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Original Article

Gray Water Conditions on the Growth of Some Natural Ground Cover Plants and the Water Quality of Plants

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ABSTRACT

Climate change and high water consumption driven by population growth have led to water stress, affecting over 2 billion people worldwide yearly. In the face of scarce water resources, traditional sewage infrastructure, especially during extreme weather, can not handle the water load and leads to pollution in freshwater sources. Treatment of rainwater and graywater can be considered a potential water source to minimize freshwater consumption and enhance water sustainability, offering simple solutions in cities. Recently, the ability of plants to remove toxic metals from dirty waters through their roots have been utilized and then water reused. In this study, a small-scale domestic graywater treatment system was developed under greenhouse conditions as a nature-based solution. In the selection of plants, species naturally distributed in Düzce province, aquatic, riparian, and understory species were preferred. Plants in the system were supplied with graywater and stored. The plants' purification levels and growth status under polluted water stress were examined. According to the results the amount of anionic substances in stored water, *Asplenium scolopendrium* L. was observed to have the highest treatment performance among the species. Although *Lythrum salicaria* L. and *Carex pendula* Huds. had a lower value compared to other species, they were shown to be a usable species in graywater treatment. *Nasturtium officinale* R. BR. had a low treatment value and was found to be a pollution-resistant species. As a result, the reuse of water is essential in today's conditions where climate zones and species distributions are changing. As seen in this study; Although species from natural vegetation have different purification potentials, they offer the opportunity to be used to purify gray water.

Keywords: Gray water, nature-based solutions, treatment, urban water management, water reuse

Introduction

Today, approximately half of the world's population lives in urban areas, and this rate is predicted to increase to two-thirds by 2050. While the rapid increase in urban population and the resulting expansion of cities increase the need for infrastructure, transportation, housing, industrial areas, and energy, it also brings environmental problems such as wastewater, noise, and air pollution. Since the industrial revolution, pollution in soil and water has been a common problem, especially in urban ecosystems and infrastructure. Pollution of freshwater resources or water scarcity due to the increase in extreme weather events, attributed to the effects of global climate change, makes access to water resources complex and threatens the urban environment and urban water cycle (Caparrós-Martínez, 2020). One-third of the world has limited or almost no access to water. According to the Water Exploitation Index (WEI+) of the European Environment Agency (EEA), water stress increases yearly, which seriously affects soil moisture and plant stress due to high water scarcity. The decrease in water resources also leads to adverse effects such as migration and epidemics.

Despite water scarcity/stress, water use is increasing at twice the rate of population growth in the last century. According to the World Water Assessment Program in the United Nations World Water Development Report, water demand increases regularly by 1% every year, and this causes the use of non-traditional water resources. Preferences such as using low-yield wells and resources, not storing rainwater, and not recycling urban surface runoff and wastewater turn the increasing water demands into situations that cannot be met during the dry months. For the sustainability of water resources, it is necessary to manage water resources and quality effectively and efficiently in cities. The way to respond to the increasing demand for water is through nature-based water management (Somarakis et al., 2019). With traditional water management approaches, water is considered as spring water (surface water/groundwater - blue water), drinking water, wastewater (gray water and black

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water), and rainwater (green water). In nature-based management of these waters, various sustainable urban water management models are being developed. There are studies aimed at preserving the water cycle in nature as much as possible with nature-based solutions such as rain gardens, green roof systems, water collection/storage/purification systems, artificial wetlands, and vertical gardens (Ekşi et al., 2016; Li et al., 2009; Tsatsou et al., 2023).

In addition to drinking water, rainwater, groundwater, and wastewater are daily produced resources. With the EU Water Reuse Directive, there are clear guidelines for the safe reuse of treated wastewater. Additionally, several countries are preparing guidelines for safely reusing treated wastewater or treated gray water, derived from World Health Organization guidelines. Moreover, HABITAT III emphasizes taking into account the water cycle in the New Urban Agenda document, improving water resources, reducing and purifying wastewater, minimizing water losses, encouraging water reuse, converting waste into energy, promoting environmentally friendly waste management, and ensuring all waste is environmentally friendly. It is emphasized that the goals of marine management, reducing marine pollution, and strengthening the sustainable management of resources can be beneficial. Collecting and using rainwater and gray water in buildings is vital for environmentally friendly buildings. In Türkiye, the "Green Certificate Implementation Communiqué for Buildings and Settlements," which includes the evaluation criteria for environmentally friendly buildings, has been published. This communiqué presents 6 criteria under the Water and Waste Management (WWM) module, with the theme of Water Management:

1. Use of appropriate fixtures for efficient and effective use of water.
2. Preventing losses and leaks in water distribution/taking necessary precautions.
3. Monitoring and recording water usage with meters.
4. Control of water quality.
5. Collecting, purifying, and using rainwater.
6. Reuse of wastewater (gray water).

The water quality of surface and groundwater worldwide is deteriorating due to activities such as the discharge of untreated domestic and industrial wastewater, agricultural irrigation, and the emission of greenhouse gases. Additionally, the mixing of pesticides, synthetic organics, NO_2, and SO_2 into the water, as well as the dissolution of naturally occurring environmental pollutants in water, contributes to this deterioration (UNWWD, 2017). The amount of water that is polluted and whose quality decreases negatively affects the water footprint, especially the gray water footprint (Caparrós-Martínez, 2020). The effective use of gray water through treatment/reuse helps reduce the burden on water resources and decrease the water footprint. Penn et al. (2013) revealed that the reuse of gray water reduces wastewater flow in urban areas by 25–40%.

In recent years, there has been increasing interest in research on gray water recovery to cope with water scarcity, especially at the domestic level. Studies conducted in arid and semi-arid climate zones show that gray water can potentially help overcome the problem of water scarcity. At the same time, as a cost-effective alternative water source, a reduction of up to 50% in water bills can be observed. This approach is also important for finding synergistic strategies to increase the circular economy in the water and waste sectors (Hossain et al., 2020).

