INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

OPEN ACCESS

Received: 06-04-2023

Accepted: 31-05-2023

Published: 19-06-2023

Citation: Gawande SM, Sarode DD (2023) Study of Different Plant Species and their Hardiness Zones for Applications and Utilization in Phytoremediation Processes. Indian Journal of Science and Technology 16(24): 1787-1794. https://doi.org/10.17485/IJST/v16i24.800

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Study of Different Plant Species and their Hardiness Zones for Applications and Utilization in Phytoremediation Processes

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Abstract

Objectives: The purpose of this study is to identify plant species that are effective in phytoremediation based on their ability to withstand various hardiness zones. This study also intends to clarify how to choose plant species appropriate for phytoremediation based on those species' capacity to adapt to various hardiness zones. The end goal of this project is to develop effective phytoremediation strategies that can help to mitigate the negative environmental consequences of wastewater. **Methods:** The USDA Hardiness Zone Map and literature on phytoremediation were used to obtain data from a variety of sources. Data analysis to find plant species that can flourish in various hardiness zones and their potential for application in phytoremediation processes. **Findings:** In various hardiness zones, many plant species, including but not limited to cattails, water hyacinths, and duckweeds, demonstrate extraordinary potential for phytoremediation. Due to their innate ability to absorb and store toxins, these species are able to efficiently remove pollutants from wastewater. **Novelty:** This study offers important information on choosing plant species for phytoremediation depending on how well they adapt to various hardiness zones. The data can be utilized to create efficient phytoremediation strategies that reduce the adverse environmental consequences of wastewater. The current study is significant since it assesses the suitability of several plant species for phytoremediation based on their tolerance of various hardiness zones. To assist reduce the negative environmental consequences of wastewater, efficient phytoremediation solutions can be developed using the data from this study.

Keywords: Hardiness Zone; USDA; Plant Species; Phytoremediation; Plant Inventory

1 Introduction

Phytoremediation is a promising approach to mitigate the adverse environmental effects of wastewater. The process involves using plants to absorb and remove pollutants from contaminated water. It is a cost-effective and environmentally friendly alternative to conventional wastewater treatment methods[1,2]. In recent years, there has been a growing interest in using different plant species in phytoremediation processes[3]. However, the success of these processes depends on the ability of plant species to adapt to different climatic conditions[4]. Several studies have investigated the use of different plant species in phytoremediation processes. However, most of these studies have focused on a specific plant species and its effectiveness in removing pollutants from contaminated water. There is a need for a comprehensive study that evaluates different plant species' suitability for phytoremediation based on their ability to tolerate different hardiness zones, a measure of climate suitability for plants.

The present study aims to fill this research gap by identifying plant species suitable for phytoremediation based on their ability to tolerate different hardiness zones. The study collected data from various sources, including the USDA Hardiness Zone Map and literature on phytoremediation. The collected data were analyzed to identify plant species that can thrive in different hardiness zones and their potential for use in phytoremediation processes.

The findings of this research paper provide valuable insights into the selection of plant species for phytoremediation based on their suitability for different hardiness zones. The information can be used to develop effective phytoremediation strategies to help mitigate wastewater's adverse environmental effects.

Previous studies have identified various plant species for phytoremediation processes. For example, studies have shown that cattails, water hyacinths, and duckweeds have high potential for phytoremediation due to their natural ability to absorb and accumulate contaminants. However, these studies have not evaluated these plant species' suitability for phytoremediation based on their ability to tolerate different hardiness zones. There is a lack of comprehensive studies that evaluate plant species' suitability for phytoremediation based on their ability to tolerate different hardiness zones. This research paper aims to fill this research gap by providing a comprehensive evaluation of different plant species' suitability for phytoremediation based on their ability to tolerate different hardiness zones and contaminants.

1.1 Hardiness zone

A geographic place is considered to be in a hardiness zone if it has a specific average annual minimum temperature, which is important for many plants' survival. In some systems, the computations also take into account additional statistics. 13 zones are identified by long-term average annual extreme low temperatures in the first and most popular system, which was created by the United States Department of Agriculture (USDA) as a general guide for landscaping and gardening[5].

While there is no formal classification for nations other than the United States, the USDA hardiness zone for a region is determined by the minimum temperature in that location. Most of India's tropical and subtropical regions fall within zones 10 to 12, with Delhi NCR falling into zone 10. The different USDA hardiness zones suitable for India as listed below in Table 1.

