ISSN-1996-918X

Pak. J. Anal. Environ. Chem. Vol. 25, No. 1 (2024) 1 – 12
http://doi.org/10.21743/pjaec/2024.06.01

Constructed Wetlands for Municipal Solid Waste Landfill Leachate treatment with different macrophytes in hot climate regions: a review

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Received 08 July 2023, Revised 12 February 2024, Accepted 28 June 2024

Abstract
Constructed wetlands are an environmentally friendly and cost-effective option for treating leachate. They rely on aquatic plants and microorganisms to efficiently remove contaminants. Temperature plays a crucial role in the performance of wetlands, as it improves overall efficiency. Oxygen accumulation in the wetland, either through photosynthesis or from the atmosphere, is essential for organic matter decomposition and nitrification. The growth of macrophytes, supported by sunlight and temperature, enhances wetland efficiency. Scientific observations confirm that macrophytes' performance depends on biomass production and oxygen fixation in the rhizosphere during the growing season. The reviewed results showed that there is a noticeable trend is that tropical climate areas tend to exhibit higher efficiency in leachate treatment across various parameters such as TSS, COD, BOD, TN, TP, and others.These macrophytes excel in tropical and temperate regions with temperatures above 30°C with the removal percentage above 90%. The review of the literature confirms that wetlands are a low-cost, eco-friendly, and efficient solution for removing various contaminants. Furthermore, the efficiency of wetlands is enhanced by approximately 20-30% in tropical and temperate regions due to higher temperatures.

Keywords: Leachate, Constructed wetland, Contaminant, Eco-friendly, Macrophyte, Efficiency.

Introduction

Treatment of landfill leachate is a hot subject, particularly in the environmental protection industries worldwide. Leachate is a combination of dissolved solids, heavy metals, and colloidal organics that is very contaminated[1]. Although the problem of Municipal Solid Waste (MSW) Landfill Leachate is not a new one, the principles behind its treatment are. In truth, MSW Landfills were originally used or introduced in the USA in the 1800s. -. Until the early 1800s[2], there was no structured system for street cleaning, collecting rubbish, sewage water treatment, or processing human waste.Before being discharged into the environment, landfill leachate, a liquid black or brown substance with numerous contaminants, must undergo thorough treatment. Due to modifications in management techniques in Europe during the past 30 years, the leachate's composition, volume, and treatment have changed [3].

The biogeochemical cycle has been disrupted by anthropogenic activities such as industrialization, urbanisation, and the use of various chemicals in homes and agriculture [4], and eutrophication is the primary reason for the disruption in the ecological system [5]. Even though modern landfills are designed to discharge garbage, they nonetheless produce 20% of the world's anthropogenic methane emissions and a significant amount of leachate emissions.Leachate eventually seeps into the earth and contaminates an aquifer that is exceedingly hard to restore. In addition to these public health problems, landfills frequently attract insects, odors, noise, scavengers, and smoke [6]. The leachate will contaminate groundwater aquifers as it percolates into the ground and will also contaminate rivers and lakes when they flow on the ground, having a detrimental effect on the surrounding ecosystem and human population [7].

One ton of landfill leachate has the same number of contaminants as 100 tons of urban wastewater, and its untreated discharge to the environment will have detrimental effects, especially if it seeps into the ground [8]. Due to their removal results for organic debris, phosphorus, heavy metals, and nitrogen, the CWs have become recognized as an effective approach [9].The removal mechanism of CWs MSW landfill leachate pollutants is shown in Fig.1.

