



Original Research Paper

PHYTOSORPTION OF COPPER, ZINC, CADMIUM AND SYNTHETIC AZO DYES BY PONTEDERIA CRASSIPES AND IPOMOEAE AQUATICA: A COMPARATIVE TOLERANCE AND REMOVAL-EFFICIENCY STUDY

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ABSTRACT

Aquatic macrophytes that combine high pollutant tolerance with strong uptake efficiency are central to the practical deployment of phytoremediation, yet co-occurring heavy-metal and dye contamination in industrial effluent is rarely tested on the same species pair under comparable conditions. *Pontederia crassipes* and *Ipomoea aquatica* — the two best-performing macrophytes identified in a companion screening of sugar-mill effluent treatment — were evaluated for phytosorption of copper, zinc and cadmium (0.01–0.50%) over 8 days, and for the synthetic azo dyes Methyl Orange, Methyl Red (0.1%) and, for *P. crassipes* alone, Eriochrome Black T (0.02–0.05%), over 5 days. *P. crassipes* tolerated a substantially broader concentration range for all three metals (Cu up to 0.05%, Zn up to 0.20%, Cd up to 0.50%) than *I. aquatica* (Cu and Zn only to 0.01%, Cd to 0.05%), and achieved higher day-8 sorption at each species' best-tolerated concentration (Cu 71.5% vs 56.6%; Zn 80.7% vs 53.6%; Cd 94.0% vs 59.7%). For the azo dyes, both species removed the majority of Methyl Orange (>90% by day 5) but only moderately removed Methyl Red (26.9–34.6%); *P. crassipes* alone survived Eriochrome Black T exposure, removing 70.0–74.4% by day 5, while *I. aquatica* perished within 24 h at both concentrations. These results identify *P. crassipes* as the more broadly tolerant and efficient phytosorbent of the two species for mixed heavy-metal and azo-dye contamination, attributable to its rapid growth, fibrous root architecture and high biomass, supporting its use as a polishing agent for industrial effluents carrying co-occurring metal and dye loads.

Keywords: phytosorption; heavy metals; azo dyes; *Pontederia crassipes*; *Ipomoea aquatica*; biosorption

1. INTRODUCTION

Heavy metals and synthetic dyes are among the most persistent and toxic co-contaminants of industrial wastewater. Inadequate recycling and disposal practices allow heavy metals to accumulate in the environment, and several are recognized as carcinogenic², while synthetic azo dyes resist conventional biological degradation owing to their complex aromatic structures and are increasingly recognized as priority pollutants in textile and agro-industrial effluent^{1,7}.

Phytoremediation offers a low-cost, low-technology alternative to physico-chemical treatment for both classes of pollutant. Plants sequester heavy metals through root-surface binding, epidermal and vacuolar sequestration and, in some cases, translocation into shoot tissue¹⁷, while biosorption of azo dyes onto root and shoot surfaces depends strongly on dye molecular structure, charge and its resulting affinity for plant functional groups^{1,3,14}. Floating and free-floating aquatic

macrophytes such as *Eichhornia (Pontederia) crassipes* have been repeatedly identified as effective, low-cost biosorbents for both metals and dyes owing to their rapid growth, high biomass and extensive fibrous root systems^{4,5,15}.

However, species vary considerably in the concentration range they can tolerate before phytotoxicity or mortality intervenes, and this tolerance window — rather than intrinsic sorption capacity alone — often determines the practical ceiling of phytoremediation performance^{6,8}. Comparative, same-conditions tolerance and sorption data across candidate species remain limited, particularly for effluents in which metals and dyes co-occur^{16,19}.

In a companion screening study of eight locally occurring aquatic macrophytes tested against sugar-industry effluent, *P. crassipes* and *I. aquatica* emerged as the two most effective species for physico-chemical polishing of the raw effluent. The present study extends that screening to two additional, environmentally relevant contaminant

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classes that frequently co-occur with organic effluent load — heavy metals (copper, zinc, cadmium) and synthetic monoazo/complex azo dyes (Methyl Orange, Methyl Red, Eriochrome Black T) — evaluating both survivability and phytosorption efficiency of these two species under controlled exposure conditions.