10% of the water consumed worldwide is used in buildings. Of this, 5% is used for cleaning, 5% for garden irrigation, 25% for reservoirs, 13% for laundry, 12% for the kitchen, and 40% for showers and sinks. In daily life, the highest water consumption occurs in toilets and bathrooms. Meeting this need by storing and reusing gray water offers a solution that reduces the water load in traditional sewage systems and supports the city's blue-green infrastructure. Gray water is defined as domestic wastewater originating from residences and small businesses, such as schools and public buildings, resulting from people's daily life activities and needs. Domestic wastewater is typically categorized into two types: gray water (from sinks, bathtubs, showers, etc.) and black water (from septic tank waste). Since the pollution load of gray water is lower than that of black water, purification is typically easier (Daigger, 2009).

The direct use of untreated gray water is common worldwide, with gray water collected from bathrooms often used for garden irrigation. However, this practice is not recommended for the preservation of plant health, soil structure, and groundwater quality due to the accumulation of salts, surfactants, oil, and grease in the water. For example, it is observed that direct gray water irrigation is practiced in countries such as Australia, Syria, South Africa, and Israel, where it is used for watering fruit trees. In response to water shortages in the southwestern region of the USA, golf courses are irrigated with purified water, often referred to as "purple gold."

Applying appropriate treatment techniques, performing regular maintenance, and complying with legal regulations are crucial when installing and using gray water systems. For instance, a Swedish study indicated that gray water can be contaminated with fecal matter and bacteria, increasing public health risks. It is predicted that gray water use in landscape irrigation may reduce soil quality (Greywater Action, 2024). Gray water contains high levels of salinity, especially from detergents and cleaning products. This salinity can cause salt to accumulate in the roots of plants, making water uptake difficult. Studies conducted in California show that high salt content negatively affects plant growth and sometimes leads to the complete drying out of plants. Since regulations on gray water use in Colorado require strict control and supervision to minimize public health risks, local governments state that it is difficult and costly to inspect these systems (Water Education Foundation, 2019).

Considering the situation of fresh water resources in the world, which continues to decrease under conditions of climate change, lack of infrastructure, and economic inadequacy; the purification of gray water has been put forward as a solution that can minimize freshwater scarcity in many parts of the world (Shafiquzzaman et al., 2021). Water, which is such a comprehensive and valuable resource, is described in the literature according to its physical/chemical character. There are different studies on domestic, textile industry, agricultural production activities, and other source wastewater (Gao et al., 2016). In the treatment of gray water, it is generally seen that the focus is on the purification of organic substances, nutrients, and pathogenic microorganisms by using artificial wetlands or establishing experimental areas in sludge systems.

The purification of gray water varies depending on field conditions and the characteristics of the gray water. Various treatment methods are employed, including physical methods such as precipitation and filtration processes, chemical methods like electrocoagulation, photocatalytic oxidation, ion exchangers, and granular activated carbon, as well as biological methods including artificial wetlands, rotary biological reactors, sequential batch reactors, and membrane bioreactors (Kotsia et al., 2020). In some biological treatment processes, the physiological properties of plants are utilized. The roots and underground stems of plants create suitable environmental conditions for the development of microorganisms and oxygen transfer. Li et al. (2009) noted in their study that due to the high nutrient (nitrogen and phosphorus) uptake potential of plants, phytopurification systems may offer the most effective solution for recycling light gray water. Vegetative purification is achieved through filtration and microbial degradation under various conditions, although its efficiency can vary depending on the plant species. The chemical parameters of gray water encompass dissolved organic matter, including biological oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC), as well as nutrients like nitrogen and phosphorus, pH levels, heavy metals, salinity, oil and grease, surface-active ingredients, and other household chemicals. In this study, the concentration of surfactants was examined both before gray water treatment and after treatment using plants.

Using natural plant species contributes to the creation or restoration of a healthy ecosystem. The use of natural plant species in water purification is gaining increasing attention as an environmentally friendly and sustainable purification method. The use of natural plants is an environmentally friendly option, although its purification efficiency and speed are lower than those of chemical purification methods. Native plant species are often available locally and are low-cost to maintain. This could reduce the cost of water purification and provide a more economical solution for communities. Moreover, it has the potential to integrate water treatment areas into natural ecosystems. This can transform water purification systems into habitats that not only clean waste but also support local biodiversity.

The main objectives of this study are as follows: i) To evaluate the graywater purification performance in natural ground cover plants identified as having purification potential. ii) To observe the morphological development state while examining the purification performance of plants. iii) To compare the quality of purified water with regulatory requirements for reuse standards. This study offers an easy, practical, and modular system for the treatment and reuse of gray water with a nature-based approach, without transferring it to traditional sewage systems. It has been demonstrated that using natural plant species contributes to sustainable water use, especially in cities with hot climate conditions in arid/semi-arid regions.

Material and Methods

Material

Asplenium scolopendrium L., *Carex pendula* Huds., *Nasturtium officinale* R. Br., and *Lythrum salicaria* L. grow naturally in Düzce city and its immediate surroundings. These constitute the types. Wetland plant species can remove many pollutants from wastewater. Additionally, the roots of wetland plants create a suitable habitat for the growth of various microbial communities that increase pollutant removal efficiency (Mustapha et al., 2018). In this direction, *Nasturtium officinale R. Br.*, which is commonly seen in the wetlands of Düzce Province, was also preferred in the trial design. It is a macro hydrophyte aquatic plant that lives in constantly flowing, clean, and cold fresh water (Duke, 1992). It is known that *Nasturtium officinale* R. Br. is used to treat wastewater (Midlen et al., 1998). *Lythrum salicaria* L. is a species used to remove heavy metals from contaminated environments in wastewater treatment (Krokaitė et al., 2023). It was used in the study because it has potential in gray water treatment and is a common species in Düzce Province, especially in wet areas next to lakes. *Carex pendula* Huds. is a species used in the purification of sludge, soil, groundwater, and sediments (Štefanac et al., 2021). The leaves and rhizome parts of *Asplenium scolopendrium* L. have the feature of storing heavy metals (Şuţan et al., 2016). In this context, the general characteristics and natural distribution areas of the preferred species are given in Table 1.