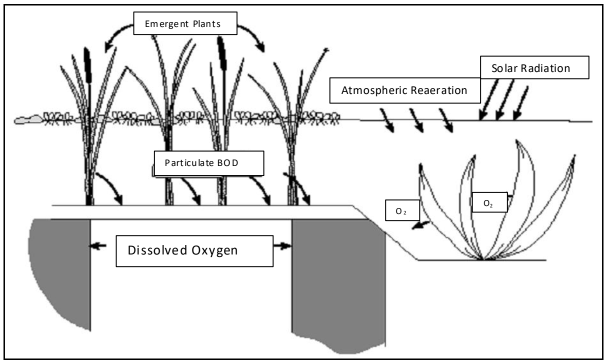

Figure 1. **The removal mechanism of pollutants from MSW landfill leachate through CW [23]**

It is a well-known fact that various wetlands' efficacy at removing pollutants variesfor a variety of reasons [10]. Variables, including the organic loading rate, hydraulic detention time (HRT), and plant species, all have a significant impact on how well contaminants are removed via physical, chemical, and biological processes [11]. Only native plants can survive in arid and semiarid environments, and it is essential that they be tolerant to salt, metals, and drought [12]. The effectiveness of removing organic materials is greatly influenced by temperature [13]. Evapotranspiration, photosynthesis, and microbial activity are all greatly aided by sun radiation and ambient temperature, and biological functions completely cease at 5^{o}C [14]. The elimination of contaminants in CWs does not work well in the arctic climate [11]. Low temperatures, especially below 100 degrees Celsius, cause a significant decrease in nitrification rates in wetlands. It has also been noted by [4] that the cold season does not aid in the removal of nutrients. According to another research by [15], the ideal temperature for microorganism performance is between 33.8 and 36.4^{o}C. It is clear that at temperatures below 33.8–36.4°C, bacteria cannot operate well. Meanwhile, the behavior and effectiveness of wetlands rely on a number of factors, including temperature [16]. It has been noted by [17] that cold temperatures are a bottleneck for microbiological reactions, particularly nitrification, and at Tompkins County, New York, it was also revealed that warm months were potentially effective for the removal of biochemical oxygen demand (BOD) and total acid number (TAN).

It is important to note here that it has valued sub-surface flow (SSF) CWs for their ability to regulate temperature in the winter. According to statistics derived from a comparison of wetland seasonal efficiency [19], mass retention was higher during the warm season by (p 0.05). While the actual percent mass retention of total suspended solids (TSS) and total phosphate (TP) throughout the cold season was 45% and 6%, respectively. BOD and Fecal Coli foam were reduced by 28% and 31%, respectively [20]. It has also been noted that the climate causes a 10% efficiency difference in all parameters, and it is unlikely that the impacts of temperature could be fully corrected. Other methods of removing pollutants include sedimentation, adsorption, filtration, precipitation, volatilization, plant absorption, and other microbiological methods. These methods are greatly influenced by internal and exterior environmental factors, such as temperature [21].

Effect of Macrophytes

Emergent macrophytes sustain aerial reproductive organs and aid in anaerobic sediments. Erect emerging plants include *Typha latifolia* and *Phragmites australis* [22]. As shown in Fig. 2, wetlands that have been planted are guaranteed to have greater microbial densities because plants contribute exudates and oxygen to support microbial development.

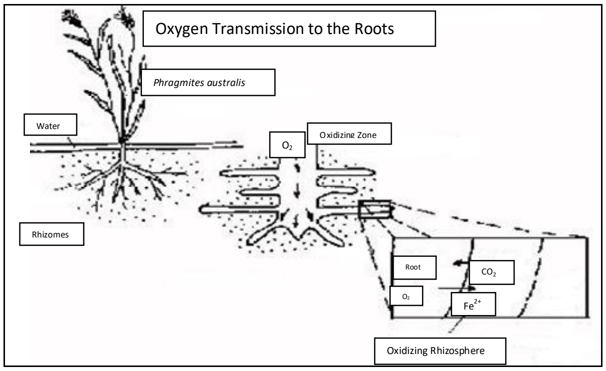

Figure 2. **Oxygen transmission in a plant from leaves to the roots [23].**

As designers of natural ecosystems, macrophytes rely on generating organic matter and releasing oxygen for the transformation and storage of nutrients [25]. A healthy plant's development indicates that further required biogeochemical interactions will occur. The biological reactions used in leachate treatments are mostly dependent on the season, and they are greatly slowed down in the winter. When ice forms in cold regions, hydraulic short circuiting is possible. Cold weather has an impact on how well CWs are removed, especially as temperature has an impact on BOD and nitrogen levels. Any wetland's ability to effectively remove contaminants is influenced by a number of variables, including temperature, plant type, and whether it is planted or unplanted.

