Heavy Metal Removal through Phytoremediation and GIS Techniques

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Abstract

One of the major crises faced in recent times is the concentration of heavy metals in the water used for agricultural purposes. In Bengaluru Rural areas, the source of water for irrigation is found to contain higher concentrations of heavy metals due to the industrial effluents and domestic sewages being discharged into the rivers in an untreated form. In this research work, This paper deals with a decentralized water treatment, coming out as untreated discharge from the Bengaluru urban areas, which enters Vrishabavathi reservoir. The main objective of the research was to generate thematic maps (drainage and watershed map) using GIS to quantify concentration of heavy metals such as Pb, Cd, Fe and Cr alongside a drainage basin, to identify the optimal location for constructing wetlands using GIS techniques and removal of heavy metals through Phytoremediation. Shape files were created for Vrishabavathi watershed basin using Topography sheets. Digital Elevation Models were used to generate slope map, the points were identified along the river, samples were collected and tested for quantifying the heavy metals. The results were compared with the water quality standards for agricultural purposes. Using the satellite imageries, the wastelands were identified near the outlet of the river basin or the points of accumulation of pollutants. Weeds based on the type of heavy metal to be removed were studied and a prototype was designed to quantify the amount of heavy metal that can be absorbed by the weed over a given period of time. Finally, constructed wetlands were proposed in the identified waste lands.

***Keywords**: Constructed Wetlands, Decentralization, Phytoremediation, Vrishabhavathi, QGIS, Water treatment.*

1.0 Introduction

In today's technologically advanced society, sustainable water treatment methods are essential. Large amounts of wastewater are produced as a

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result of the expanding population, which is untreated and poses a major threat to public health. The best approach would be to treat this water in a scientific way which is also economical. The study of Vrishabhavathi reservoir, one of Bengaluru's heavily polluted regions, aims to provide an improved method to treat it using phytoremediation techniques because it is cost-effective and efficient.

Vrishabhavathi River is perennial due to the contribution of domestic and industrial effluents. It drains Bengaluruurban area and is the outlet for the domestic and industrial wastes of that area. Earlier this river water was mainly used for agricultural and drinking purposes only [1]. Water was collected in the Vrishabhavathi reservoir after secondary treatment in which major heavy metals like Hg, Cr, Cd, Pd, Fe, Ni, Zn, etc. were found to be present [2]. Water from the reservoir is used for irrigation purposes by the farmers of nearby villages, which introduces the heavy metals into the food chain, which calls for their treatment. Research has been conducted on treating heavy metals using Phytoremediation through Constructed Wetlands (CW) [3]. In recent years, there is growing interest in treating municipal and industrial wastewaters through CW as an alternative to conventional treatment technologies. Phytoremediation is one of the cost-effective and simple methods to treat wastewater. Ability of aquatic macrophytes to absorb and retain heavy metals, particularly Hg from wastewater is studied. Some of the transgenic plants can absorb 2 to 3 times more metals than non- genetically engineered species. Many such macrophytes are used to treat the heavy metals in the water bodies. In this study, two macrophytes; Azolla pinnata (water fern) and Pistia stratiotes (water lettuce) were selected by studying the characteristics and environmental factors of macrophytes.

The selected macrophytes were used to check the ability of heavy metal absorption. Azolla pinnata is a free-floating macrophyte having a distinct capacity to absorb various nutrients from water bodies. Previous studies on A. pinnata showed its application in the biological treatment of different types of wastewaters including, composite effluent, coal mine effluent, domestic waste, etc., However, the growth patterns of aquatic plants depend on the availability of nutrients and also the genetic compatibility to toxicants [4]. Pistia stratiotes is another macrophyte used in the study, it floats on the water surface with its roots submerged in the water. This plant can exhibit a high accumulation capacity of heavy metals while it grows in a nutrient-rich medium. Water lettuce is considered to be a potential phytoremediator plant. Another useful weed is Azolla, which helps in aquatic phytoremediation as it has a fast-doubling time and it is easy to harvest [5-6].

2.0 Methodology

The shape files were created for the Vrishabhavathi watershed basin using Topography sheets. Digital Elevation Models were downloaded to generate slope maps and to create the watershed boundary. The sampling points were identified along the river and collected and tested for quantifying the heavy metals. The results were compared with the water quality standards for agricultural purposes. Using the satellite imageries, the wastelands were identified near the outlet of the river basin. Weeds based on the type of heavy metal to be removed were selected. A prototype was designed to quantify the amount of heavy metal that can be absorbed by the weed over a given period. Constructed wetlands were proposed in the identified wastelands. Making use of open-source software like QGIS, the drainage map and watershed map were generated for the Vrishabhavathi river.