2. MATERIALS AND METHODS

2.1 Plant material

Pontederia crassipes and *Ipomoea aquatica* were collected from the banks of the Gosthani River near Korukonda village, Vizianagaram district, Andhra Pradesh, India, and rinsed thoroughly under running tap water to remove adhering soil and debris prior to use. These two species were selected on the basis of their superior performance among eight macrophytes screened for physico-chemical remediation of sugar-mill effluent in a companion study.

2.2 Phytosorption of heavy metals

Phytosorption efficiency was evaluated for copper, zinc and cadmium at five concentrations (0.50, 0.20, 0.05, 0.02 and 0.01%) in 20 L plastic tubs containing 5 L distilled water, with two replicate tubs per concentration. Rinsed plants (~1 kg) were exposed under natural sunlight (≥ 10 h day⁻¹) for 8 days at concentrations permitting survival. Residual metal concentration was determined daily by gravimetric precipitation: 20 mL aliquots were treated with precipitating reagent and copper sulphate solution, and the resulting precipitate was dried and weighed to obtain the final metal weight (W^f), compared against the initial weight (W^i) of a standard metal solution. Percentage sorption was calculated as:

$$\text{Sorption (\%)} = [(W^i - W^f) / W^i] \times 100$$

Table 1. Concentration-dependent survival of *P. crassipes* and *I. aquatica* exposed to Cu, Zn and Cd for 8 days.

Metal	<i>P. crassipes</i> — tolerated conc.	<i>P. crassipes</i> — lethal conc.	<i>I. aquatica</i> — tolerated conc.	<i>I. aquatica</i> — lethal conc.
Copper (Cu)	0.05, 0.02, 0.01%	0.50, 0.20%	0.01%	0.50, 0.20, 0.05, 0.02%
Zinc (Zn)	0.20, 0.05, 0.02, 0.01%	0.50%	0.02, 0.01%	0.50, 0.20, 0.05%
Cadmium (Cd)	0.50, 0.20, 0.05, 0.02, 0.01%	—	0.05, 0.02, 0.01%	0.50, 0.20%

At the highest concentration each species tolerated, both plants showed a steady, near-linear increase in metal sorption from day 1 to day 8 (Fig. 1). *P. crassipes* reached 71.5% Cu (0.01%), 80.7% Zn (0.20%) and

2.3 Phytosorption of synthetic azo dyes

The same two species were assessed for their ability to remove the synthetic monoazo dyes Methyl Orange and Methyl Red (0.1%), and, for *P. crassipes* alone, the complex azo dye Eriochrome Black T (0.05% and 0.02%). Analytical-grade dye stocks were prepared in distilled water and diluted to working concentrations in 20 L containers holding 5 L solution. Plants (~1 kg) were exposed under natural sunlight for 5 days, with periodic monitoring of pH and conductivity. Samples were agitated (120 rpm, 35 °C), centrifuged (3000 × g, 3 min), and residual dye concentrations determined spectrophotometrically at each dye's λ_{max} . Percentage dye removal was calculated as:

$$\text{Sorption (\%)} = [(C^0 - C^t) / C^0] \times 100, \text{ where } C^0 \text{ and } C^t \text{ denote initial and final dye concentrations, respectively}^{28}.$$

2.4 Statistical analysis

All measurements were obtained from replicate treatments and expressed as mean values. Data were compared between species and among concentrations by one-way ANOVA with post-hoc tests, with significance set at $p < 0.05$.

3. RESULTS

3.1 Heavy-metal tolerance and sorption

Survival trials with Cu, Zn and Cd (0.01–0.50%) showed *P. crassipes* to be markedly more metal-tolerant than *I. aquatica* (Table 1). *P. crassipes* survived Cu up to 0.05%, Zn up to 0.20% and Cd up to 0.50%, whereas *I. aquatica* survived only the lowest concentration tested for Cu and Zn (0.01%) and up to 0.05% for Cd; plants exposed to lethal concentrations died within 24 h, showing dry, wrinkled foliage.

94.0% Cd (0.20%) removal by day 8, compared with 56.6% Cu, 53.6% Zn and 59.7% Cd for *I. aquatica* at its respective best-tolerated concentrations (Table 2).

Table 2. Metal-sorption efficiency (%) of *P. crassipes* and *I. aquatica* from day 1 to day 8, at the highest concentration each species tolerated.