Study area and location of the species used in the study area

In this study, we searched for nature-based solutions in Düzce province and its surroundings, and selected plant species that could show the best potential in terms of resistance and purification to gray water with their plant root structure. These species were determined in the study conducted by Kaya (2022) according to the species detected within the borders of Düzce plain and their percentage of occurrence. In Düzce University research greenhouses, the species we obtained from nature were brought and adapted, and gray water was added to accumulate them. As a result, the samples taken were examined in a laboratory environment and evaluated during this project phase. Location information regarding the habitats of the species taken is given in Figure 1. *Asplenium scolopendrium* L., from the Muncurlu town forest border, *Carex pendula* Huds., and *Nasturtium officinale* R. BR. from the stream bank in the same region. It was obtained from the stream in Kemerkasım Village, near *the Lythrum salicaria* L. Efteni Lake Wildlife Development Area (Figure 2).

Method

Collecting plants and designing the research pattern

There is a need for research studies in real-world conditions outside laboratory environments (in a residential area, high school bathroom wastewater, office building, on examining the reusability of plant-growing environments or water (Pucher et al., 2022). In this study, an evaluation was made to identify natural ground cover species that have the potential to purify domestic gray water under greenhouse conditions. To carry out this study, naturally occurring species were collected from the field and left for adaptation for four weeks in the Düzce University Faculty of Forestry Research Greenhouse. Species left to adapt were observed to grow in a 1:1:1 (sand-peat-perlite) environment. Afterwards, a control group and an application group were prepared for each species (Figure 3), and eight treatment groups were created for a total of four plants (Table 2).

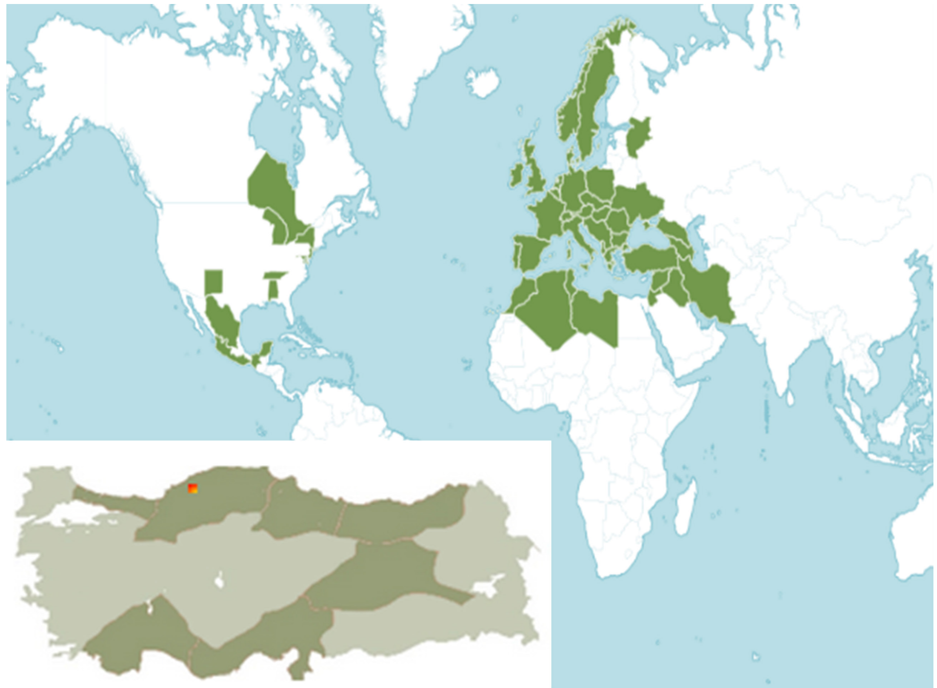
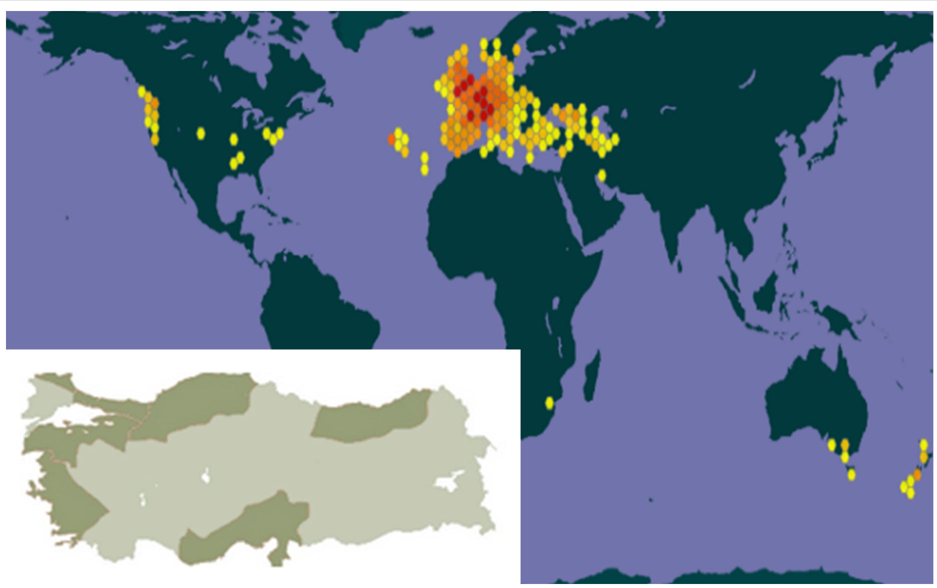
Gray water applications and morphological measurements

In the study, gray water concentration (Shampoo (100 mL/L), Liquid Soap (100 mL/L), Shower Gel (100 mL/L), Dish Detergent (100 mL/L)) was prepared for gray water applications. The amount of anionic substances in the gray water obtained was analyzed, and the rates in other studies were compared in Table 3. During the 4-week adaptation period of the plants, their development was monitored by giving 2 L of clean water every 2 days. After the adaptation process, gray water (1L) and clean water (1L) were mixed in certain proportions and given to the gray water application groups every2 days. In the control groups, irrigation water (2 L) without adding dishwashing detergent was used. While the control groups were subjected to irrigation every other day, the treatment groups were exposed to gray water every other day. Water leaking from the growing environment was stored for analysis. Two morphological changes, namely height and crown measurements of the plants, were observed every 2 weeks, and the 2-month trial period was recorded (Table 4).

