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Economic Efficiency and Effectiveness of Salix acmophylla in Reducing Wastewater Characteristics : A Case study in Varzaneh Wastewater Treatment Plant, Isfahan, Iran.

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ABSTRACT

Introduction: Phytoremediation is a sustainable, cost-effective, and environmentally friendly process that utilizes plants and microorganisms for purification of the polluted land. In this study, the fast-growing species *Salix acmophylla* from the Salicaceae family was selected for phytoremediation purposes.

Materials and methods: With the aim of exploring the potential of *Salix acmophylla* in wastewater purification, a research initiative was launched in 2020, Following initial land preparation on a 5-hectare site next to a wastewater treatment plant, 60,000 *Salix acmophylla* cuttings were planted. By 2022, the trees had matured to a height of 3-4 meters. Wastewater samples were then collected and analyzed for pollutant levels both before entering the planted area and after passing through drainage channels built among the trees. This allowed researchers to calculate the average efficiency of *Salix acmophylla* in reducing wastewater pollutants.

Results: The results regarding the impact of *Salix acmophylla* trees on the reduction of wastewater Characteristics in the cultivation area were the following: COD, BOD5, TSS, TDS, EC, and turbidity exhibited reductions of 38%, 42%, 17.5%, 79%, 52.2%, and 45.6%, respectively. Additionally, the estimated income from the cultivation of these trees was approximately $49,000.

Conclusion: Planting *Salix acmophylla* trees significantly contributes to the reduction of wastewater pollutant parameters, suggesting the recommendation of this species for similar climates.

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Introduction

The rapid growth of the human population and industrial development has significant implications for the environment and human health [1, 2]. Water

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pollution is a critical environmental issue caused by the continuous release of organic and mineral pollutants into natural water sources [3, 4]. The continuous discharge of pollutants into natural water sources can have detrimental effects on aquatic ecosystems, posing a threat to natural habitats and human health. As a result, proper wastewater treatment is essential before discharging it into the environment. While conventional wastewater treatment methods can significantly reduce pollutants, they often leave behind residual traces in the treated water [5]. The detrimental impact of pollutants on human health and aquatic life necessitates the exploration of innovative wastewater treatment solutions [6, 7].

Various methods of conventional treatment are utilized to remove organic and mineral pollutants, including ion exchange, adsorption, reverse osmosis, chemical precipitation, electrochemical treatment, and others [5]. However, these treatment methods face serious challenges, including high energy requirements, carbon emissions, excessive sludge disposal, and high maintenance costs. To ensure sustainable water management and maintain aquatic ecosystem health, it's crucial to adopt environmentally friendly and cost-effective techniques. These methods can protect our water resources while minimizing negative impacts on the environment [7].

Recent studies have highlighted the potential of plants for removing mineral and organic pollutants. Phyto-purification, a branch of phytoremediation, utilizes plants for wastewater treatment. The root system has the capacity to absorb nutrients from wastewater. Certain plant species used for phytoremediation exhibit the capacity to accumulate various pollutants [8, 9]. Although Cheney introduced the use of plants in phytoremediation in 1983, the history of employing this method dates back approximately 300 years [10]. In recent years, this method has garnered significant attention due to its minimal environmental impact, lack of need for specialized personnel and expensive equipment, low costs, recyclable plant products, on-site applicability, and scalability[11].

Studies suggest that various plant species, including agricultural, pasture, and tree species, can absorb different pollutants from their growing environment [12]. In contrast, tree species possess unique characteristics that make them suitable for pollutant absorption. For example, tree species produce substantial biomass, are not sources of food for quadrupeds compared to agricultural and pasture species, and have a developed root system for pollutant absorption from the soil. Furthermore, their high transpiration and evaporation rates facilitate the movement of pollutants from the tree to aerial parts [10].

So far, studies using trees have been used for biomonitoring of heavy metals. One of these studies was in the northwest of Iran and around Lake Urmia. This study demonstrates that *Populus alba* from Salicaceae family is suitable for biomonitoring of heavy metals. [13].

Among tree species, those belonging to the *Salicaceae* family, such as pines and willows, are not only favored for their rapid growth and high biomass production, but also for their deep and extensive root systems and high water absorption capacity [14]. Moreover, their resistance and the ability to form multiple modified clonal colonies make them ideal choices for phytoremediation [15].

Phytoremediation is an economical and eco-friendly technology that utilizes live plants directly to purify soil and water pollution; on the other hand, yellow poplar is adaptable in arid climates, which has demonstrated its effectiveness in phytoremediation studies.