3.0 Weeds and Prototype

Weeds were investigated for phytoremediation; growing conditions, weed characteristics, and other requirements for the prototype were examined. Five weeds were chosen from a variety. Table 1 provides a comparison of these weeds. Two weeds, Azolla Pinnata and Pistia stratiotes, were chosen for the experiment after taking the environmental conditions, availability, and other factors into account.

Table 1. Comparison of weeds

Particulars	**Azolla pinnata**	**Eichhornia crassipes**	**Pistia stratiotes**	**Lemna minor**	**Azolla caroliniana**
Common name	Water fern	Water hyacinth	Water lettuce	Duckweed	Fairy moss
Native	Africa, Asia, Australia	India, Nigeria	Pantropical	Africa, Asia, Europe, North America	America
pH for growth	4 to 7	6.5 to 8.5	6.5 to 7.2	6.5 to 8	4.5 to 7
Temp.(K)	293-303	301-303	295-303	279-306	298-303
Metals absorbed	Fe, Hg, Pb, Zn, Cr, Cd	As, Hg, Ni, Pb, Zn, Cu, Ag	Fe, Hg, Pb, Cr, Cd, Zn, Ni	Cr, Pb, Cd, Ni, Cu	Cu, Cr, Pb, Ni
Efficiency (%)	80 to 90	60	75 to 90	80	70

4.0 Prototype

A. Pinnata was collected from University of Agricultural Sciences GKVK, Bengaluru, and Pistia stratiotes were collected from a nearby nursery. Both plants were kept in tubs filled with tap water for 2 days before using it for the experiment. Eight tubs were collected for the experiment, thereby providing different conditions for the growth and comparison of the weeds. Water was collected from the Vrishabhavathi reservoir, near Bidadi, Karnataka, to analyse the concentration of heavy metals and to reduce the same. The concentration of heavy metals was within the standard limits for irrigation and agricultural purposes. Hence, to check the ability of the macrophytes to reduce the concentration of heavy metals in the water, heavy metals were introduced manually into distilled water.

Three different concentrations of the heavy metal solution were introduced in 6 different tubs for both the plants and two separate tubs were used for water collected from the reservoir. Four litres of water were used in all the tubs for phytoremediation. The tubs were filled with soil of thickness of one to two inches to provide nutrients for the plants to grow well. The plants were washed in tap water followed by distilled water to remove pollutants before implanting them inside the tubs.

After 21 days, the water was given for testing. It was evident from the results that there was a decrease in metal concentration in all the samples. The higher efficiency of the weeds is seen in the tubs with high concentration, except for iron. The efficiency of the weeds decreased with an increase in the concentration of iron. From the results, we can say, that the concentration of metals has gradually decreased in the tubs with Azolla pinnata. On the other hand, there is a fluctuation in the decrease of heavy metal concentration in the tubs with Pistia stratiotes. Though the environmental conditions required for both the weeds are almost the same, other characteristics like absorption rate, availability, disposal, etc are also essential. By comparing the results of both the weeds, it can be said that Azolla pinnata has better efficiency compared to Pistia stratiotes under different metal concentrations. The availability of Azolla pinnata is easier and it is cost effective compared to Pistia stratiotes. Disposal of Azolla pinnata after the phytoremediation is easier than Pistia stratiotes. It was observed that Pistia stratiotes has more efficiency in wastewater compared to Azolla pinnata.

Three different concentrations of the heavy metal solution were introduced in six different tubs for both the plants, Fig.1 and the plants were kept for 21 days in partial sunlight.

Fig. 1. The prototype

The phytoremediation ability of different weeds was studied in detail. A comparison was made between five weeds and out of them two weeds which were best suited for our conditions was selected. Azolla pinnata and Pistia stratiotes were studied in detail and prototype was prepared to test the heavy metal absorption capacity of these weeds. Prototype involved three tubs of different metal concentration solutions and a tub of water collected from Vrishabhavathi reservoir for each weed.

Wetlands are significant landscape elements that offer a wide range of useful functions to both people and animals. Many of these activities, or operations, include managing surface water flow during dry spells, preserving and increasing water quality, and storing floodwaters. The distinctive natural qualities of wetlands lead to these beneficial functions. It plays an important role in maintaining the ecology of the watersheds. The project's ultimate goal is to offer the best location for the construction of artificial wetlands so they can clean the water that accumulates in the Vrishabavathi reservoir from diverse sources.