Water analysis

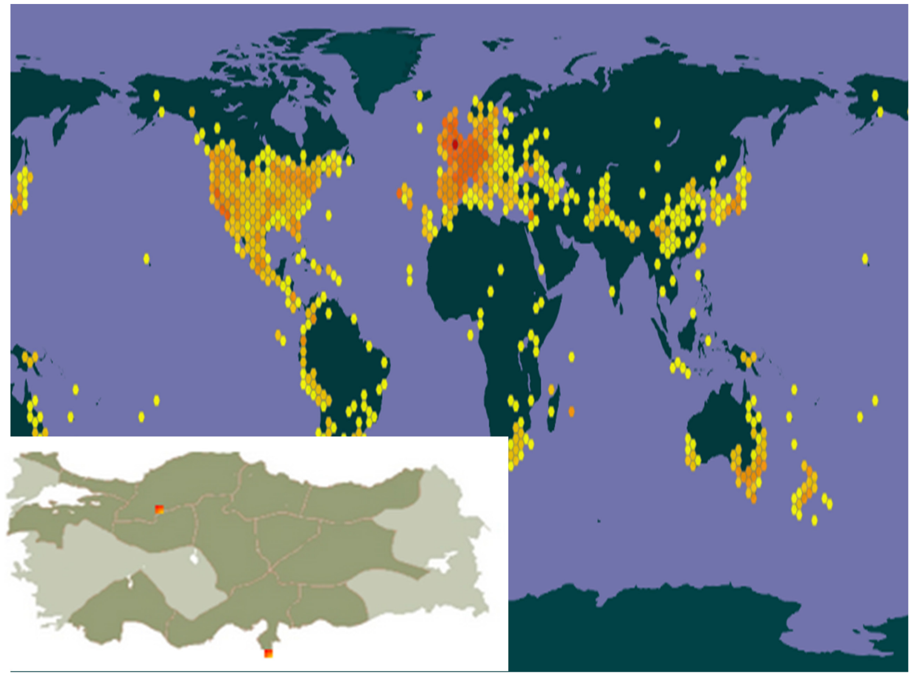
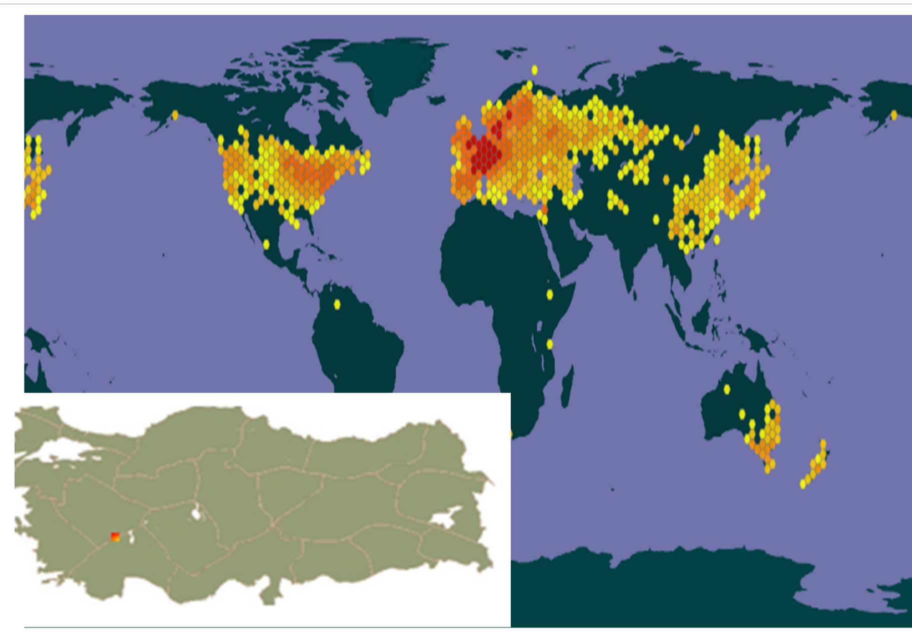
Wastewater obtained after gray water applications applied to plants was measured in terms of total anionic pollutants by Düzce University Scientific and Technological Research Application and

Table 1.
General Characteristics and Natural Distribution Areas of the Species used in the Study

Species Name	General Features	Map of Natural Distribution Areas
Asplenium scolopendrium L.	*Asplenium scolopendrium* L. is an evergreen perennial species. The sporulation period is May-August. It develops in soils with high pH and mineral soils with little humus, between sea level and 2100 m altitude. They can grow naturally in forests, moist, shady, stony, and rocky mountain regions (Bremer, & Jongejans, 2010).	 *Asplenium scolopendrium* L. distribution in the world (Royal Botanic Gardens Kew, 2023).
Carex pendula Huds.	*Carex pendula* Huds. is a perennial herb. It creates habitat in forests or other shaded areas, stream edges, springs, or depressions. It is seen in the altitude range of 0–2000 m. It is distributed in the European-Siberian Thrace, Outer Anatolia, Western and Central Europe, Mediterranean region, Crimea, Caucasus, Northwest and Northern Iran, and Khorasan regions (TUBIVES, 2023).	 *Carex pendula* Huds. distribution areas in the world (GBIF, 2022).

(*Continued*)

Table 1.
General Characteristics and Natural Distribution Areas of the Species used in the Study (*Continued*)

Species Name	General Features	Map of Natural Distribution Areas
Nasturtium officinale R. Br.	*Nasturtium officinale* R.BR. It is perennial and herbaceous (rhizomatic) in structure. Its habitats are wetlands such as streams and ponds. It can be seen at altitudes of 0–1650 m. It is distributed in temperate Europe, Asia, and N. Africa. It is seen in Thrace, Northern, Southern, Central, and Eastern Anatolia regions of Türkiye (TUBIVES, 2023).	 *Nasturtium officinale* R. Br. distribution areas in the world (GBIF, (2022).
Lythrum salicaria L.	*Lythrum salicaria* L. is a perennial herbaceous species. It is widespread in Europe, Asia, and North America. It is distributed in wetlands in Türkiye up to an altitude of 1400 m. It can be found in the form of herbs and shrubs, 20 to 200 cm tall. Many types of wetlands, including wet meadows, meadow holes, river and stream banks, lake shores, tidal and non-tidal marshes, and ditches are habitats (Agren, 1996).	 *Lythrum salicaria* L. distribution areas in the world. (GBIF, 2022).