Metal (best-tolerated conc.)	<i>P. crassipes</i> Day 1 (%)	<i>P. crassipes</i> Day 8 (%)	<i>I. aquatica</i> conc.	<i>I. aquatica</i> Day 1 (%)	<i>I. aquatica</i> Day 8 (%)
Copper	17.6 (0.01%)	71.5 (0.01%)	0.01%	15.3	56.6
Zinc	19.7 (0.20%)	80.7 (0.20%)	0.01%	14.3	53.6
Cadmium	15.0 (0.20%)	94.0 (0.20%)	0.01%	12.3	59.7

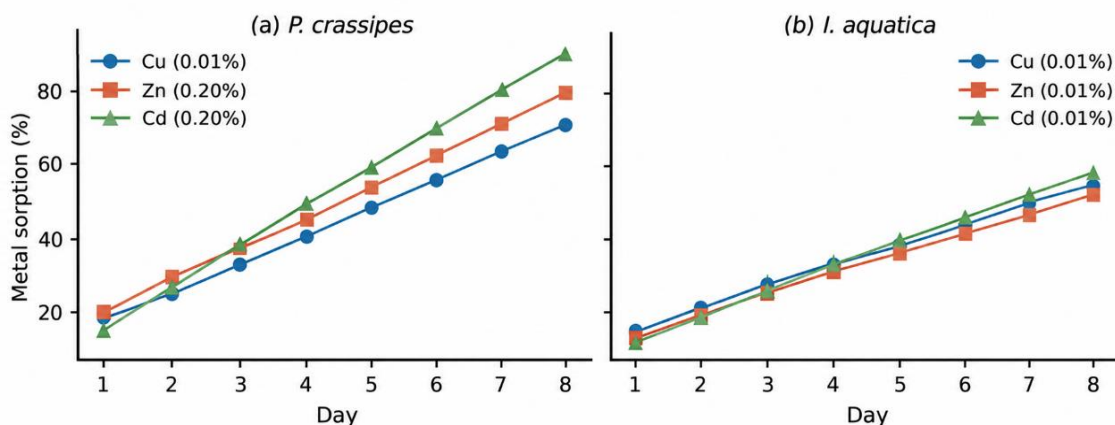


Fig. 1. Time-course sorption (%) of Cu, Zn and Cd by (a) *P. crassipes* and (b) *I. aquatica* over 8 days at the best-tolerated concentration of each metal.

3.2 Removal of synthetic azo dyes

Both species tolerated Methyl Orange and Methyl Red (0.1%) for the full 5-day trial, whereas only *P. crassipes* survived Eriochrome Black T (0.05% and 0.02%) beyond day 1; *I. aquatica* perished within 24 h at both concentrations of this dye. Treatment lowered medium conductivity for every dye–species combination, while pH moved toward neutrality for *P. crassipes* with Methyl Orange but became more acidic for both species with

Methyl Red and for *P. crassipes* with Eriochrome Black T.

By day 5, *P. crassipes* removed 91.8% of Methyl Orange, 34.6% of Methyl Red, 74.4% of Eriochrome Black T (0.05%) and 70.0% of Eriochrome Black T (0.02%); *I. aquatica* removed 90.5% of Methyl Orange and 26.9% of Methyl Red but showed no measurable removal of Eriochrome Black T (Table 3, Fig. 2).

Table 3. Dye-removal efficiency (%) of *P. crassipes* and *I. aquatica* after 1 and 5 days of exposure.

Dye (concentration)	<i>P. crassipes</i> Day 1 (%)	<i>P. crassipes</i> Day 5 (%)	<i>I. aquatica</i> Day 1 (%)	<i>I. aquatica</i> Day 5 (%)
Methyl Orange (0.1%)	50.3	91.8	45.7	90.5
Methyl Red (0.1%)	14.8	34.6	11.0	26.9
Eriochrome Black T (0.05%)	29.6	74.4	— (perished d1)	— (perished d1)
Eriochrome Black T (0.02%)	29.9	70.0	— (perished d1)	— (perished d1)