The wastewater treatment plant in the city of Varzaneh is designed for a population of slightly more than ten thousand people. Currently, it is active with maximum capacity for more than fifteen thousand people; however, the ponds of the treatment plant are not efficiently addressing the requirements. Therefore, in this study, the effectiveness of *Salix acmophylla* was investigated for the treatment of wastewater effluent Characteristics.

Materials and Methods

Study area

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The city of Varzaneh, located in Isfahan province, is the central city of Varzaneh County. It is near the Gavkhouni Wetland and is traversed by Zayandehrud River, which ultimately flows into the international Gavkhouni Wetland, approximately 25 kilometers from Varzaneh. According to the general population and housing census conducted in 2016, the population of this city was 17,714 individuals. Around 5 hectares of land in Varzaneh urban wastewater treatment plant area have been cultivated with 60,000 saplings of yellow poplar since March 2020.

The plant used for phytoremediation

The plant choosed for phytoremediation is willow tree, scientifically known as *Salix acmophylla*. They are short to medium-sized tree with branches that are usually reddish. Its branches are often somewhat drooping. The young leaves exhibit a light green color, while the mature leaves have a dark green upper surface and a lower surface adorned with white, round hairs. Additionally, these mature leaves feature small or nearly complete sharp-toothed tips. The leaf tips gradually extend to form a slender, pointed tip. The leaves are 60-160 millimeters long and 7-20 millimeters wide. The tree was chosen due to its compatibility with the region's climate and its high efficiency. Additionally, it possesses significant added value. The rapid growth and adaptation to the region's climate, as well as the efficiency of the trees of this family in reducing pollutants in the studies, were the main reasons for choosing the yellow willow in this study[11].

Stages of preparation to harvest

In the first stage, after collecting shrubs and stubbles from the area, the leveling of a 5-hectare land adjacent to the wastewater treatment ponds was carried out using a laser scraper (Figure 1 a). Subsequently, plowing was performed using a plow machine. In the final stage, furrows were created, and 60,000 willow tree cuttings were planted (Figure 1 b). During the growth period, besides weed removal and control of other plants, pruning of the growing willow trees was done (Figure 1 c). After regular flood irrigation, the height of the willow trees reached 3 meters (Figure 1d). At this stage, the economically -viable harvest began (Figure 1e).