Research Center (DUBIT). Working procedure: In the measurement made with the Hach Kango lck 332 kits, anionic surfactants (there are cations such as sodium, potassium, and ammonium. These cations, together with negatively charged groups such as carboxylate, sulfonate, sulfate, and phosphate form the polar group of the molecule) methylene to form extracted complexes. It reacts with blue chloroform and is evaluated photometrically. The data obtained gives the value of the total anionic substance in the water in mg/L (Işık et al. 2018).

The data were subjected to descriptive statistics and correlation analysis to determine the relationships between morphological and anionic substances. Microsoft Excel and The Statistical Package for Social Sciences version 23.0 software (IBM Corp.; Armonk, NY, USA) were used in the study.

Results and Discussion

Factors such as root structures, leaf morphology, and growth rates of varying plants are important in determining gray water treatment

Figure 1.
Locations Where the Natural Ground Cover Species Used Were Taken.

potential. The root structures of plants are related to their ability to absorb pollutants in water. Roots can absorb and metabolize organic and inorganic substances found in water. This can help clean water and shows how effective plants can be in water purification. In the study, anionic substance load measurements and the ability of plants to absorb pollutants were evaluated together with the results of previous literature studies. Morphological developments determine how quickly these plants can remove pollutants from the water. Fast-growing plants can provide more remarkable water purification, providing a more efficient solution to gray water treatment. In the study, their development under pollution stress was evaluated by length and diameter measurements. Within this framework, the gray water treatment performance of selected natural ground cover plants and their potential for reusing treated water was revealed.

Total Anionic Measurements

Heterotrophs carry out the removal of the anionic substances through biodegradation. In a related study in the literature, it has been demonstrated that the anionic substance acts as an energy source for heterotrophs (Katam & Bhattacharyya, 2018). It has also been observed that microalgae can remove anionic matter from wastewater in an algae-based system (Shafiquzzaman et al., 2021). With these properties, it seems that some plants are used to clean chemicals in soil and water. Such plants can accumulate substances in their roots and aboveground green areas. Pollutants can be removed from the environment by harvesting the plants after accumulation. It is known that after the Chernobyl nuclear power plant disaster, soil contaminated with uranium was cleaned with sunflower plants. It has been shown that many species, such as mustard plants, ferns, clover, poplars, willows, junipers, and some grass species, can store 200 times more arsenic than the soil in which they grow (Alsabbagh & Abuqudaira, 2017).

When some studies on water improvement are examined, it has been shown that there are no significant differences in efficiency between systems in which plants are used and water systems without plants in removing organic matter, solids, and nutrients (Kotsia et al., 2020). Some

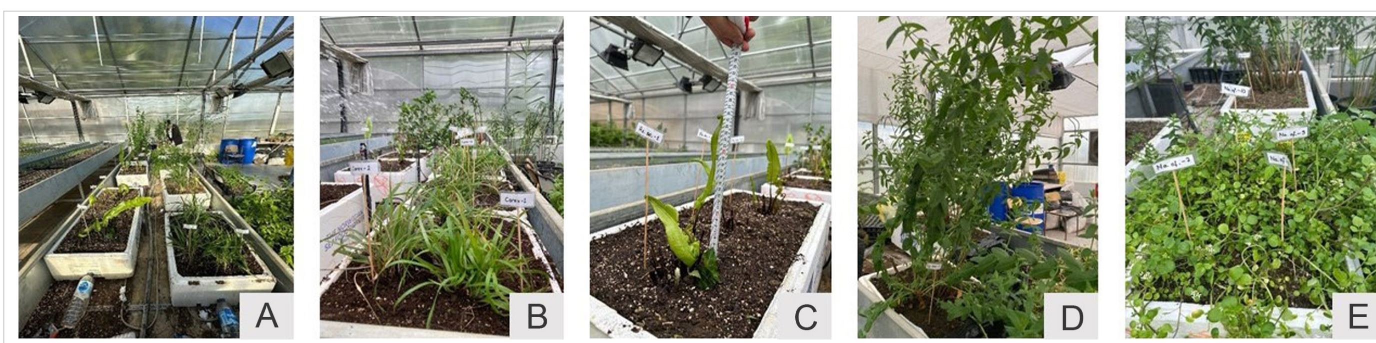


Figure 2.
Greenhouse Condition (A). Plants' Situation: (B) Carex pendula Huds; *(C) Asplenium scolopendrium L.; (D) Lythrum salicaria L.; (E) Nasturtium officinale* R. Br.

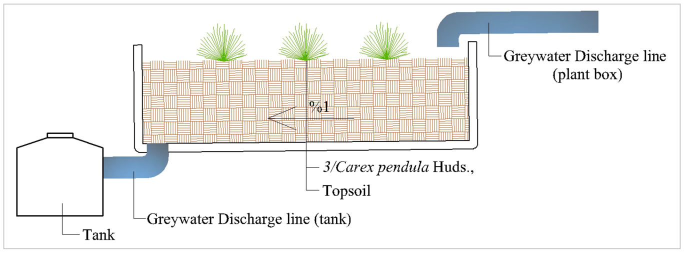


Figure 3.
Application Graphical Chart.

studies have revealed that plants significantly affect cleaning wetlands (Hu et al., 2023). Especially in studies on cleaning wetlands, it is seen that the genera *Carex, Cyperus, Juncus, Typha,* and *Phragmites* are mostly preferred (Goncalves et al., 2021). Nyieku et al. (2022), in their study, evaluated the pollutant removal efficiency of three native plant species (*Typha latifolia, Ruellia simplex, and Alternanthera philoxeroides) and plants* in the oil field wastewater effluent in Ghana. The study revealed that the wetland control system without plants had lower efficiency than the system with other plants. Ekşi et al. (2016), in their studies on rain gardens, evaluated ornamental plants such as Anemone *nemorosa, Viola odorata, and Iris germenica,* revealed that they are preferable species in water reuse opportunities. Fowdar et al. (2017), in their study in a greenhouse environment, examined gray water treatment potentials for five climbing plants (*Vitis vinifera, Parthenocissus tricuspidata, Pandorea jasminoides, Billardiera scandens,* and *Lonicera japonica).* The values regarding removing organic matter and suspended solids in the treated water were successful.