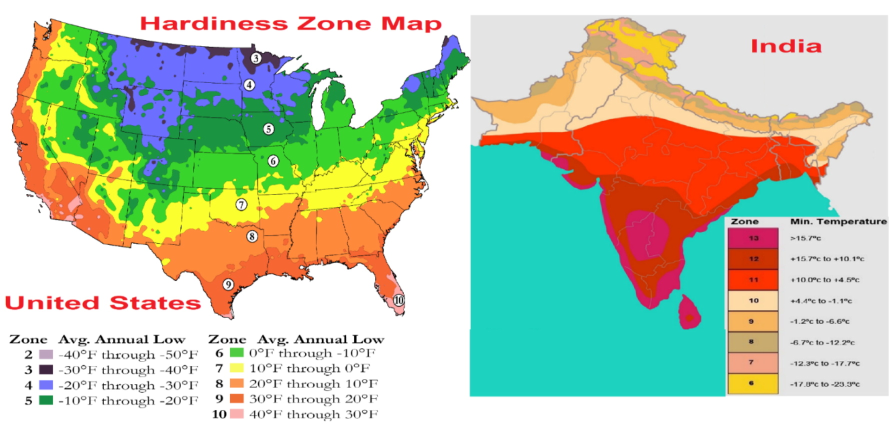

Fig 1. Showing the hardiness zone map for the United States and India. Source- Images are taken from the respective web pages

Table 1. Hardiness zones of India with reference to USDA

Indicators	Hardiness Zone							
	6	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Temperature	-17.8°C to -23.3°C	-12.3°C to -17.7°C	-6.7°C to -12.2°C	-1.2°C to -6.6°C	+4.4°C to -1.1°C	-10.0°C to +4.5°C	+15.7°C to +10.1°C	>15.7°C
Geographical location	**Zone 6**- Ladakh, Himachal Pradesh, Parts of Uttarakhand. **Zone 7**- Jammu & Kashmir, Parts of Himachal Pradesh, Parts of Uttarakhand. **Zone 8**- Jammu & Kashmir, Parts of Uttarakhand, Parts of Assam. **Zone 9**- Rajasthan, Punjab, Parts of J&K, Parts of H.P., Parts of UK, Parts of UP, Sikkim, Arunachal Pradesh, Parts of Nagaland, Manipur, Mizoram. **Zone 10**- Parts of Rajasthan, Haryana, Parts of Punjab, Parts of UK, Parts of UP, Parts of Bihar, Assam, Parts of Mizoram. **Zone 11**- Parts of Rajasthan, Gujarat, Madhya Pradesh, Parts of UP, Parts of Bihar, Parts of Meghalaya, West Bengal, Jharkhand, Odisha, Chhattisgarh, Parts of Maharashtra. **Zone 12**- Parts of Gujarat, Parts of Maharashtra, Parts of Karnataka, Parts of Telangana, Andhra Pradesh, Parts of Odisha, Tamil Nadu, Parts of Kerala. **Zone- 13**- Cost line of Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, and Parts of Odisha, Parts of Maharashtra, Parts of Karnataka, Parts of Telangana.							

1.2 Conditions for effective phytoremediation

The effectiveness of phytoremediation, however, depends on several factors, including the type of contaminant, soil characteristics, plant species, and climatic conditions.

a) Contaminant- The type of contaminant is one of the most critical factors affecting the effectiveness of phytoremediation. Some organic pollutants, such as petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAHs), can be effectively removed or degraded by plant roots, shoots, and associated microorganisms. In contrast, phytoremediation of nutrients such as nitrogen and phosphorus is limited, and other remediation methods may be more effective. Heavy metals, such as lead, arsenic, and cadmium, can also be removed through phytoremediation, as they can be immobilized in plant tissues or transformed into less toxic forms[6,7].

b) Soil- Soil characteristics are also important for successful phytoremediation. High organic matter content, good drainage, and appropriate pH levels can support plant growth, increase microbial activity, and enhance contaminant uptake and metabolism. The soil texture also plays a role in contaminant mobility and bioavailability, as sandy soils with low organic matter content may allow more leaching of contaminants than clay soils[8,9].