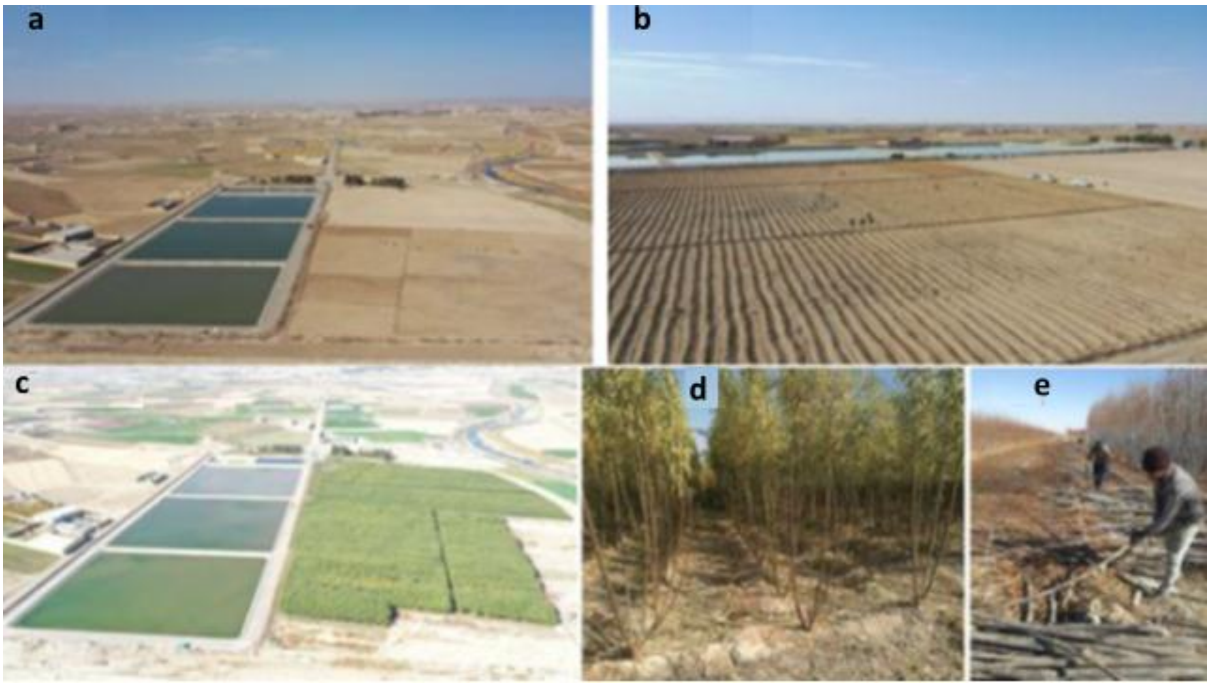

Figure 1. The stages of land a) preparing and leveling b) planting, c) growing, d) harvesting of *Salix acmophylla* or e) yellow willow tree after flood irrigation and reducing the pollutants of urban wastewater effluent in Varzaneh City.

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Sampling method

The planted seedlings were irrigated as needed with treated wastewater. During the summer, irrigation was performed every three days, and during the winter, it was done every 15 days. After two years, when the height of the yellow willow trees reached an average of 3 to 4 meters, in the second stage of the study in 2022, the effluents were measured in the streams before entering the plantation area.

Experiments method

The Chemical Oxygen Demand (COD) of wastewater samples was determined using the Reactor method. This method is based on chemical reactions between the wastewater sample and potassium dichromate solution and measures the consumption of oxygen in water. Biochemical Oxygen Demand for 5 days (BOD5) was measured on wastewater samples using Respirometry method. This method relies on measuring the volume changes of gases produced during the organic decomposition process by microorganisms which determines the amount of biochemical oxygen demand[16].

Total Suspended Solids (TSS) in wastewater samples were measured using Gravimetric method. This method is based on determining the weight of suspended solids in wastewater samples. Total Dissolved Solids (TDS) were measured by Weight Gravimetric method, which involves measuring the weight of the remaining dry mass after evaporating the total wastewater. This method as employed to measure the total amount of dissolved materials in wastewater. Electrical Conductivity (EC) of wastewater samples was measured using Platinum Electrode method. This method is based on measuring the electrical resistance of water to determine the concentration of dissolved substances. Turbidity of wastewater samples was measured using Turbidity Meter equipment or Nephelometer (Hach LT2000,USA). This method was employed to assess the level of cloudiness and light reflection in water. Each of these tests were carried out in compliance with water standards using calibrated and appropriate equipment[16].

In the next step, a trench with a depth of one meter was created between yellow willow trees, where only the water from drainage was collected. One to two hours after irrigation, pollutants in the water resulting from drainage effect were measured in the trench. These measurements were repeated before and after a specific irrigation in three stages. Then, the average of the three stages of measuring effluent pollutants before and after entering the tree plantation area was calculated. To investigate the soil's impact on pollutants' absorption, a portion of the land with all the above conditions, but without tree planting, was used to determine the efficiency of trees in removing pollutants from wastewater.

Results

Efficiency of yellow willow trees in wastewater treatment

The results of the second stage of the study regarding the effect of yellow willow trees on reducing effluent pollutants in the planting area were as the following: COD level decreased from 262 to 62 mg/l with a net efficiency of 38%; BOD5 level decreased from 121 to 20 mg/l with a net removal efficiency of 42%;TSS level decreased from 188 to 63 mg/l liter with a net removal efficiency of 17.5%; TDS level decreased from 1462 to 1086 mg/l with an efficiency of 79%; EC level decreased from 3180 to 1727 micro Siemens per centimeter with an efficiency of 52%; Turbidity decreased from 98 NTU to 13 with an efficiency of 45.6% (Table 1).

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Table 1: Average measured parameters of wastewater after the implementation of the project at Varzaneh city's wastewater treatment plant

Parameter	Unit	Inlet to the treatment plant	Outlet from the treatment plant	Drainage without trees	Drainage with trees	Reduction efficiency with trees (%)	Reduction efficiency without trees (%)	Net efficiency with trees (%)
COD	mg/L	819	262	168	62	74.34	35.87	38.34
BOD5	mg/L	418	121	71	20	83.74	41.32	42.42
TSS	mg/L	342	188	96	63	66.48	48.93	17.55
TDS	mg/L	1242	1462	2180	1086	30.27	49.11	79.38
EC	µS/cm	2520	3180	3390	1727	45.69	6.6	52.29
Turbidity	NTU	232	98.1	58	13.2	86.54	40.87	45.67

These results illustrate the efficiency of yellow willow trees in reducing various pollutants in wastewater at the Varzaneh wastewater treatment plant.