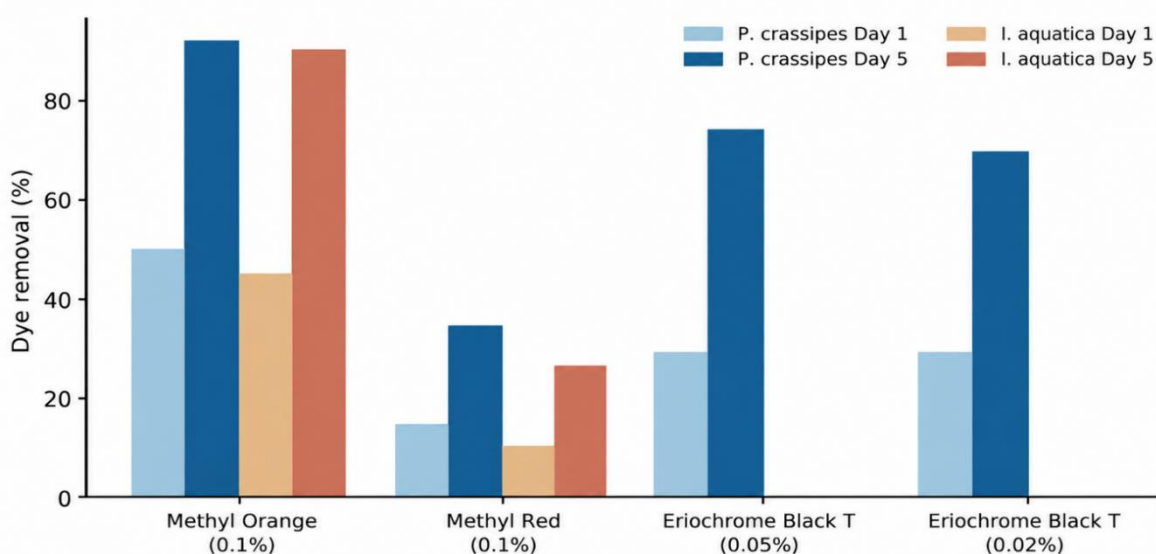


Fig. 2. Removal efficiency of Methyl Orange, Methyl Red and Eriochrome Black T by *P. crassipes* and *I. aquatica* after 1 and 5 days.

4. DISCUSSION

4.1 Heavy-metal tolerance and uptake

The superior Cu, Zn and Cd tolerance and sorption capacity of *P. crassipes* relative to *I. aquatica* is consistent with its recognized status as a hyperaccumulator of copper and other metals, attributed to abundant root-surface binding sites and active translocation of metal ions into shoot tissue⁴⁻⁶. The near-linear rise in sorption from day 1 to day 8 for both species indicates that, within the tolerated concentration range, uptake had not plateaued by the end of the observation period, implying that longer exposure could yield further removal, though eventually limited by saturation of binding sites or the onset of phytotoxicity at higher tissue metal loads⁴. The narrower tolerance window of *I. aquatica* reflects its rooted, terrestrial-aquatic growth habit and more limited capacity for the epidermal and vacuolar metal sequestration on which free-floating species such as *P. crassipes* rely^{7,8}. These patterns broadly parallel metal-accumulation comparisons reported for other wetland and constructed-wetland plant assemblages⁹⁻¹².

4.2 Azo-dye biosorption

Both species removed the majority of Methyl Orange within 5 days, but Methyl Red removal was substantially lower for both, and only *P. crassipes* tolerated and removed Eriochrome Black T. This dye-specific response is consistent with reports that biosorption of azo dyes depends strongly on molecular structure, charge and the resulting affinity for root-surface functional groups^{13,14}, and echoes prior demonstrations of *Eichhornia crassipes* as an effective natural adsorbent for reactive and azo dyes in textile effluent^{15,16}. The inability of *I. aquatica* to survive Eriochrome Black T exposure, in contrast to its tolerance of Methyl Orange and Methyl Red, indicates a dye-specific toxicity threshold rather than a generalized sensitivity, and highlights *P. crassipes* as the more broadly applicable candidate where influent dye composition is mixed or variable¹⁷⁻¹⁹.

4.3 Comparative species performance and mechanistic basis

Taken together, the metal and dye trials point to a consistent mechanistic basis for the superior performance of *P. crassipes*: rapid growth, high biomass production and an extensive fibrous root system that maximizes the surface area available for both metal-ion binding and dye adsorption^{20,21}. This is consistent with the same species' leading performance in the companion physico-chemical screening trial, where growth rate and root architecture — rather than taxonomic grouping — were identified as the principal determinants of remediation efficiency across eight macrophytes.