c) Plant species- The choice of plant species is crucial for effective phytoremediation. Different plants have varying degrees of tolerance to contaminants, uptake capacity, and ability to metabolize pollutants. Some plant species have been shown to be effective in removing heavy metals, while others are effective in removing organic pollutants. The selection of plant species also depends on the local climatic conditions and hardiness zone, as plants need to be adapted to the temperature, rainfall, and sunlight intensity of the area[10–12].

d) Climatic conditions- Climatic conditions can affect the effectiveness of phytoremediation by influencing plant growth, contaminant uptake, and microbial activity. Cold temperatures and frost can slow down plant metabolism and reduce the effectiveness of the process, while drought conditions can limit plant growth and reduce the uptake of contaminants. Hot and humid conditions, on the other hand, can enhance microbial activity and plant growth, increasing the effectiveness of phytoremediation[13–15].

1.3 Class of Plant species

1. (a) **Accumulator**- Accumulator plants are able to absorb and accumulate significant amounts of a particular substance, such as heavy metals, in their tissues without experiencing negative effects on growth or reproduction. These plants are often used in phytoremediation, which is the use of plants to clean up contaminated soils or water[16]

   (b) **Hyper-accumulator**- **H**yper-accumulator plants are a specific type of accumulator plant that can absorb and accumulate exceptionally high levels of certain substances, often at levels that would be toxic to other plant species. Hyper-accumulator plants are rare, but they have been identified as potential candidates for use in phytoremediation of heavily contaminated sites.

(c) **Tolerant**- Tolerant plants are those that are able to grow and thrive in soils or environments with high levels of a particular substance, such as salt. These plants have adaptations that allow them to tolerate or even use the substance in question, and they can be useful for improving soil quality or preventing soil erosion.

Table 2. List of plant species and their suitability in phytoremediation process with essential agro climatic conditions

Plant species	Suitability	Class	HZ	Agro-climatic conditions
Acer rubrum (Red Maple)	Cesium, Plutonium	A	3 to 9	Grows well in a range of soil types, including sandy, loamy, and clay soils. It prefers moist, well-drained soil and can tolerate occasional flooding. Red Maples grow best in full sun to partial shade.
Acer saccharinum (Silver Maple)	Polychlorinated Biphenyl (PCB), Trichloroethylene (TCE) And By-Products, Vinyl Chloride	A	3 to 9	It is adaptable to a variety of soil types, but they prefer moist, well-drained soil. It can grow in full sun to partial shade.
Achillea millefolium (Yarrow)	Cadmium	A	3 to10	It prefers well-drained, sandy or loamy soil and can tolerate drought conditions. It grows best in full sun
Acorus calamus (Sweet Flag)	Iron, Manganese	A	5 to 11	It grows best in wet, marshy soil and can tolerate a wide range of soil types. It prefers full sun to partial shade.
Agapanthus africanus (Lily-of-the-Nile)	Petroleum	T	9 to11	It prefers well-drained soil and can tolerate drought conditions. It grows best in full sun to partial shade.
Agrostis stolonifera (Bent-grass)	Aluminum, Arsenic, Lead, Manganese, Zinc, Hydrocarbons	A & HA	4 to 8	It grows best in moist, well-drained soil and can tolerate a range of soil types. It prefers full sun to partial shade.

Table 3. List of plant species and their suitability in phytoremediation process with essential agro climatic conditions