5.0 Thematic Maps

The watershed map, Drainage map and the Land Use Land Cover (LULC) are the thematic maps considered in this study. Watershed map is obtained from watershed atlas as shown in the Fig. 2. Drainage map as shown in the Fig. 3 is prepared from the Digital Elevation Model through automation method in QGIS open-source software and validated using Google earth Pro. LULC is a map that provides information about an area and it helps the users understand the current landscape. The term "land cover" describes the material that covers the surface of the ground, such as vegetation, urban infrastructure, water, bare soil, etc. Land cover identification creates the baseline data for tasks like thematic mapping and change detection analyses. The term "land use" describes the function that a piece of land performs, such as agriculture, wildlife habitat, or recreation. The planning, management, and monitoring of programs at the local, regional, and national levels heavily rely on LULC maps. LULC helps to identify the wastelands near the Vrsihabhavathi region which are required to propose constructed wetland to carry out phytoremediation. Among the various types of wastelands are deteriorated woods, overgrazed pastures, pastures affected by drought, eroded valleys, mountainous slopes, wet marshy regions, and arid terrain, among others. There are two different kinds of wastelands: culturable wastelands and unculturable wastelands. The development of wastelands causes the ecological balance to deteriorate by adversely affecting the many ecosystem components that are directly or indirectly dependent on that specific area.

Fig.2. Watershed Map

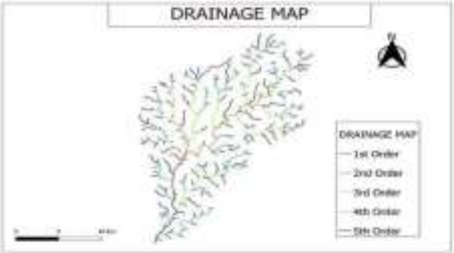

Fig.3. Drainage Map

5.1 LULC map of the Vrishabhavathi watershed region

To find an optimal location for proposing constructed wetland it is important to identify wastelands in the Vrishabhavathi watershed region. Conducive to it LULC was obtained from the Bhuvan website using the thematic services. Land use land cover map of the entire Karnataka region having 50k resolution was imported as Web Map Service (WMS) layer in QGIS with the help of the URL provided. Using the watershed map of the Vrishabhavathi reservoir that was generated before, the LULC map was generated for the Vrishabhavathi watershed region. The steps to obtain LULC are depicted in Fig.4 and the map generated is shown in Fig.5.

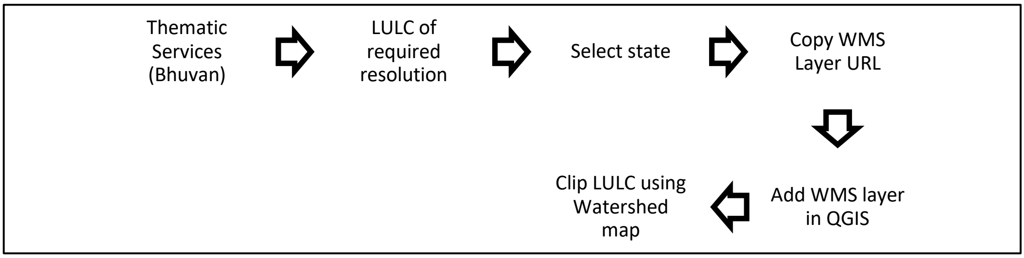

Fig. 4. Steps to obtain LULC of the Vrishabhavathi watershed region

Fig. 5. LULC map of Vrishabhavathi watershed region**.**

5.2 Waste Land Identification

By analysing the LULC obtained, barren/uncultivable lands near the points of sample collection were identified. Four wastelands, which were near the sample points were selected and made into polygons and were named with id 1,2,3,4. The areas of each wasteland and their distance from the points of sample collection were measured using the QGIS platform. Wasteland with ID 4 had the highest a area of 80271.475 square meters. The hub distance tool was used to measure the nearest wasteland distance from each sampling point. Fig.6 shows the wastelands along with their area and distances from the sampling points.

