Novel properties of *Epipremnum aureum* for treatment of fluoride-contaminated water

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Abstract

Groundwater is the primary source of drinking water, and high concentrations of fluoride in it may cause skin diseases, crippling of bones and brain damage. Three plants have been considered, namely money plant, water hyacinth and duckweed for removal of fluoride from water without supplying any nutrients to these plants. It is found that water hyacinth and duckweed died in fluorided and highly alkaline groundwater (pH $\approx$ 9) within 10 days. However, consistent growth is observed in the money plant (*Epipremnum aureum*). Preliminary results of this study demonstrate that money plant can remove both fluoride and the total dissolved solids from contaminated water and can survive for more than 2 months without nutrients. Furthermore, water physicochemical analysis shows that money plant can accumulate dissolved heavy metals and anionic contaminants such as chloride and sulfate. Unlike other plants, the money plant can adapt to temperate, tropic and subtropic climatic conditions, and therefore, it may be a potential candidate for the cost-effective, green and sustainable fluoride treatment for fluoride-contaminated water.

Keywords Phytoremediation · Fluoride · *Epipremnum aureum* · TDS

1 Introduction

Fluoride (F^-) contamination is a worldwide problem as it is the very persistent and non-biodegradable pollutant that enters into the water through different natural and anthropogenic sources [1, 2]. Consumption of water with high fluoride concentrations can result in adverse impacts on human health like dental caries, lesions of the thyroid, endocrine glands, brain damage, osteoporosis, bone fluorosis [3]. The permissible limits of fluoride in water are 0.5–1.5 mg/L as per World Health Organization (WHO) standards [4]. The fluoride-rich sources of rocks and their interactions with water for a prolonged time also enhance the fluoride levels in water [5, 6]. Numerous low-cost materials have been used for fluoride removal such as brick powder as adsorbent [7], natural soil [8], MnO_2 -coated tamarind fruit (*Tamarindus indica*) shell [9], apatite materials in aqueous solution [10] and waste mud [11]. Recent

laboratory studies also suggest that hybrid biogeochemical techniques, which combine chemical and biological treatment methods, are very effective in the treatment of fluoride in wastewaters and groundwater [12–14]. There are many districts in Telangana state, India, which are polluted by fluoride, out of which commonly noted district is Nalgonda, and the overall fluoride levels observed were in the range of 0.1–20 mg/L in different studies [15, 16]. Phytoremediation is widely known for removing heavy metals from soil and different sludges [17, 18]. It is defined as the use of plants to remove pollutants from the environment and restore balance [19]. Zhou et al. (2012) have used five submerged plants for fluoride removal from water, and their studies related to F^- ions show an adverse effect on the physiological function of plant and their growth [20–22]. A vast variety of plants were tested to find the best fluoride accumulator such as an *Eichhornia crassipes*, *Spirodela polyrrhiza*, *Hydrilla verticillata*, *Camellia sinensis* (L.)

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O. Kuntze roots of tea plants, *Pistia stratiotes*, *Urtica dioica* L. [23–28]. Here, the activity of *Epipremnum aureum* (money plant) associated with fluoride removal in conjunction with duckweed and water hyacinth has been investigated. *Epipremnum aureum* belongs to family Archaea and is native to southeastern Asia and New Guinea [29]. It is an ornamental plant mostly seen in every household hanging in pots or plastic bottles. It has antimicrobial properties, and it is a potential accumulator of both dissolved heavy metals and air pollutants [30, 31].

The various properties of the money plant have motivated us to consider this plant in the present study, and therefore, an experimental study was carried out to find the potential of *E. aureum* in the defluoridation process. The use of a money plant in defluoridation has not yet been reported anywhere in the literature.

2 Experimental protocols

A laboratory experiment was conducted by using *E. aureum*, with natural fluoride-contaminated water. Three similar glass beakers A, B, and C were filled with 500 ml of field samples in triplicates in which money plant, water hyacinth and duckweed were planted in these beakers, respectively (Fig. 1). Water samples were collected in 1-l polyethylene plastic bottles as per the standard American Public Health Association (APHA) method from Kurmedu village in Nalgonda district, India [32]. In previous studies related to phytoremediation of contaminants, the plants were grown hydroponically by using Hoagland solution [33]. However, an effort has been made to find out the plants, which can survive by utilizing TDS and other minerals present in natural water. To achieve this task, plants

were grown at room temperature without adding nutrients to the water. The initial concentration of fluoride in samples was measured as 3.44 ppm.