Raphael et al. (2023) in their study, stated the importance of choosing naturally occurring plants in gray water treatment studies. It has been noted that some influential macrophytes of native species may accumulate more pollutants than others. In this regard, after the selected plant species were irrigated with gray water, the number of anionic substances in the filtered water was examined. The graph of the results obtained regarding this is given in Figure 4.

Chen et al. (2007) revealed that plants with rhizomatic roots are more resistant to pollution than those with filamentous roots. *Typha* has a rhizomatic root system consisting of thick roots. *Cyperus alternifolius* and *Cynodon dactylon* (L.) have a fibrous root system with thin roots (Wenyin et al., 2007). Accordingly, Mustpha et al. (2018) stated in their study that the *Typha latifolia* plant species performed better than other plant species. However, some studies argue that plants with fibrous, hairy roots have better purification performance (Pradhan et al., 2019). In the studies of Li et al. (2011), they mentioned that the anatomical root characteristics of some rhizome plants are similar to those of fibrous

Table 2.
Application Pattern

Species Name	Control Group Number of Repetitions (C)	Number of Repetitions in Gray Water Application Group (D)
Asplenium scolopendrium L.	4 pcs	4 pcs
Carex pendula Huds.	4 pcs	4 pcs
Nasturtium officinale R. Br.	4 pcs	4 pcs
Lythrum salicaria L.	4 pcs	4 pcs

Table 3.
Comparison of the Average Value of Anionic Substance Content of the Gray Water Used in the Study with the Values in Other Studies

	Gray Water Values		
Parameter	Shafiquzzaman et al., 2021 Study (Minimum–Maximum (Mean))	Previous Studies[a] (Minimum–Maximum)	This Study (Mean)
Anionic surfactant (AS) (mg/L)	16.5–33.1 (21.9)	30–76	7.45

[a]Fountoulakis et al., 2016; Oteng-Peprah et al., 2018.

root plants and that research on more species is needed. Among the species selected in this study, *Asplenium scolopendrium* L. has rhizomatous and hairy fibrous roots. When the amount of anionic substances in the gray water application group of this species is examined; according to Figure 4, it was observed that it was the type with the highest performance in purifying dirty water (after treatment: 0.65 ($p < .05$), gray water: 7.45). In *Lythrum salicaria* L., it was approximately equal to *Asplenium scolopendrium* L. (after treatment: 0.64 ($p < .05$), gray water: 7.45). However, the same performance was not observed in morphological development. *Lythrum salicaria* L. has a fringe root structure. This reveals that both species with different root structures can show similar purification performance. Although *Carex pendula* Huds. has a low value compared to other species, its performance revealed that it is a species that can be used in domestic gray water treatment (after treatment: 0.81 ($p < .05$), gray water: 7.45). With its hairy root structure, it is a type of dirty water treatment recommended in previous studies. *Nasturtium officinale* R. Br. is a plant that can be recommended for nitrogen bioremediation in domestic and industrial wastewater. Musavi et al. (2016) revealed that it is a very effective species in removing nitrogen (ammonium) pollutants. It has been stated that the water purified by these species can be used in landscape irrigation, urinals, and toilet flushing. However, this study showed that *Nasturtium officinale* R. Br. has low performance in purification compared with other species (after purification: 7.09 ($p < .05$), gray water: 7.45). It is predicted that due to non-aquatic growing conditions, the species could not get enough water purification. When the values of the control group given clean water were analyzed; it was observed that the pollution load of clean water increased (irrigation water control group after treatment: 1.51 ($p < .05$), irrigation water: 0.37). *Nasturtium officinale* R. Br. transferred the anionic substance it took from the soil into clean water. It has been shown that this species does not retain anionic substances in its body.

Morphological features

Aquatic plants and algae are widely preferred in removing organic and inorganic pollutants in wastewater. In the study, species preferring aquatic, moist sub-forest habitats and water edges were preferred. The diversity in these living environments and their morphological development under pollution stress in the same environment were examined. Within the scope of the study, three measurements were made and the 6-week development of the plants was measured in two-week periods (Figures 5 and 6).

Asplenium scolopendrium L. is distributed in moist, shaded areas under the forest. In the study, it was adapted to greenhouse conditions. However, these conditions could not be offered to these species, which spread in the forest undergrowth and moist, shaded areas, in greenhouse conditions. While a proportional increase in height was observed during the irrigation period, a decrease in diameter was observed. For these species,

Table 4.
Gant Chart

	May 2023							
	W1		W2			W3		W4
Time	12.05	15.05	17.05	19.05	22.05	26.05	28.05	31.05
Plant Groups								Process
Ly. shawl.								1L
Ly. shawl.								1L
Na.off.								1L
Na.off.								1L
Ace. sco.				adaptation				1L
Ace. sco.								1L
Ca.pen.								1L
Ca.pen.								1L

Time	June 2023													
	W1		W2				W3					W4		
	02.06	05.06	06.06	09.06	13.06	15.06	16.06	17.06	18.06	19.06	20.06	21.06	22.06	23.06
Plant Groups														
Ly. shawl.	2L	2L	2L	2L	3L	5L	–	3L	4L	3L	3L	3L	3L	3L
Ly. shawl.	1L	1L	–	1L	1L	–	2L	1L	2L	1L	1L	1L	1L	1L
Na.off.	2L	2L	2L	2L	3L	5L	–	3L	4L	3L	3L	3L	3L	3L
Na.off.	1L	1L	–	1L	1L	–	2L	1L	2L	1L	1L	1L	1L	1L
Ace. sco.	2L	2L	2L	2L	3L	5L	–	3L	4L	3L	3L	3L	3L	3L
Ace. sco.	1L	1L	–	1L	1L	–	2L	1L	2L	1L	1L	1L	1L	1L
Ca.pen.	2L	2L	2L	2L	3L	5L	–	3L	4L	3L	3L	3L	3L	3L
Ca.pen.	1L	1L	–	1L	1L	–	2L	1L	2L	1L	1L	1L	1L	1L
					Clean Water			dirty water				adaptation process		