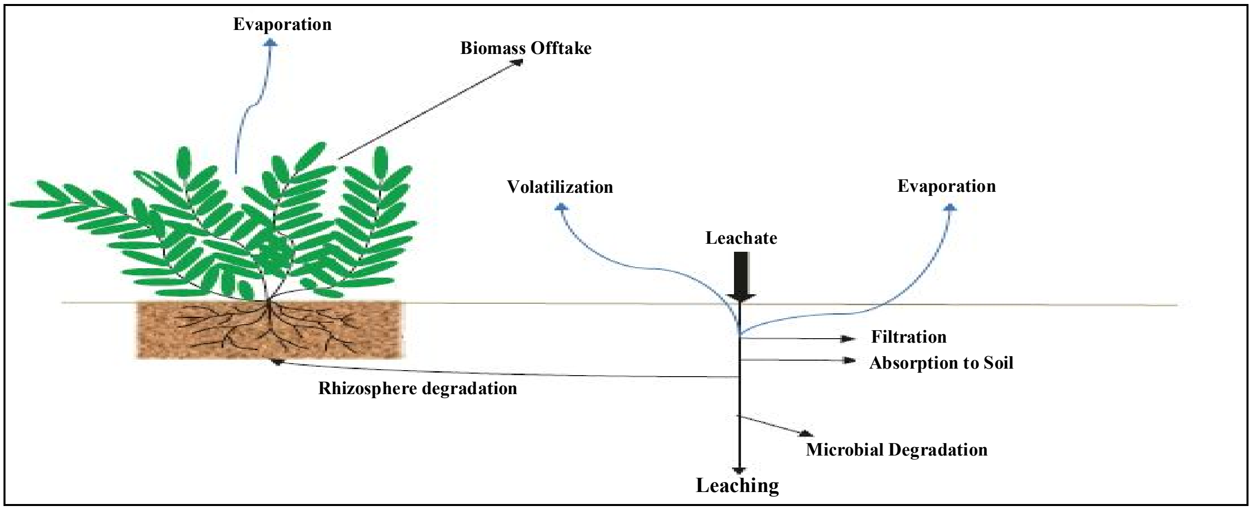

Figure 3. **Landfill leachate and mechanism in CWs[24].**

While the removal of dissolved organic matter (OM) increases throughout the growth season, poor removal efficiency is visible during the cold season due to root zone oxidation status, which is reliant upon redox potential (Eh) and sulphate SO4 [13]. Numerous studies have demonstrated that macrophytes even thrive in moderate climates [23]. While it was noted [26] that *Typha latifolia* spikes vanished in the winter and *Phragmites australis* thrived in the summer, making it difficult to get any data in the winter. In this situation, TN and TP are both absorbed by the macrophytes up to 70-84% and 90-92%, respectively, in the summer. Due to the need for TP and TN for growth, plant uptake capacity increases in the summer. It is undeniably true that temperature impacts how well plant function and the functioning of wetlands is at its best in temperate parts of the planet. Warm climates aid in plant development year-round, and microbial activities are linked to it [27]. The higher temperatures aid the increased plant productivity in tropical regions, and the ongoing availability of sunshine exacerbates the breakdown process, which leads to efficient pollution treatment [27]. It has also been demonstrated in several investigations that plants and algae cannot synthesize oxygen through photosynthesis in the absence of sunshine.

The wetlands in temperate or tropical climates have an advantage in producing better outcomes in the elimination of toxins since the cold areas are obviously cloudier and see less sunshine[82]. Nitrogen transformation slows down in cold climates because it depends on oxygen, warmth, and sunshine to decrease phosphorus. The effectiveness of pollutant removal varies significantly between wetlands in tropical and cold climates. A particular water storage facility is needed during winter in places with cold climates, necessitating special architectural considerations. Additionally, an extra freeboard for year-round systems and particular design considerations for input and outflow structures are needed to handle the impacts of extended below-freezing temperatures.