2.1 Measurement of physicochemical parameters

The core physicochemical parameters like pH, redox potential (mV), TDS (mg/L), fluoride concentration (mg/L) and conductivity (σ in mS/cm) were measured every fifth day. Five milliliters of a water sample is collected for the measurement of chemical parameters by using a new syringe (Fig. 1). An electrochemical analyzer (Consort C6030, Topaz Inc., USA) kit was used to measure water physicochemical parameters. These parameters were measured by using respective electrodes connected to the analyzer which were cleaned with deionized (DI) water before and after the measurements to avoid contamination.

2.2 Measurement of fluoride concentration

Ion-selective electrode (ISE) is used for the estimation of fluoride concentration in water samples collected from the experiment. ISE is based on the principle that the electrical potential measured by ISE is proportional to the negative logarithm of activity of fluoride [34, 35]. The minimum sample volume of 10 ml is required for the estimation of fluoride concentration by ISE method. Thus, water samples (10 ml) were collected for the estimation of fluoride concentration at regular interval of 5 days. Fluoride (F^-) in the sample was analyzed by adding 10 ml of sample collected and 10 ml of ISA (Ionic strength adjuster) into a beaker.

2.3 Determination of fluoride content in different parts of plant

After completion of the experiment, different parts of the plant are separated and dried for the estimation of fluoride accumulation in the plant. Fluoride concentration was estimated by adopting the methodology described elsewhere [36, 37]. Fluoride concentration in leaf, leaf attachments, stems and roots was determined by extracting the ground and sieved samples with 0.1 N perchloric acid.

2.4 Trace metal and anionic analysis

Trace metals were detected in water using inductively coupled plasma-atomic emission spectroscopy (ICP-AES). ICP-AES analysis was performed on a fresh sample at the beginning and the end of the experiment. Concentrations of major anions are measured using ion chromatography (IC) twice during the entire period of the experiment. Samples (10 ml) were collected and filtered through the filter papers of grade HM1 (11 μ m) for removing suspended

Fig. 1 Experimental setup consisting of three similar beakers A, B and C filled with fluorided groundwater collected from Kurmedu village in Nalgonda district, Telangana (India); money plant, water hyacinth and duckweed are planted in beakers, respectively

particles and then stored in 15-ml glass bottles. Sample bottles were sealed with parafilm and stored in 4 °C temperature in the refrigerator for eliminating the further degradation of the sample. The anionic analysis was carried out by using a sterile syringe or bottle rinsed three times with sample water and then filtered through 0.45 µm (or smaller) filters. The collection vials should likewise be rinsed three times with filtrate before being filled brim/full of the sample filtrate. The minimum volume of sample required for cationic analysis is approximately 5 ml.

2.5 Measurement of evapotranspiration

After sample collection on every fifth day for measurements of chemical parameters and estimation of fluoride concentration, new marks were labeled on the beakers. Any decrease in water level below the new mark is the measure of loss of water via evapotranspiration. Water loss through evapotranspiration (EVT) is compensated by pouring DI water up to the mark on respective measurement days. The water loss by evaporation only reduces the volume of water and does not cause a reduction in dissolved chemical species. Both evaporated water and DI water contain the negligible concentration of chemical species. Thus, the addition of DI water for compensation for loss of water due to evaporation will not affect the chemical properties of contaminated water.

2.6 Plant growth and weight measurements

The wet weight of the plant (WWOP) is estimated every fifth day to get information on the biomass accumulation. Some visual observations are made such as an increase in the length of the plant, growth of leaves and roots. Any growth in plants in alkaline and fluorided water may be an indicator of tolerance of the plant. The growth measurements may provide information about the ability of plant survival in highly alkaline and fluoride-contaminated water without any added nutrients. WWOP is calculated as

$$WWOP = W_T - W_b - W_w \quad (1)$$

where W_T = total weight of the experimental setup up including beaker, plant and water, W_b = weight of the empty beaker, W_w = weight of the water in the beaker (volume of the water multiplied by the density of water).