Economic analysis of planting yellow willow trees

All costs, including land leveling, plowing and grading, purchase of yellow willow tree saplings, planting costs, maintenance, pruning, and harvesting were calculated, resulting in a total cost of $2,078. The income from the sale amounted to $50,980. In total, a profit of $48,902 was obtained from planting yellow willow trees (Table 2&3).

Table 2: Costs of tree plantation for reducing wastewater pollutants

Row	Title	Years 2020 to 2022
1	Land leveling, plowing, and drainage cost	In exchange for the disposal of sludge from anaerobic pond
2	Cost of purchasing 60,000 seedlings	$902
3	Planting, maintenance, and pruning cost	$1176
4	Harvesting cost (on the buyer)	Buyer's responsibility
5	Total cost	$2078

Cash generated

Table3: Economic Analysis of Yellow Willow Tree Cultivation

Row	Title	Amount
1	Sales	$50,980
2	Profit	$48,902

Note: The cost values are in dollars.

Discussion

In the present study, the efficiency of willow trees in wastewater treatment was 38.34%, the reduction percentages of COD, BOD_5, TSS, TDS, and EC were 42.42%, 17.55%, 79.38%, and turbidity was, , 52.29%, and 45.67%, respectively. Several factors influence the success of phytoremediation, including the duration of exposure, pollutant levels, environmental conditions like pH and temperature, and the specific plant chosen (species, root system, etc.) [7]. In Iran, few studies, such as the present study, have evaluated the efficiency of phytoremediation in reducing wastewater pollution in the field. Most studies have been conducted in laboratory-scale or used potted plants. Internationally, numerous studies have explored the use of aquatic plants and stemless plants for treating various types of wastewater, but there is limited research on large-scale wastewater treatment using trees, which makes it challenging to compare the results.

For instance, in a study by Rahman et al., municipal wastewater was treated using *Eichhornia crassipes*, resulting in a 49% reduction

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in COD [17]. Patel and Kanunge used *Hydrilla verticillata* to treat domestic wastewater, and found a 15.66% reduction in electrical conductivity, a 15.8% reduction in TSS, and a 36.14% reduction in COD [18]. In another study by Aguiar et al., *Myriophyllum aquaticum* was used for river water treatment, achieving a 75% reduction in BOD and a 39.45% reduction in COD [19].

Studies on the efficiency of willow tree species for wastewater treatment have also been conducted. For example, Wu et al. found that *Salix babylonica* could remove 96% of BOD and 97% of TSS [20]. Jing et al. demonstrated that this tree has the ability to remove 37.6% of COD [21]. Turner and Healey reported a 34 to 44% reduction in fine suspended solids during the use of Floating Treatment Wetland (FTW) for storm water treatment [22].

Research has shown that willow trees, including *Salix babylonica*, have the ability to remediate salt-contaminated soil up to 2000 micromolar of sodium chloride. Therefore, considering the tolerance of these plants in submerged methods and their root filtration capacity, they are recommended for remediating industrial and agricultural pollution. Planting these trees in urban green spaces, coastal and riparian areas, and wetland environments contaminated with chemical and biological pollutants can be considered in operational plans. Additionally, using wastewater from treatment plant ponds for irrigating non-fruit-bearing trees reduces potential reservoirs and vectors of diseases [23-25].

There is a diverse range of plants, including various shrubs, edible, and ornamental plants which can be used as biological absorbers for soil and water purification in both natural and urban environments. To remediate polluted environments, plants employ various mechanisms such as purification, stabilization, transpiration, and extraction. Regardless of the method used, these processes generate significant amounts of biomass which requires proper management. Mass growth of weed biomass can limit and prevent the transfer of pollutants into food chains, serving as a suitable source for renewable energy production [26].

The selecting yellow willow species in the current study, after consulting with experts, included several non-fruiting plant species such as non-fruiting mulberry, pine, lantana, eucalyptus, paulownia, and royal paulownia. These selections were done with regard to the region's climate and compatibility with wastewater. Moreovere, the obtained biomass was not utilized in livestock feed but in various industries, alleviating the concerns related to the accumulation of pollutants [26]. The study results indicated that significant reductions in the levels of various pollutants in municipal wastewater occurred through irrigation using yellow willow's phytoremediation technique.