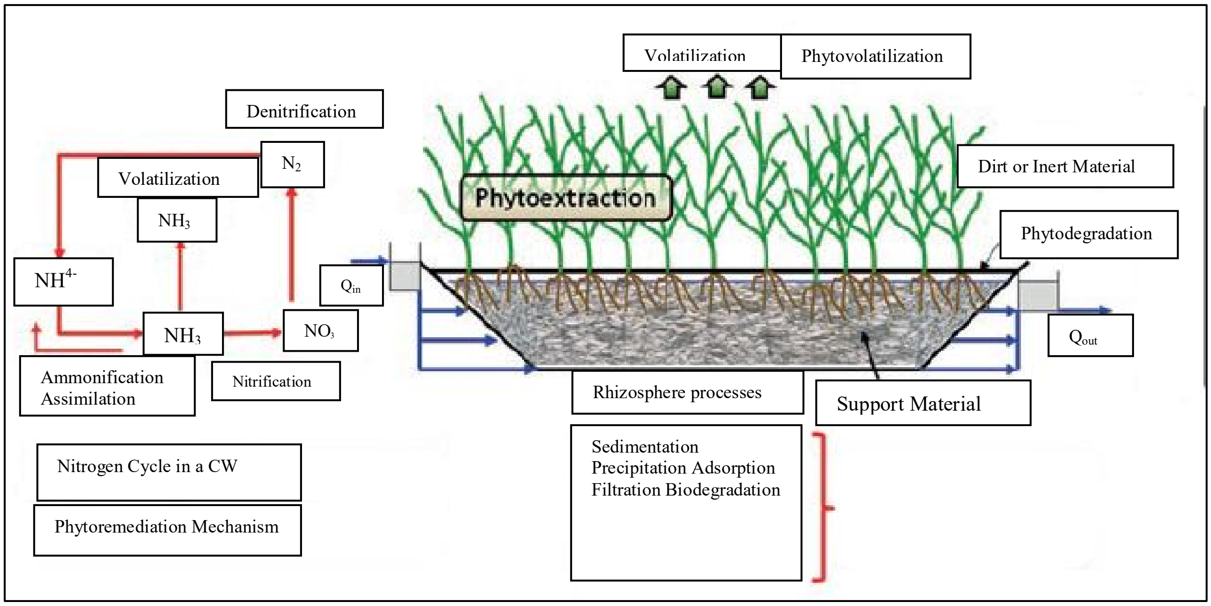

Figure 4. **Nitrogen flow in constructed wetland and phytoremediation [24]**

Assessment of contaminants in cold and tropical climates

Due to poor engineering, highly contaminated leachate from older dump sites seeps into the soiland impacts the subterranean waterways [80]. When combined with food chains, Leachate can also have carcinogenic consequences [7]. Leachate from landfills contains 200 harmful chemicals, on average. These contaminants continue to threaten aquatic life and the food chain, endangering both people and the environment [81].

TSS removal in cold and tropical climates

The filtration, sedimentation, and bacterial breakdown of organic materials are to blame for the drop in total suspended solids [28].Tropical zones have demonstrated high TSS elimination efficiency [29]. There has been a reduced efficiency of about 84.3%. Another finding by[30]show a total TSS removal of 95%–97%, demonstrating the little difference in TSS removal across different climates. While [31] has demonstrated a little decline in HSSF CW efficiency for TSS concentration in cold climates of up to 4%.

TSS removal in cold and tropical climates

The photosynthetic process in plants tends to result in a reduction in BOD and COD. This process raises the amount of dissolved oxygen (DO) in the water, resulting in anaerobic conditions that encourage the growth of aerobic bacteria and lower the need for oxygen [34, 35, 36]. It has been demonstrated in several studies that one factor that affects biological processes is temperature, and that wetlands may function worse in cold climates. Low temperature has an impact on the purifying effectiveness of BOD_5, total, and soluble CBOD [37, 38]. Another study [41] found that for planted wetlands, BOD/COD removal effectiveness decreased by up to 81% at freezing temperatures. On the other hand, warmer summers allow for increased BOD mass removal rates [42]. In tropical locations, the average dry BOD reduction efficiency was 92%, while the average COD removal efficiency was 97.6% [29].