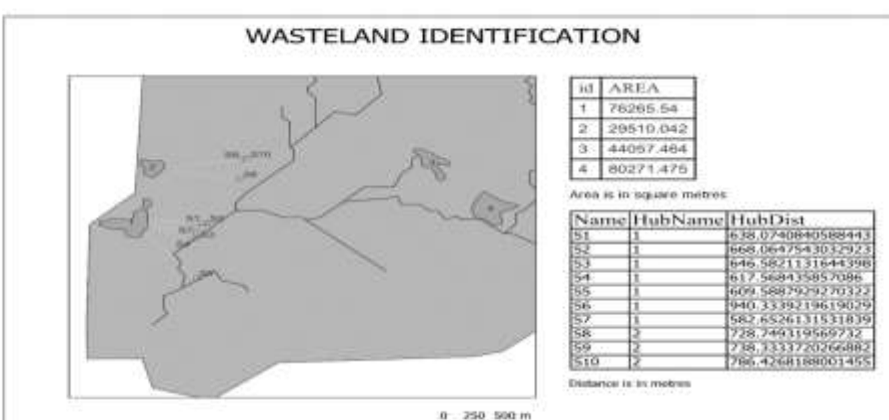

Fig. 6. Wasteland Identification

The availability of wastelands identified was verified using google Maps provided by quick map services in the QGIS platform. Fig.6 shows all the four wastelands along with the sampling points. The wasteland with id 1 is near an engineering institute, and constructing a wetland over there to treat wastewater may hinder the ambiance of the institute and discomfit the students with bad odour.

Wasteland with id 2 has a smaller area than all the identified wastelands and thus may not be an optimal selection to treat large quantity wastewater. Wasteland with id 3 is situated close to a residential colony and may affect the health of people on constructing a wetland over there. Thus, it can be concluded that wasteland with id 4 would be the best choice to construct wetland as it is an isolated region and has the added advantage of a large area as shown in Fig. 7. However further quantitative and qualitative analysis needs to be done before constructing a wetland to treat wastewater using phytoremediation techniques.

6.0 Results and Discussion

Heavy metal concentration in wastewater and metal solutions prepared is obtained after treatment by Azolla pinnata and Pistia stratiotes and is shown in Table 2.

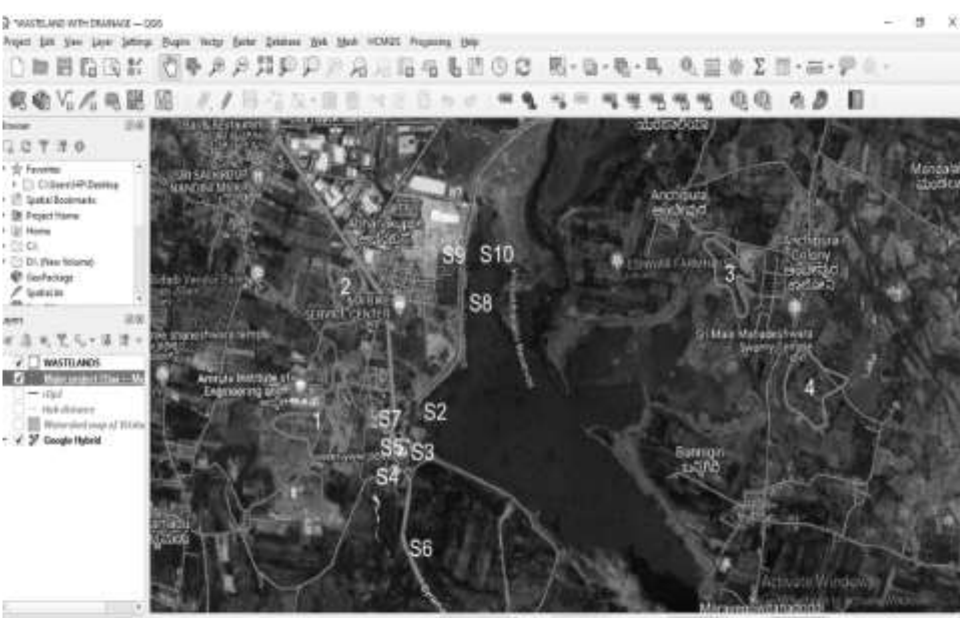

Fig. 7. Optimal wasteland identification

Table 2. Test results of water samples after treatment

Samples	Metal conc (in ppm) Before treatment	Metal concentration (in ppm) After treatment			
		Cd	Cr	Fe	Pb
Azolla Tub1	0.1(Cd,Cr) 0.5 (Fe,Pb)	0.039	0.038	0.188	0.244
Azolla Tub2	0.15 (Cd,Cr)1(Fe,Pb)	0.035	0.055	0.571	0.362
Azolla Tub3	0.2(Cd,Cr) 1.5 (Fe,Pb)	0.038	0.065	1.162	0.260
Azolla Wastewater	0.042 (Cd), Not Detected(Cr),1.38(Fe),0.82(Pb)	0.035	Not Detected	0.031	0.442
PistiaTub1	0.1(Cd,Cr) 0.5 (Fe,Pb)	0.031	0.092	0.005	0.375
PistiaTub2	0.15 (Cd,Cr)1(Fe,Pb)	0.038	0.123	0.008	0.420
PistiaTub3	0.2(Cd,Cr) 1.5 (Fe,Pb)	0.035	0.037	0.024	0.392
Pistia Wastewater	0.042 (Cd), Not Detected(Cr),1.38(Fe),0.82(Pb)	0.034	Not Detected	0.007	0.439