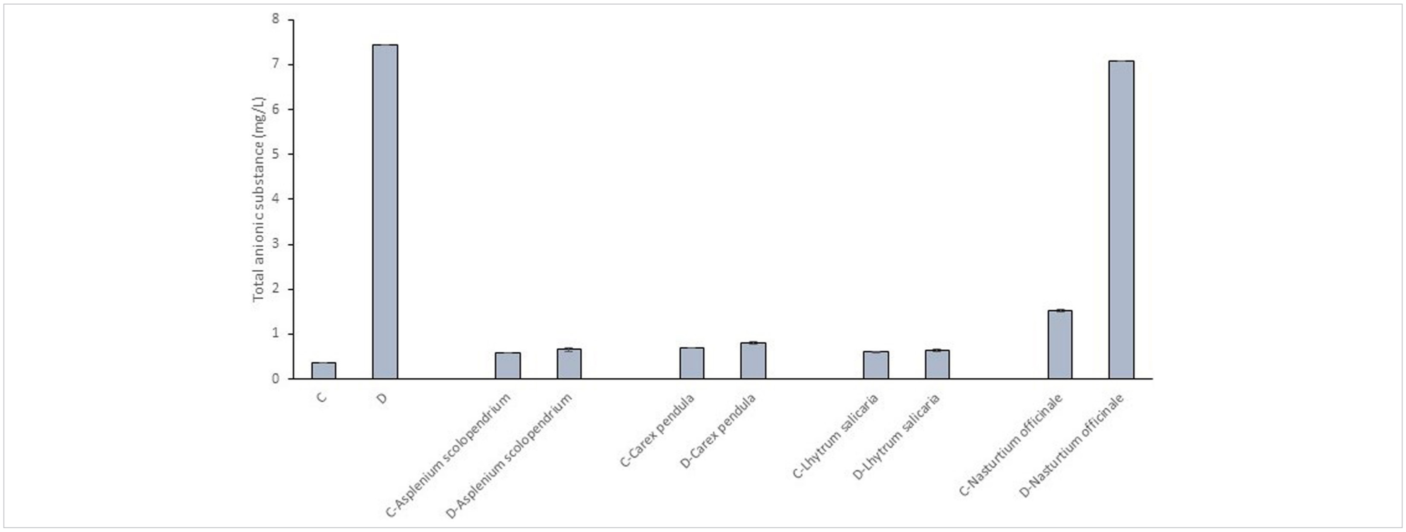


Figure 4.
Total Amount of Anionic Substance (C, Clean Water; D, Gray Water).

which had a high water need, development took place under stressful, arid conditions. Despite the polluted water yield, *Lythrum salicaria* L. was observed to thrive at a rate similar to that of the control group, which was given a clean water. While height growth occurred at a high rate compared with other species, a decrease in diameter was observed in the clean water control group. The greenhouse environment may not provide a suitable humid environment for *Lythrum salicaria* L., which is a waterside plant. It is thought that the nutrients required for the diameter development seen in the group given dirty water were obtained from this water. *Carex pendula* Huds. continued to grow in the polluted irrigated group but showed slow performance. Clean water showed the same improvement as the control group. Dirty water did not produce any remarkable results in morphological development. Dirty substances accumulating in the root may prevent development. *Nasturtium officinale* R. Br. is an aquatic species with fringe roots. By using all the water actively, its growth in dirty water gave good results.

Correlation analysis was performed to determine the relationships between height, crown measurements, and gray water applications (Table 5). According to the analysis results, it was observed that there was a positive relationship between height development and the values of purified water. It has been shown that some substances in dirty water pass into the body of plants and support their development. However, it is an average value. When the species were examined in detail, it showed that measured different height development rates or started to abort in morphology, such as *Lythrum salicaria* L.

Conclusion and Recommendations

This study aimed to determine the performance of some plant species naturally distributed in Düzce Province and its surroundings in the purification of domestic gray water. The selected *Asplenium scolopendrium* L., *Lythrum salicaria* L., *Carex pendula* Huds., and *Nasturtium officinale* R. Br. These species have successfully adapted to gray water irrigation regimes and have played an important role in gray water treatment in previous studies. According to the results of this study, it has been shown that the purification capacity was observed to differ among the species. Differences in purification efficiency and development in

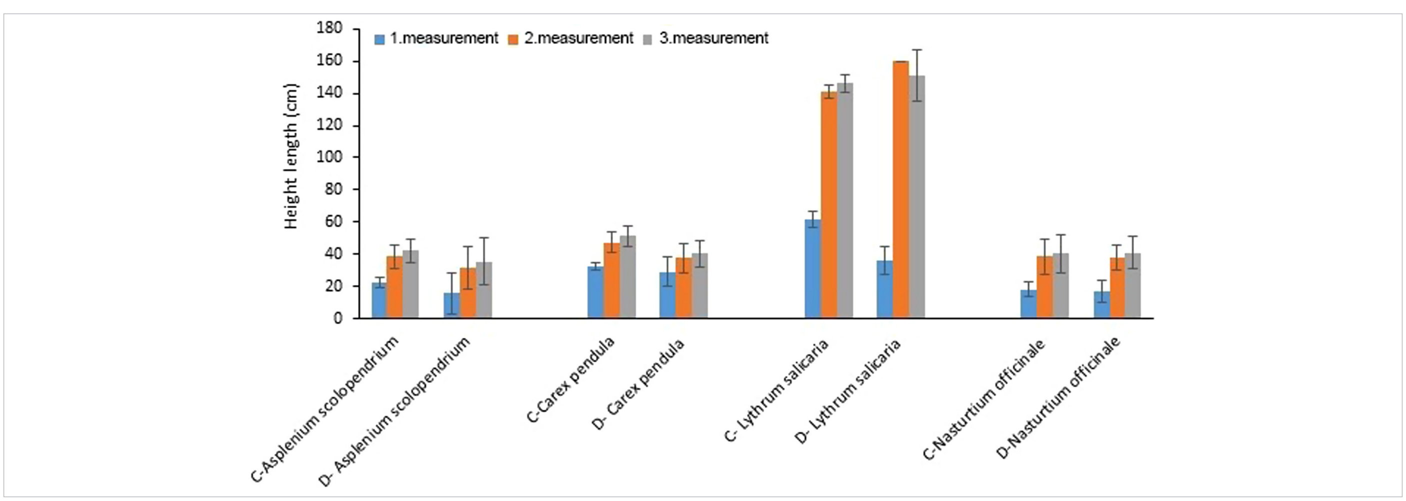


Figure 5.
Height length values (C, clean water; D, gray water).