Soil pollution by excessive chemical substances has raised concerns about the environment. In phytoremediation, the focus is on selecting suitable plant species, using the bacteria resistant to various pollutants, and employing plant growth stimulants to enhance the root system and increase biomass production. Plant biomass absorption increases with rising pollutant concentration, in the condition that it does not exceed the toxicity threshold for the plant [27, 28]. Organic biogeochemical concentrations may have a lower impact compared to the aforementioned substances. Phytoremediation techniques were utilized less in Iran, only conducted experimentally in laboratories. Due to the lack of awareness, this method had never been employed as an effective wastewater treatment process in Iran [29].

Willow is known as one of the most promising agricultural crops with rapid forestry growth and the potential to contribute to sustainable development, increase employment in rural areas[30], provide additional income for farmers, and boost export.[31] Willows are among the bioenergy crops extensively cultivated in Europe. In many European Union countries, the land area dedicated to willow cultivation has increased in recent years based on requests for planting financial support. British government financially supports the establishment of willow farms. Since 2009, establishing willow farms in Latvia and Poland has been an incentivized activity. Sweden has various support mechanisms for farmers and is currently a

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pioneer in establishing willow farms [32]. In this study, all the costs until the harvest amounted to 2078 dollars, and the income from sales reached 50980 dollars, resulting in a total profit of 48902 dollars from yellow willow tree cultivation. Few quantitative studies have focused on the economic analysis of willow tree cultivation. According to Daugaviete et al.'s study, the costs of planting willow trees per hectare included excessive growth removal (300 euros per hectare), herbicide (24 euros per hectare), fertilizer (173 euros per hectare), plowing (55 euros per hectare), herbicide transportation (18 euros per hectare), herbicide spraying (23 euros per hectare), plowing (40 euros per hectare), planting (33 euros per hectare), fertilizer transport (18 euros per hectare), and fertilizer spreading (19 euros per hectare), totalling 701 euros per hectare. Considering that 13,000 willow saplings were planted per hectare, the total planting cost per hectare was 1060 euros [33]. As evident from this study, the cost of planting and maintaining willow trees was lower. The main reasons included non-use of pesticides, elimination of fertilizer and pesticide transportation costs, utilization of wastewater, and community assistance for tree planting. Therefore, based on the economic analysis conducted, planting willow trees was highly cost-effective.

Conclusion

The results of this study indicated a high efficiency of yellow willow trees in purifying pollutants from municipal wastewater, which can be considered as one of the most suitable methods for soil remediation. In fact, with relatively high efficiency, this plant can serve as a crucial ecological tool for reducing or removing pollutants from contaminated soil regarding municipal wastewater. However, the performance and efficiency of this technology require further investigations, taking into account different geographical locations and climatic conditions. Economic management and utilization of wood production from these trees is attracting more and more attention every day. It is suggested that the precise impact of phytoremediation and cultivation soil substrate on pollution reduction be thoroughly examined in future research projects. According to the geographical location of Isfahan province with a large and dense population, wastewater treatment facilities in different parts, and extensive industries in this region, there is growing concern regarding the risks of various chemical and urban pollutants; it is recommended to use the phytoremediation process method to reduce pollutants which is a very effective and low-cost.

Limitations of the study

If measuring heavy metals was among the objectives of this study, the authors could have effectively demonstrated the impact of yellow willow tree on phytoremediation process. It is recommended that yellow willow be used in the biomonitoring of heavy metals in the region. Isfahan province is one of the regions where heavy industries are densely located.

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Conflict of interests

The authors declared no conflict interests.

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Ethical issues

The authors confirmed that the data collected in this study were as presented in the manuscript. They have not or will not be published in the journal or elsewhere.

Authors' contribution

Conceptualization of the article was done by Abdoreza Ahaki Varzaneh; data curation by Abdoreza Ahaki Varzaneh and Zahra Bagheri Varzaneh; formal analysis by Saeid fadaei, Reza Ali Fallahzadeh and Zahra Bagheri Varzaneh; methodology by Rouhullah Dehghani; Abdoreza Ahaki Varzaneh; Saeid fadaei and Reza Ali Fallahzadeh; software analysis by Marzieh Akbari and Somaye Dolatabadi Arani.

Supervision by Saeid fadaei and Rouhullah Dehghani; wrote the–original draft; Rouhullah Dehghani; Abdoreza Ahaki Varzaneh; Saeid fadaei; Reza Ali Fallahzadeh; Marzieh Akbari; Somaye Dolatabadi Arani and Zahra Bagheri Varzaneh. were involved with writing, reviewing, and editing the manuscript.

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