As shown in Table 2, the concentration of the heavy metals Cd, Cr, Fe, and Pb decreased significantly as compared to the initial metal concentration before treatment. Cr was below detectable levels in the wastewater sample. The percentage reduction of heavy metal concentration and the efficiency of the weeds are shown in Table 3.

Table 3. Percentage reduction of heavy metals in different water samples

Samples	Cd	Cr	Fe	Pb
AzollaTub1	61%	62%	62.4%	51.2%
AzollaTub2	76.6%	63.3%	42.9%	63.8%
AzollaTub3	81%	67.5%	22.5%	82.67%
Azolla waste water	16.6%	ND	97.75%	46%
PistiaTub1	69%	8%	99%	25%
PistiaTub2	74.67%	18%	99.2%	58%
PistiaTub3	82.5%	81.5%	98.4%	73.8%
Pistia Waste water	19%	ND	99.49%	46.46%

It can be observed from the graphs plotted that the efficiency of removal of Fe decreased with an increase in the concentration of heavy metals in the water treated with Azolla pinnata, whereas in the case of water treated with Pistia stratiotes the efficiency of removal of Fe fluctuated with an increase in concentration. The efficiency of weeds in the removal of heavy metals from wastewater is shown in Fig.8. It can be observed that the efficiency of absorption of Fe by weeds is higher than the rest of the heavy metals.

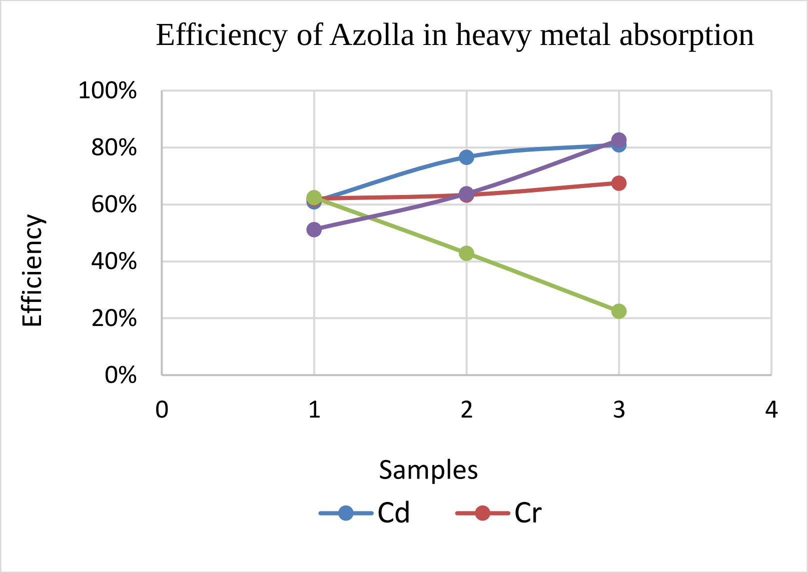

Fig. 8. Efficiency of Azolla in heavy metal absorption

7.0 Conclusion

The thematic maps (drainage map and watershed map) were generated for the Vrishabhavathi reservoir. The catchment area was found and the points of sample collection were marked on the thematic maps.Water samples were collected and tested for heavy metal concentration. The effectiveness of the weeds in heavy metal concentrations was evaluated in the water samples. The results revealed that Pistia stratiotes and Azolla pinnata were effective in removing the heavy metal concentration in wastewater and metal solutions of different concentrations, respectively. One of the main observations was that when the concentration of the metal solutions was increased, iron absorption efficiency decreased.The heavy metals Cd, Cr, Fe, and Pb were effectively treated utilizing the phytoremediation method using A. Pinnata and Pistia stratiotes. The wastelands near the LULC were located on a map. To determine the ideal place for constructing wetlands to treat Vrishabhavathi reservoir water using phytoremediation techniques, the wastelands close to the Vrishabhavathi reservoir were located using the LULC map that was obtained. After carefully evaluating all of the alternatives, the wasteland with ID 4 having an area of 80271.475 sq. m was proposed as an optimal location for the construction of wetlands.

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