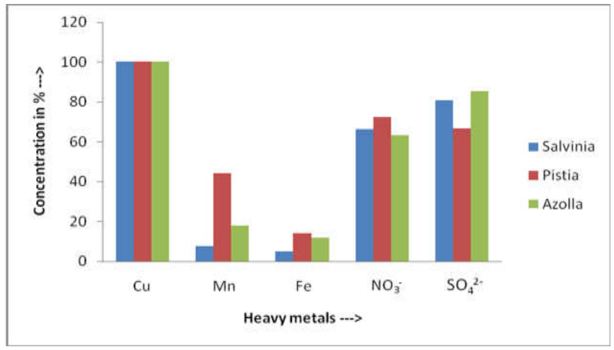

Fig 6. Percentage reduction of textile effluent heavy metals in 50% concentration

Heavy metals of textile effluent before and after treatment at 25% concentration

Table 16- trail 1

Heavy metals	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
Copper	0.0077	0.0	0.0	0.0
Manganese	2.9	0.7	0.0	2.5
Iron	5.93	4.16	4.00	3.84
Nitrate	18.79	9.37	8.15	10.26
Sulphate	2.10	0.49	0.82	0.35

Table 17- trail 2

Heavy metals	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
Copper	0.0078	0.0	0.0	0.0
Manganese	3.0	0.8	0.0	2.7
Iron	5.89	4.10	4.05	3.71
Nitrate	18.65	9.30	8.19	10.03
Sulphate	2.00	0.50	0.80	0.31

Table 18- trail 3

Heavy metals	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)
Copper	0.0077	0.0	0.0	0.0
Manganese	3.1	0.9	0.0	2.3
Iron	5.90	4.32	4.10	3.91
Nitrate	18.772	9.41	8.03	10.17
Sulphate	2.00	0.48	0.83	0.29

Table 19: Average and standard deviation of textile effluent heavy metals at 25% concentration

Heavy metals	Raw effluent (mg/l)	Salvinia (mg/l)	Pistia (mg/l)	Azolla (mg/l)	Stdev
Copper	0.007733	0	0	0	±0
Manganese	3	0.8	0	2.5	±1.276715
Iron	5.906667	4.193333	4.05	3.82	±0.188336
Nitrate	18.73733	9.36	8.123333	10.15333	±1.023035
Sulphate	2.033333	0.49	0.816667	0.316667	±0.253888

STDEV- Standard Deviation

Table 20: Percentage reduction of textile effluent heavy metals in 25% concentration

Heavy metals	Salvinia (%)	Pistia (%)	Azolla (%)
Copper	100	100	100
Manganese	73.333	100	16.666
Iron	29.006	31.433	35.327
Nitrate	50.046	56.646	45.812
Sulphate	75.901	59.836	84.426

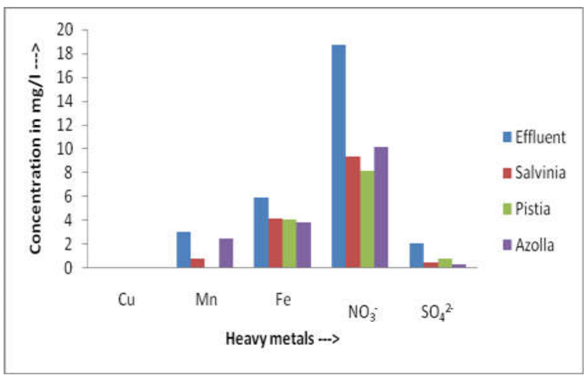

Fig 7. Average of textile effluent heavy metals at 25% concentration

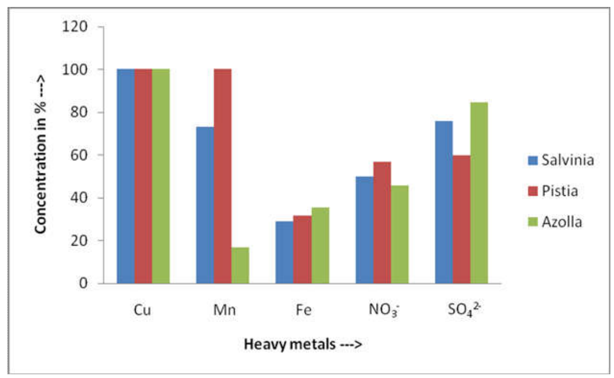

Fig 8. Percentage reduction of textile effluent heavy metals in 25% concentration

Conclusion

The phytoremediation using aquatic plants is very effective and eco-friendly technology in the treatment of industrial effluents. This work revealed that the selected aquatic macrophytes are highly efficient in absorbing most the of pollutants from the effluent thereby reducing the pollution load. The plants are more efficient in removing the pollutants at 25% concentration of the effluent. *Pistia* and *Salvinia* were found to reduce the color of the effluent as compared to *Azolla*. Heavy metals Copper, Manganese, Iron, Nitrate and Phosphates are the major contaminants in the textile effluent. The study explores the fact that textile industries discharged effluent having heavy metal used in various dyeing and printing processes that is toxic to the aquatic life. *Pistia stratiotes*, *Salvinia molesta* and *Azolla pinata* were found to play a comparatively key role in removal of heavy metals. These macrophytes showed different trend in their percentage removal of heavy metals. It was observed that *Pistia stratiotes* removed more percentage of Nitrates, *Salvinia molesta* exhibited maximum percentage reduction for Manganese and *Azolla pinnata* was able to remove Sulphate from the effluent. From the foregoing observations it can be concluded that pyhtoremidiation is an, efficient , cost effective, alternate technology for treatment of recalcitrant industrial wastes. The study proves that Pistia, Azolla and Salvinia which are considerd as unwanted aquatic weeds can be successfully utilized for the degradation of textile industry waste. In order to control secondary pollution, this work can be implemented practically for the treatment of industrial effluents in an eco-friendly way.

Ethics

All the authors read and approved the manuscript and no ethical issues involved.

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