Plant species	Suitability	Class	HZ	Agro-climatic conditions
Alyssum wulfenia (Alpine Alyssum)	Nickel	A	6	It prefers well-drained, sandy or rocky soil and can tolerate drought conditions. It grows best in full sun.
Amaranthus retroflexus (Red-root Amaranth)	Cadmium, Cesium, Nickel, Zinc	A	3 to 10	It can grow in a variety of soil types, including sandy, loamy, and clay soils. It prefers full sun.
Ambrosia artemisiifolia L. (Common ragweed)	Lead	HA	4 to 8	It can grow in a range of soil types, including sandy, loamy, and clay soils. It prefers full sun
Andropogon gerardii (Big Bluestem)	Anthracene, Arsenic, Atrazine, Copper, Polychlorinated Biphenyl (PCB)	HA	4 to 8	It prefers well-drained, sandy or loamy soil and can tolerate drought conditions. It grows best in full sun
Bacopa monnieri (Smooth Water Hyssop)	Cadmium, Chromium, Copper, Lead, Mercury	A	9 to 10	It prefers growing in warm, tropical and subtropical regions. It grows best in moist soil and prefers acidic soils with pH ranging from 5.5 to 7.
Brassica juncea (Indian Mustard)	Cadmium, Cesium, Gold, Lead, Nickel, Plutonium, Uranium, Zinc	A & HA	9 to 11	It grows best in moist, well-drained soil with a pH range between 6.0 and 7.5. It can tolerate a range of soil types, including sandy, loamy, and clay soils and in full sun.
Brassica napus (Canola)	Barium, Copper, Lead, Mercury, Triazine, Zinc Ha To Barium	A & HA*	8 to 11	It prefers well-drained soil with a pH range of 6.0 to 7.5. It requires adequate moisture and a growing season with cool temperatures.
Carex lyngbyei (Lyngbye's Sedge)	Cadmium, Lead	A	3 to 9	It grows in moist, well-drained soils, and prefers acidic soils with a pH range of 4.5 to 6.5 and in full sun to partial shade.

Continued on next page

Table 3 continued

Cassia corymbosa (Senna)	Petroleum	A	11	It prefers well-drained soils and grows in a wide range of soil types, including sandy, loamy, and clay soils and in full sun to partial shade.
Cerastium arvense (Field Chickweed)	Cadmium	A	8	It grows in moist, well-drained soils and prefers neutral to alkaline soils with a pH range of 6.5 to 7.5 and in full sun to partial shade.
Claytonia perfoliata (Miner's Lettuce)	Cadmium	A	6 to 9	It prefers moist, well-drained soils with a pH range of 5.5 to 7.5 and full sun to partial shade.

Table 4. List of plant species and their suitability in phytoremediation process with essential agro climatic conditions

Plant species	Suitability	Class	HZ	Agro-climatic conditions
Eichhornia crassipes (Water Hyacinth)	Cadmium, Cesium, Chromium, Copper, Lead, Mercury, Strontium, Uranium, Zinc	HA	9 to 11	It grows in aquatic environments, including freshwater ponds, lakes, and streams. It requires warm temperatures and grows in a wide range of water types, including stagnant and slow-moving waters.
Gerbera jamesonii (Gerbera Daisy)	Benzene, Formaldehyde, Trichloroethylene (TCE) And By-Products	HA	9 to 11	It prefers well-drained soils with a pH range of 5.5 to 6.5 and full sun to partial shade.
Glycine max (Soybean)	Arsenic, Cobalt, Copper, Nickel	A	7 to 9	It prefers well-drained soils with a pH range of 6.0 to 7.5. It requires adequate moisture and a growing season with warm temperatures.
Helianthus annuus (Sunflower)	Arsenic, Cadmium, Chromium, Copper, Lead, Manganese, Nickel, Polychlorinated Biphenyl (Pcb), Zinc	HA	3 to 10	It prefers well-drained soils with a pH range of 6.0 to 7.5 and full sun.
Hordeum vulgare (Barley)	Total Petroleum Hydrocarbons (Tphs), Aluminum	A	8	It prefers well-drained soils with a pH range of 6.0 to 7.5 and requires adequate moisture and a growing season with cool temperatures.
Iris pseudacorus (Yellow Iris)	Phosphate and other nutrients	A	5 to 9	It grows in moist soils, including marshes, swamps, and along the edges of streams and ponds and prefers neutral to alkaline soils with a pH range of 6.5 to 7.5.
Thlaspi caerulescens (Alpine penny grass)	Cadmium, Zinc, Lead, Nickel	A & HA	9 to 11	It grows best in high-altitude environments with cold temperatures and low levels of soil nutrients and prefers acidic, well-drained soils with a low pH.
Silense vulgaris (Bladder Campion)	Zinc, Cadmium, Copper	A & HA	5 to 9	It prefers well-drained soils and is tolerant of a wide range of soil types and grows in full sun or partial shade.
Brassica oleracea (Cabbage)	Zinc, Cadmium, Copper, Nickel	A	6 to 9	It prefers well-drained soils with high organic matter content and grows best in cool climates with moderate moisture.