3 Results and discussion

Duckweed and water hyacinth died within 10 days, and therefore, activities of these plants have not been discussed in this section. These plants may require additional nutrients for their survival. The quality analysis of observed

data is performed by fitting linear and polynomial functions to various observed and calculated parameters. The quality assurance has been determined by computing R^2 (coefficient of determination) and standard error ($SE = \text{standard deviation } (s) / \sqrt{n}$, 's' is a standard deviation and 'n' is a number of observations). Standard error is inversely proportional to square root of total number of observations, and therefore, it decreases with increase in number of observations. An excellent fit between fluoride concentration and time ($R^2 = 0.9912$) has been found, and the standard error in measurements has been represented by error bars ($SE = 0.376$). It is observed that fluoride removal has taken place at a constant rate of 0.021 ppm/day from 3.43 to 2.81 ppm (Fig. 2a). Consistent decrease in F^- concentration up to day 30 signifies that money plant may be a potential fluoride accumulator. The standard errors in Fig. 2b–d have been represented by errors, and SE varies from 0.5 to 0.3. Results thus obtained from total fluoride estimation in different parts of the plant indicate that leaf and leaf attachments contain 52% of total accumulated fluoride, whereas 48% of total accumulated F^- is absorbed by root and stems (Fig. 2b). Anionic analysis of the freshwater sample and the sample collected after the completion of an experiment on day 30 shows a significant decrease in concentrations of F^- , chloride (Cl^-) and sulfate (SO_4^{2-}). However, nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}) and bromide (Br^-) were not present in the water samples (Fig. 2c). Reduction in estimated concentrations of F^- (44.7%), Cl^- (10.89%) and SO_4^{2-} (7.49%) signifies that the money plant could be a potential accumulator of fluoride. The concentrations of dissolved metals in water samples including Ca (55.4%), K (53.5), Cu (40.88%) and Cr (37.18%) have been depleted (Fig. 2d). Significant reduction in the concentrations of Cu and Cr suggests that there is a possibility of removal of heavy metals by money plant. However, iron (Fe) has not been found both in a fresh sample and in the sample analyzed after the completion of the experiment. Variations in pH and Eh of the water samples were measured at a regular interval of 5 days. It has been observed that pH has increased from 7.66 to 9.02 and Eh (mV) from –119 to 39.80 (Fig. 3a). Variations in pH and Eh within 10 days were attributed to the rapid uptake of calcium (Ca) and magnesium (Mg) by the plant, which are conjugate acids of weak bases. Both Ca and Mg form weak bases in aquatic systems as $Ca(OH)_2$ and $Mg(OH)_2$. The hydroxides of calcium ($Ca(OH)_2 \leftrightarrow Ca^{2+} + 2OH^-$) and magnesium ($Mg(OH)_2 \leftrightarrow Mg^{2+} + 2OH^-$) ionized in aqueous system. Accumulation of Ca^{2+} and Mg^{2+} in plant resulted in elevated concentration of hydroxyl ion (OH^-), which was responsible for increase in pH of the water. The temperature could not be maintained in the laboratory during the first week, and after that, it was maintained at $25 \text{ }^\circ\text{C} \pm 1 \text{ }^\circ\text{C}$.

Fig. 2 **a** Fluoride concentration in water decreased linearly within 30 days; **b** accumulation of fluoride in different parts of the plant, **c** maximum decrease in F^- (44.7%) followed Cl^- (10.8%) and SO_4^{2-} (7.5%), **d** concentrations of dissolved metals including Ca (55.4%), K (53.5%), Cu (40.88%) and Cr (22%) were depleted (error bars represent standard error in data)

Fig. 3 **a** pH and Eh are stabilized after 1 week from the start of the experiment. **b** TDS decreases linearly with time, whereas σ decreases nonlinearly in time. **c** R was stabilized within 10 days as

the uniform temperature was maintained in laboratory. **d** Inverse linear relationships of WWOP with variations in concentrations of F^- and TDS

A linear fit with $R^2 = 0.9294$ showed a linear relation between fluoride concentrations and time, and estimated $SE = 0.564$ has been represented by error bars (Fig. 3b). A polynomial of degree 4 ($\sigma = 1E-05 \text{ day}^4 - 0.0008 \text{ day}^3 + 0.0176 \text{ day}^2 - 0.1587 \text{ day} + 1.9647$) has been fitted between conductivity and time. A high value of R^2 (0.9628) and low SE (0.371) show the excellent fit and good quality of data (Fig. 2b). The SE is defined as an estimate of how far the

sample mean is likely to be from the population (data) mean. The SE (0.371) indicates that the sample mean is within ± 0.742 ($= 2 \times SE$) of the population mean. Therefore, it indicates that the quality of the measured data is excellent. It has been found that TDS was used by money plant as the nutrients for its growth, which has been indirectly well supported by the decrease in TDS from 1049 to 672 mg/L and reduction in conductivity from 1.974 to

1.336 mS/cm (Fig. 3b). The decrease in fluoride concentration, conductivity and TDS shows that money plant is beneficial for the treatment of both fluoride and TDS. Thus, the money plant is very useful in improving water quality without any additional cost except the disposal cost of the used plants. Money plant can be propagated by branch cutting, stem cutting and tip cutting, which requires very little care.