Nitrogen removal in cold and tropical climates

Ammonia removal from built wetlands involves a number of procedures. Volatilization, nitrification (with oxygen present), adsorption, absorption by living things and plants, and anammox (without oxygen) are some of these [41]. Ammonium ions and nitrogen were taken up by plants through their root systems, which resulted in a reduction in ammonia nitrogen [42]. The nitrification-denitrification process is to blame for the drop in ammonia nitrogen amount [42].

The microorganisms' denitrification is the cause of the reduced NO^3-N value [43]. Plants also take up NO^3-N through their root systems.Numerous processes are involved in the process. However, bacterial nitrification and denitrification are the most significant and effective mechanisms[12].The primary cause of the nitrogen loss is due to microbial activity in the root zone, where temperature is a key factor. [12] confirmed that rising temperatures cause a rise in ammonia volatilization. Volatilization rose by 1.3–3.5 times for every 100°C rise in temperature from 0 to 30°C, while denitrification increased by 1.5–2.0 times for every 10°C rise in temperature. Therefore, it is obvious that bacterial multiplication, metabolism, and microbial nitrification are suppressed in high temperature environments as opposed to low temperature environments.

Phosphorous removal in cold and tropical climates

Plants require a large amount of phosphorus when they are growing rapidly in order to increase their biomass. Phosphorus is very necessary to safeguard the metabolic process [44].

In addition to precipitation in the water column, phosphorus is eliminated through bacterial activity, plant absorption, microbial immobilization, aeration of wetland soils, and adsorption by porous media [45, 46]. Phosphorus is liberated from the precipitates throughout the winter owing to the decomposition of litter and microbial biomass, which causes phosphorus to solubilize in water and eventually affectsphosphorous removal [47].Temperature variations have been shown to significantly affect the removal effectiveness of PO and TP, with values of roughly 50.7% and 41.8% at temperatures below 15°C and 79.2% and 70.1% at temperatures above 15°C[48]. The CWs are suitable for tropical climates, and phosphorus removal efficiency increased by up to 21.4% as a result.

Trace element removal in cold and tropical climates

Numerous investigations have shown that the environment significantly affects the effectiveness of removing trace elements [49, 50]. Additionally, it has been noted that various plant species and elemental properties can impact the absorption, accumulation, and transfer of metals in wetlands.[51, 52] discovered that the effects of temperature on *Phragmites australis* removal effectiveness boosted Chromium (Cr) accumulation in July up to (36.96 mg/g DW) and decreased removal efficiency in August and beyond[53].Another aspect was the decreased interaction between sediments and plant roots in the colder months. Due to an increase in root biomass, high metal concentrations have also been seen in plant roots during periods of rising temperatures, from March through September.

Continental Evidence

Although the connection between temperature, phytoremediation, and artificial wetlands has not received much attention, its significance cannot be denied. Several studies have examined the efficiency of CWs in diverse geographical locations and climates. In Montana, USA, research conducted by [54] focused on a subsurface-flow wetland and found that lower temperatures negatively impacted the effectiveness of removing organic materials. Another study in Montana, USA, highlighted by [55], evaluated CW performance throughout the active growth season for plants, raising questions about treatment efficacy during the winter months. Additionally, in Nairobi, Kenya, investigations indicated promising results for CWs in tropical climates, with successful elimination of contaminants demonstrated [56]. These studies evidently proved the importance of considering climatic variations when assessing the performance of CW systems, with implications for their application and effectiveness in different regions. Table 1 presents a comparison of treatment results on a global level, showcasing various plant species and their efficiency in treating different sources of leachate in different countries.