Table 5. List of plant species and their suitability in phytoremediation process with essential agro climatic conditions

Plant species	Suitability	Class	HZ	Agro-climatic conditions
Raphanus sativus (Radish)	Cadmium, Chromium VI, Nickel, Lead	A	2 to 11	It prefers well-drained, fertile soils with a neutral pH and can grow in full sun or partial shade.
Arabidopsis thaliana (Mouse Ear Cress)	Chromium, Mercury, Lead, Cadmium, Arsenic	HA	3 to 10	It prefers well-drained soils with a neutral pH and moderate moisture and grows in full sun or partial shade.
Canna Indica (Indian shot)	Chromium, Lead, Cadmium, Arsenic, Zinc, Nickel	A	10	It prefers fertile, well-drained soils with a neutral pH and tolerate full sun or partial shade.
Colocasia esculenta (Green Taro)	Cadmium, Nickel,Cr, Pb , Ar	A	8 to12	It prefers moist, well-drained soils with a neutral pH. It can grow in full sun or partial shade.

Continued on next page

Table 5 continued

Cyperus alternifolius (Umbrella Palm)	Copper, Zinc, Lead, Nickel, Cadmium	A	9 to 12	This plant species is known for its ability to remove organic pollutants from the soil and prefers moist, well-drained soils with a neutral pH. It can grow in full sun or partial shade.
Juncus bufonius (Toad Rush)	Manganese	A	9	It prefers moist, well-drained soils with a neutral pH. It can grow in full sun or partial shade.
Scirpus validus (Soft-stem Bulrush)	Manganese, Zinc, Cadmium, Copper, Lead	A	3 to 9	It prefers moist, well-drained soils with a neutral pH. It can grow in full sun or partial shade.
Pennisetum Purpureum (Purple Fountain Grass)	Cadmium, Zinc	A	8 to 10	It prefers well-drained soils with a neutral pH and moderate moisture. It can tolerate full sun or partial shade.
Strelitzia reginae (Bird of Paradise)	Petroleum	A	10 to 12	This plant species is native to South Africa and is commonly used in landscaping. It prefers well-drained soils with a neutral pH and moderate moisture. It can tolerate full sun or partial shade and is relatively drought-tolerant.
Zantedeschia aethiopica (Canna Lily)	Iron, Arsenic	A	8	It prefers moist, well-drained soils with a neutral pH. It can tolerate full sun or partial shade and requires moderate moisture.
Lythrum Salicaria (Purple Loosestrife)	Nickel, Zinc	A	3 to 9	It prefers moist soils with a neutral pH and can tolerate full sun or partial shade. It grows in standing water and is often used in phytoremediation of wetlands contaminated with heavy metals.

Table 6. List of plant species and their suitability in phytoremediation process with essential agro climatic conditions

Plant species	**Suitability**	**Class**	**HZ**	**Agro-climatic conditions**
Centella asiatica (Indian Pennywort or Brahmi)	Copper, Zinc, Lead, Manganese, Iron	A	7 to 10	It prefers moist, well-drained soils with a neutral pH and partial shade.
Ipomoea aquatica (Water spinach)	Lead, Iron, Aluminum, Cadmium	A	10 to12	It prefers moist soils with a neutral pH and can grow in standing water. It requires full sun and is often used in phytoremediation of contaminated water bodies.
Salvinia molesta (Kariba weed)	Phosphate, Ammonia	A	7 to 10	It prefers warm water with a neutral pH and high levels of nutrients. It can tolerate low light conditions.
Pistia stratiotes (Water cabbage)	Cadmium, Zinc, Manganese, Iron	A	8 to 10	It prefers warm water with a neutral pH and high levels of nutrients. It can tolerate low light conditions.
Spathiphyllum wallisii (Peace lily)	Benzene, Formaldehyde, And Other Pollutants	HA	10 to 11	It prefers well-drained soils with a neutral pH and partial shade.

A= Accumulator **HA**= Hyper-Accumulator **T**= Tolerant **HZ**= Hardiness Zone

2 Result and Discussion

Phytoremediation is a cost-effective and eco-friendly approach to treating wastewater and removing contaminants from the environment. The success of phytoremediation largely depends on the selection of appropriate plant species, which have the ability to accumulate, degrade, or immobilize the contaminants of concern. The selection of plant species is based on their ability to tolerate the environmental conditions, the nature and concentration of contaminants, and the duration of the phytoremediation process.