4.4 Implications for effluent management

These results support *P. crassipes* as the more broadly tolerant and efficient phytosorbent for effluents carrying co-occurring heavy-metal and azo-dye loads, with *I.*

aquatica as a viable secondary option restricted to lower contaminant concentrations. Because *P. crassipes* is a well-documented invasive species, its deployment for metal and dye phytosorption should be confined to contained or engineered systems, with harvested biomass managed to prevent re-release of accumulated metals or dyes into the environment²²⁻²⁷.

4.5 Limitations and future work

Metal and dye trials were conducted over fixed 8-day and 5-day windows respectively, under controlled laboratory conditions with single-species stands and single-contaminant exposures; tissue-level partitioning of metals and dyes between root and shoot was not directly measured. Extrapolation to longer exposure, mixed-contaminant and continuous-flow systems, and quantification of internal versus surface-bound metal and dye fractions, would clarify uptake mechanisms and inform biomass-disposal strategy.

5. CONCLUSION

P. crassipes proved markedly more tolerant of copper, cadmium and zinc than *I. aquatica*, surviving a broader range of concentrations for each metal and achieving higher removal efficiency at its best-tolerated concentration — an advantage attributable to its rapid growth, extensive fibrous root system and high biomass production. The same pattern held for synthetic dyes: both species handled Methyl Orange and Methyl Red reasonably well, but only *P. crassipes* survived and effectively removed Eriochrome Black T, underlining its broader applicability where effluent contains a mixed or variable pollutant load. These findings identify *P. crassipes* as the most effective and versatile phytosorbent of the two species tested, with *I. aquatica* as a strong secondary option restricted to lower contaminant concentrations. Because *P. crassipes* is also a well-known invasive weed, its practical use should rely on controlled cultivation and timely harvesting, with harvested biomass properly managed to prevent accumulated metals or dyes from re-entering the environment.

REFERENCES

1. Ali, H., Khan, E. and Sajad, M.A. 2013. Phytoremediation of heavy metals — concepts and applications. *Chemosphere* 91: 869–881.
2. Ghor, N.H., Ghor, T., Hayat, M.Q., Imadi, S.R., Gul, A., Altay, V. and Ozturk, M. 2019. Heavy metal stress and responses in plants. *International Journal of Environmental Science and Technology* 16: 1807–1828.
3. Ali, S., Abbas, Z., Rizwan, M., Zaheer, I.E., Yavas, I., Unay, A., Abdel-Daim, M.M., Bin-Jumah, M., Hasanuzzaman, M. and Kalderis, D. 2020. Application of floating aquatic plants in phytoremediation of heavy metals polluted water: a review. *Sustainability* 12: 1927.