***Table 1.* represents comparison of treatment results on global level.**

Plants	Effluent	Removal %	Country	Reference
Alpiniapurata, Heliconiapsittacorum Arundinabambusifolia	Domestic wastewater	TSS= (34-88) COD= (48-95) BOD = (95)	Brazil	[57, 57]
Canna Indica Linn and Cana Indica.	Domestic and municipal wastewater	BOD= (86-89) COD= (77-82) TP= (>82) and TN= (>85)	China	[58, 59]
Cannaspp. And Iris sp. Zantedeschiaaethiopica.	Sewage	TP= (60),TN= (53) and BOD= (82)	Chile	[60]
Heliconiapsíttacorum.	Domestic	NH3= (57), COD= (70)	Colombia	[61]
Heliconiapsíttacorum.	Synthetic landfill leachate	COD, TKN and NH4= (all: 65-75)	Colombia	[62]
Ludwigiainucta, Zantedechia aetiopica, Hedychiumcoronarium and Canna generalis	Dairy raw manure	BOD=(62), NO3-N= (93), PO4-P= (91), TSS=(84)	CCosta Rica	[63]
Canna sp.	Municipal	TSS=(92), COD= (88), BOD=(90)	Egypt	[64]
Canna indica	Paper mill effluent	9,10,12,13-tetrachlor- ostearic acid= (92) and 9,10-dichlorostearic acid=(96)	India	[65]
Iris pseudacorus	Domestic	TN=(30), TP= (28)	Ireland	[66]
Zantedeschiaaethiopica, Canna Indica	Synthetic	N=(65-67), P= (63-74), Zn and Cu= (98-99),Carbamazepine= (25-51), LAS= (60-72)	Italy	[67]
Canna sp.	Flower farm	BOD=(87),COD=(67), TSS=(90),TN=(61)	Kenya	[68]
Zantedeschiaaethiopoca	Municipal	COD=(35), TN= (45.6)	Mexico	[69]
Canna latifolia	Municipal	TSS=(97), COD= (97), BOD=(89), TP=(>30)	Nepal	[70]
Canna indica mixed with other plants	Tannery	COD=(41-73), BOD=(41-58)	Portugal	[71]
Iris sp.	Domestic	Bacteria=(37)	Spain	[72]
Canna iridiflora	Municipal	BOD= (66), TP= (89), NH4-N= (82),N-NO3= (50)	Sri Lanka	[73]
Canna indica	Domestic	N-NH4=(73),BOD=(11)	Taiwan	[74]
Canna sp.	Domestic	COD=(92), BOD=(93), TSS=(84), NH4-N=(88), TP=(90)	Thailand	[75]
Iris australis	Municipal	NH4-N=(91), NO3-N=(89), TN=(91)	Turkey	[76]
Canna flaccida, Gladiolus sp., Irissp.	Domestic	Baceria=(~50)	USA	[77]
Canna generalis	Fishpond	BOD=(50),COD=(25-5)	Vietnam	[78]
Iris pseudacorus	Herbicide polluted water	Atrazine= (90-100)	United Kingdom	[79]

These results showed that there is a noticeable trend is that tropical climate areas tend to exhibit higher efficiency in leachate treatment across various parameters such as TSS, COD, BOD, TN, TP, and others.

Conclusion

The review contends that wetland performance is influenced by seasonal behavior. Through physical, chemical, and biological processes, plants assist in the remediation of various pollutants, heavy metals, and other contaminants. The health of the plant is a guarantee of the health of the bacterial populations, and vice versa. Promising methods for improving these processes include phytoextraction, phytoremediation, and rhizosphere microorganisms. This review paper clearly examined and demonstrated that the efficiency of the phytoremediation using constructed wetlands for the treatment of landfill leachate is higher in hot climatic regions than to the colder one. Furthermore, it is well-known that these plants thrive during the growth season.Given the scientific information offered by several scientists, it has been clearly determined that temperature significantly impacts the effectiveness of any wetland, whether it be natural or artificial. Therefore, it is possible to promote both natural and artificial wetlands in temperate and tropical climates, where plant development maximizes phytoremediation, phytoextraction, and microbiological activities and eventually shows to be an efficient, cost-effective, and environmentally friendly option today. The effectiveness of wetland technology for contaminant removal in hot climates will be better understood via more study and testing, however, it is also recommended to study phytoremediation using constructed wetlands in the cold region with the amalgamation of the other processes in order to maximize the efficiency.

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