Among the plant species listed, several have been reported to be useful in phytoremediation for the contaminants mentioned. Red Maple (*Acer rubrum*), Silver Maple (*Acer saccharinum*), and Yellow Iris (*Iris pseudacorus*) have been shown to accumulate cadmium, lead, and zinc from contaminated soils. Water Hyacinth (*Eichhornia crassipes*), Soft-stem Bulrush (*Scirpus validus*), and Water Cabbage (*Pistia stratiotes*) have been used to treat wastewater contaminated with petroleum, aluminum, ammonia, and phosphate. Indian Mustard (*Brassica juncea*), Canola (*Brassica napus*), and Cabbage (*Brassica oleracea*) have been used to remove heavy metals such as cadmium, chromium, nickel, and zinc from contaminated soils.

The Sweet Flag (*Acorus calamus*) has been used for the removal of arsenic, lead, and mercury from contaminated soils. Barley (*Hordeum vulgare*) has been shown to be effective in the removal of cadmium, lead, and nickel from contaminated soils. Sunflower (*Helianthus annuus*) has been used to remove chromium, lead, and zinc from contaminated soils. Water spinach

(*Ipomoea aquatica*) has been used for the removal of benzene and formaldehyde from contaminated water. Purple Fountain Grass (*Pennisetum purpureum*) has been used to remove hydrocarbons, polychlorinated biphenyl (PCB), and total petroleum hydrocarbons (TPHS) from contaminated soils. Indian Pennywort (*Centella asiatica*) has been shown to remove lead, cadmium, and nickel from contaminated soils.

The selection of appropriate plant species is crucial for the success of phytoremediation. Several plant species listed above have shown promise in the removal of contaminants such as heavy metals, organic contaminants, and petroleum-based contaminants from wastewater and contaminated soils. However, the selection of plant species should be based on a thorough assessment of the contaminants of concern, the environmental conditions, and the duration of the phytoremediation process.

India has diverse climates, from tropical to temperate and from arid to humid. As a result, different hardiness zones exist in different parts of the country. However, India does not have an official hardiness map like other countries, such as the United States. Despite the lack of an official hardiness map, some resources are available for gardeners and horticulturists in India to determine the suitability of plants for their climate. The Indian Council of Agricultural Research (ICAR) has published a map of agro-climatic zones in India, which provides information on the climate and soil types in different regions. This map can be used as a rough guide to determine the hardiness of plants in other parts of the country.

A hardiness map is highly relevant in the context of phytoremediation, as it helps identify the most suitable plants for a given region's climate conditions. Different plant species have varying levels of cold hardiness, which is the ability to survive low temperatures. Selecting the right plants can be critical to the success of phytoremediation efforts.

3 Conclusion

In order to address environmental contamination problems, phytoremediation is a potential technique. In this method, pollutants from the soil, water, or air are removed by plants. Through their roots, plants take in pollutants, which they either convert into innocuous molecules or store in their tissues.

Numerous plant species that can be used for phytoremediation can grow well in the tropical and subtropical climate. Heavy metals, insecticides, and organic compounds are among the major contaminants in the soil and water of India. India has a wide range of soil types, from sandy soils to clay soils, alkaline soils to acidic soils. The success of phytoremediation depends on choosing the right plant species that can adapt to various soil types and pH levels as well as effectively absorb and collect contaminants. Additionally, choosing plant species that can endure water scarcity is essential in areas with scarce water supplies.

When choosing plants for phytoremediation, it's essential to take the depth of the surface and the amount of groundwater into account. For sites with a shallow surface layer, shallow-rooted plants are best, whereas for sites with a deep surface layer and groundwater, deep-rooted plants are best. Sites with high groundwater levels are best suited for plants that can withstand changing water tables.

Exposure to various contaminants, including Cesium, Plutonium, Polychlorinated Biphenyl (PCB), Vinyl, Cadmium, Iron, Manganese, Petroleum, Aluminum, Arsenic, Lead, Zinc, Hydrocarbons, Nickel, Anthracene, Atrazine, Copper, Chromium, Mercury, Uranium, Barium, Triazine, Benzene, Formaldehyde, Cobalt, Total Petroleum Hydrocarbons (TPHS), Phosphate, Chromium VI, Ammonia, and Strontium, can lead to a range of health issues such as respiratory problems, neurological disorders, developmental issues, reproductive problems, cancer, and damage to the immune system.

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