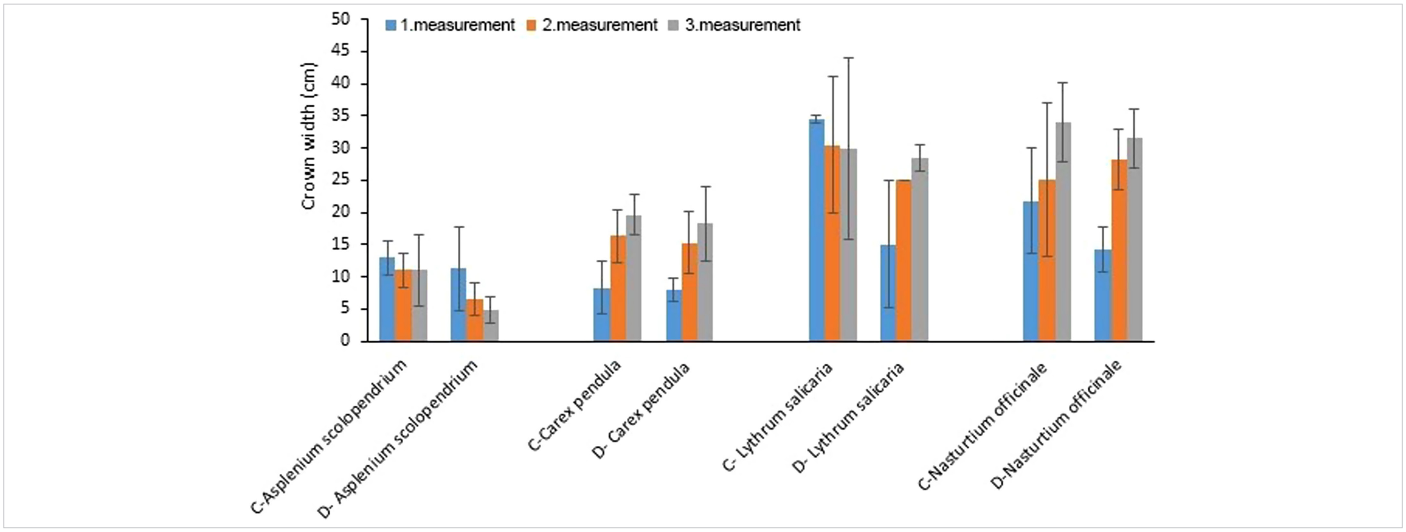


Figure 6.
Crown Values (C, Clean Water; D, Gray Water)

polluted water were observed according to plant species. The performance success in purification is as follows: *Asplenium scolopendrium* L. > *Lythrum salicaria* L. > *Carex pendula* Huds. > *Nasturtium officinale* R. Br. In Düzce City, *Asplenium scolopendrium* L. and *Lythrum salicaria* L. are species that can naturally spread naturally in shade and moist areas. Although they experienced pollution stress in terms of development, they showed growth. However, *Lythrum salicaria* L. showed low in the third morphological measurement. If measurements continue, these species may fail to maintain their long height during dirty water. On the other hand, while these species absorbed gray water, their purification was successful. Long-term morphological measurements can be the focus of future studies with these species. *Carex pendula* Huds. can be easily used in home gardens and balconies and can be recommended as a type of gray water treatment. Since its development is slower than that of others, it can be preferred in small areas. *Nasturtium officinale* R. Br. showed continued morphological development under pollution stress. However, the predicted performance in water treatment was not obtained. It is thought that this species will be more successful in aquatic systems such as artificial wetlands than in natural purification systems that are becoming widespread. Additionally, this study showed that despite *Nasturtium officinale* R. Br. being considered a gray water treatment species in previous studies, it had low purification effectiveness in this study. However, these species continued morphological development. Since it is an aquatic plant, it is thought that it requires a more aquatic environment, unlike the greenhouse environment. In future studies, these species can be examined in different ambient conditions such as aquatic, mid-aquatic, and clayey environments.

This study revealed the application potential for analyzing wastewater management in urban areas using natural plant species. Considering the expected water crises due to climate change, it is important to determine the purification potential of naturally occurring species in studies on water reuse. Especially in cities where agricultural areas with high water scarcity are common in arid/semi-arid regions, there is a need for practices such as establishing vegetative treatment systems and turning them into a resource that supports food production. Gray water treatment systems established with natural species offer the possibility to be used in parks, medians, agricultural areas, cut flower

Table 5.
Correlation Analysis

Correlations				
		Diameter_Measurement	Height_Measurement	Water_Measurement
Diameter_measurement	Pearson Correlation	one	−.198	.019
	Shallow. (2-tailed)		.638	.965
	N	8	8	8
Height_measurement	Pearson Correlation	−.198	one	.817*
	Shallow (2-tailed)	.638		.013
	N	8	8	8
Water_measurement	Pearson Correlation	.019	.817*	one
	Shallow (2-tailed)	.965	.013	
	N	8	8	8

*Correlation is significant at the 0.05 level (two-tailed).

production areas, nurseries, and many other areas in addition to domestic use. The use of natural species within the system reduces maintenance and supports the spread of natural species instead of invasive species in the urban landscape. This system offers an ecological and low-cost solution with its simple, effective, and modular structure. In disasters such as floods due to extreme weather events, it can also support cities to become more water-resistant by reducing the capacity of the traditional infrastructure system of cities. It has the potential to reduce water consumption from freshwater resources and improve waste costs and pollution. It is a nature-based solution for access to clean water specified in Sustainable Development Goal-6. It is possible to build an urban water management model by integrating these gray water treatment systems with other water management supporting solutions (rain gardens, vertical gardens, biological water retention areas, biological ditches). To improve this study, it can be developed as a new study by providing the same species and common living conditions outside the greenhouse environment.

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