An excellent linear relationship was obtained by fitting a line between WWOP and time ($WWOP = 0.523 \text{ day} + 50.758$, $R^2 = 0.982$), and it has been shown in Fig. 3c. Estimated SE (0.374) is very low, and it signifies the good quality of data. The plot of WWOP against time shows a steady increase in WWOP, and it signifies an increase in biomass (Fig. 3c). The evapotranspiration rate (EVT) per day is calculated by dividing the total water loss (ml) between two consecutive measurements by time interval (day). A polynomial of degree 4 has been fitted with observed EVT and time ($EVT = -2E-05 \text{ day}^4 + 0.0013 \text{ day}^3 - 0.0306 \text{ day}^2 + 0.2971 \text{ day} + 0.0227$, $R^2 = 0.9524$), and SE has been estimated as low as 0.370 (Fig. 3c). EVT initially increases rapidly due to poor control of room temperature and sudden change in climatic temperature. EVT was stabilized after the tenth day of the experiment (Fig. 3c).

The growth of the plant has been observed visually, and photographs were taken every 10 days. The presence of new leaves and branch supports the growth of *E. aureum* in the presence of high TDS. WWOP is measured at regular intervals by using Eq. 1. To understand the relationship between growth in biomass, TDS and F^- , a linear fit between WWOP and decrease in F^- concentration ($F^- = -0.0398WWOP + 5.4393$, $R^2 = 0.9708$) and linear fit between WWOP and TDS ($TDS = -0.0224WWOP + 2.1539$, $R^2 = 0.9126$) have been obtained (Fig. 3d). Standard errors in TDS (0.39) and fluoride (0.40) are shown by error bars in Fig. 3d. It is found that both TDS and F^- concentration in water have an inverse linear relationship with WWOP. WWOP is measured at regular intervals by using Eq. 1. WWOP increases with a decrease in concentrations of TDS and fluoride in the water samples that indicates that plant may be utilizing dissolved minerals and solids as the nutrients (Fig. 3d). Reduction in concentrations of anions and metals confirms the capability of the money plant as a TDS accumulator, which is well supported by TDS measurements (Fig. 3b). Additionally, it has been observed that there were no dead biomass and precipitates. Therefore, there was no possibility of occurrence of chemical precipitation of fluoride.

Disposal of plants after phytoremediation may be performed through composting, pyrolysis, gasification, or combustion of plants [38]. However, phytomining, a process of extraction of accumulated fluoride from the used plant, could be helpful in safe disposal of the plants and

reusing the extracted fluoride [39]. An appropriate scheme for disposal of used plants needs to be considered before implementing remediation of fluoridated water and estimating the cost-effectiveness of the proposed method.

4 Summary and conclusions

Preliminary results demonstrate the money plant could be a cost-effective and sustainable tool for defluoridation of water. In this study, unlike phytoremediation studies reported in the literature, no chemicals or costly growth media were used for growing plants. Results obtained from water physicochemical analysis confirm that money plant can be used as an accumulator of trace metals and other anionic contaminants such as chloride and sulfate. More than 50% of fluoride is accumulated in leaf and leaf attachments of the plant. Thus, disposal of leaf and leaf attachments needs utmost care to avoid induction of fluoride in any natural or engineered systems. This study indicates that defluoridation of water using a money plant is almost free of cost except for the cost of disposal of used plants and eco-friendly. The proposed technique is straightforward to use, and it does not need any specific technical knowledge. It has been recommended that phytoremediation of fluoride using money plant might be useful in defluoridation of water and removal of trace metals. Furthermore, depleted concentrations of Cr (37.18%) and Cu (40.88%) in water samples indicate the possibility phytoextraction of dissolved heavy metals by the *E. aureum*, and it needs to be investigated in future studies. Nevertheless, this experimental study can be a breakthrough in phytoremediation research for defluoridation of water.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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