4. Hasan, S.H., Talat, M. and Rai, S. 2007. Sorption of cadmium and zinc from aqueous solutions by water hyacinth (*Eichhornia crassipes*). *Bioresource Technology* 98: 918–928.
5. Mokhtar, H., Morad, N. and Fizri, F.F.A. 2011. Phytoaccumulation of copper from aqueous solutions using *Eichhornia crassipes* and *Centella asiatica*. *International Journal of Environmental Science and Development* 2: 205–210.
6. Hu, C., Zhang, L., Hamilton, D., Zhou, W., Yang, T. and Zhu, D. 2007. Physiological responses induced by copper bioaccumulation in *Eichhornia crassipes* (Mart.). *Hydrobiologia* 579: 211–218.
7. Dhir, B., Sharmila, P. and Pardha Saradhi, P. 2009. Potential of aquatic macrophytes for removing contaminants from the environment. *Critical Reviews in Environmental Science and Technology* 39: 754–781.
8. Yin Ouyang. 2002. Phytoremediation: modelling plant uptake and contaminant transport in the soil-plant-atmosphere continuum. *Journal of Hydrology* 266: 66–82.
9. Stoltz, E. and Greger, M. 2002. Accumulation properties of As, Cd, Cu, Pb and Zn by four wetland plant species growing on submerged mine tailings. *Environmental and Experimental Botany* 47: 271–280.
10. Mays, P. and Edwards, G. 2001. Comparison of heavy metal accumulation in a natural wetland and constructed wetlands receiving acid mine drainage. *Ecological Engineering* 16: 487–500.
11. Yoon, J., Cao, X., Zhou, Q. and Ma, L.Q. 2006. Accumulation of Pb, Cu and Zn in native plants growing on a contaminated Florida site. *Science of the Total Environment* 368: 456–464.
12. Kumar Maiti, S. and Jaiswal, S. 2007. Bioaccumulation and translocation of metals in the natural vegetation growing on fly ash lagoons. *Environmental Monitoring and Assessment* 116: 263–273.
13. Vengata Mohan, S., Chandrasekhar Rao, N. and Karthikeyan, J. 2002. Adsorptive removal of direct azo dye from aqueous phase onto coal-based sorbents: a kinetic and mechanistic study. *Journal of Hazardous Materials* 90: 189–204.
14. Malik, A. 2007. Environmental challenge vis-a-vis opportunity: the case of water hyacinth. *Environment International* 33: 122–138.
15. Xia, H. and Ma, X. 2006. Phytoremediation of ethion by water hyacinth (*Eichhornia crassipes*) from water. *Bioresource Technology* 97: 1050–1054.
16. Pramanik, S.K., Abdullah-Al-Shoeb, M., Ibn Sina, A.A., Uddin, M.J., Datta, S. and Uddin, M.A. 2011. Natural adsorbents for dye effluent of high strength COD and their microbiological analysis. *Chemistry Journal* 1: 29–35.
17. Govindwar, S.P. and Kagalkar, A.N. 2010. *Phytoremediation Technologies for the Removal of Textile Dyes: An Overview and Future Prospectus*. Nova Science Publishers, New York.
18. Ekambaram, S.P., Perumal, S.S., Rajendran, D., Samivel, D. and Khan, M.N. 2018. New approach of dye removal in textile effluent: a cost-effective management for cleanup of toxic dyes by water hyacinth. In: *Toxicity and Biodegradation Testing* (E. Bidoia and R. Montagnolli, Eds.), pp. 241–267, Humana Press, New York.
19. Muthusamy, S., Govindaraj, D. and Rajendran, K. 2018. Phytoremediation of textile dye effluents. In: *Bioremediation: Applications for Environmental Protection and Management* (S. Varjani et al., Eds.), pp. 359–373, Springer, Singapore.
20. Rane, N.R., Patil, S.M., Chandanshive, V.V., Kadam, S.K., Khandare, R.V., Jadhav, J.P. and Govindwar, S.P. 2016. *Ipomoea hederifolia* rooted soil bed and *Ipomoea aquatica* rhizofiltration coupled phytoreactors for efficient treatment of textile wastewater. *Water Research* 96: 1–11.
21. Muneer, B., Shakoori, F.R., Rehman, A. and Shakoori, A.R. 2007. Chromium resistant yeast with multi-metal resistance isolated from industrial effluents and their possible use in microbial consortium for bioremediation of wastewater. *Pakistan Journal of Zoology* 39: 289–297.
22. Pratas, J., Paulo, C., Favas, P.J. and Venkatachalam, P. 2014. Potential of aquatic plants for phytofiltration of uranium-contaminated waters in laboratory conditions. *Ecological Engineering* 69: 170–176.
23. Vijayaraghavan, K. and Balasubramanian, R. 2015. Is biosorption suitable for decontamination of metal-bearing wastewaters? A critical review on the state-of-the-art of biosorption processes and future directions. *Journal of Environmental Management* 160: 283–296.
24. Salt, D.E., Blaylock, M., Kumar, P.B.A.N., Dushenkov, V., Ensley, B.D., Chet, I. and Raskin, I. 1995. Phytoremediation: a novel strategy for the removal of toxic metals from the environment using plants. *Bio/Technology* 13: 468–474.
25. Sharma, S., Singh, B. and Manchanda, V.K. 2015. Phytoremediation: role of terrestrial plants and aquatic macrophytes in the remediation of radionuclides and heavy metal contaminated soil and water. *Environmental Science and Pollution*

Research 22: 946–962.

26. Guittonny-Philippe, A., Masotti, V., Höhener, P., Boudenne, J.-L., Viglione, J. and Laffont-Schwob, I. 2014. Constructed wetlands to reduce metal pollution from industrial catchments in aquatic Mediterranean ecosystems. *Environment International* 64: 1–16.
27. Wickramasinghe, S. and Jayawardana, C.K. 2018. Potential of aquatic macrophytes *Eichhornia crassipes*, *Pistia stratiotes* and *Salvinia molesta* in phytoremediation of textile wastewater. *Journal of Water Security* 4: 1–8.
28. Trivedy, R.K. and Goel, P.K. 1987. *Chemical and Biological Methods for Water Pollution Studies*. Environmental Publications, Karad, India.