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Sustainable Water Management Practices at ETUT: Innovations and Policies

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Abstract. This paper delves into the water management strategies of the Oguz Han Engineering and Technology University of Turkmenistan (ETUT), emphasizing sustainable practices and regulatory compliance. The ETUT employs various innovative techniques, such as rainwater collection through rain gardens, permeable pavements, and cisterns to mitigate runoff and enhance water quality. Rainwater is stored for irrigation, reducing reliance on municipal sources and contributing to groundwater recharge. A water-recycling program repurposes rainwater and fountain water, whereas innovative structures promote plant growth and water conservation by condensing atmospheric moisture. The university utilizes advanced wastewater treatment methods that incorporate plants and microorganisms to efficiently purify water. Complying with national regulations ensures safe drinking water and resource protection. Regular monitoring aids in assessing policy effectiveness and fostering continuous improvement. The ETUT's commitment to sustainability and environmental stewardship is reflected in its comprehensive water conservation program, fostering a culture of innovation and responsibility within the university community.

Keyword:

Water management techniques, water conservation program, novel

devices for plant growth, wastewater treatment, monitoring

1. Introduction

Water is a source of life. It is considered common wealth for all humanities [1]. Unconscious usage of natural resources and rapid industrial and agricultural development have led to the emergence of environmental problems such as soil erosion, desertification, loss of biological diversity, water scarcity, and disruption of ecological systems [9]. Water scarcity and pollution are pressing challenges faced by societies globally and demand innovative solutions for sustainable water management.

The five major sources of water in Turkmenistan are the Amu Darya, Murgab, Tedjen, Atrek, and Sumbar rivers. The other natural water bodies are small rivers on the northwestern slope of the Kopetdag mountain range, the Turkmen part of Caspian Lake, Sarygamysh Lake, and freshwater aquifers. Additionally, Turkmenistan has artificial water bodies. These water bodies include Kara Kum, Turkmen Canals, the “Altyn Asyr” Lake, and all artificial water reservoirs within the country [2].

The water complex of Turkmenistan is an integral. Irrigation is the main water-consuming sector. The water complex of the country supports not only the irrigation needs of agriculture, but also the requirements of other sectors of the economy. Irrigation canals and reservoirs are the sources of water for municipal, domestic, and drinking water supplies in rural areas, and they also secure watering levels for pastures. In addition, various other uses of water are also supported, including commercial fishing, energy production, transportation, recreational fishing, navigation, and landscaping in residential areas. Nevertheless, these sectors require proper water management activities.

The management of water resources is one of the main directions of the ETUT’s environmental policy. According to environmental policy, the university developed water conservation and water recycling programs. Various innovative water management techniques have been implemented on the ETUT campus. Implementation of such innovative techniques provides the management, treatment, saving, monitoring, and recycling of water and will allow us to achieve SDGs within the ETUT.

This paper presents notable efforts undertaken at the ETUT campus to enhance environmental sustainability. These efforts include rainwater harvesting, use of water-efficient technologies for plant cultivation, and implementation of advanced methods for treating wastewater. Moreover, the university complies with national water regulations, including the Water Code of Turkmenistan, and drinking water standards, ensuring the provision of safe drinking water and protecting water resources. Regular monitoring and evaluation of water consumption data allow the ETUT to assess the effectiveness of its water policies and share experiences with the community and stakeholders.

2. Sustainable Water Management Practices

2.1. Methods of Collecting Rainwater

Rainwater harvesting is a crucial practice in sustainable water management, and the ETUT employs various innovative methods to collect rainwater effectively. These methods not only help in reducing the strain on local sewer systems but also contribute to the preservation and improvement of water quality.

2.1.1 Rain Gardens

Rain gardens are critical components of the rainwater collection strategy of the ETUT. These gardens are specifically designed to reduce the amount of runoff entering the local sewer system. By allowing rainwater to percolate into the soil, rain gardens help recharge groundwater supplies and contribute to the overall improvement of water quality in surrounding areas.

2.1.2 Permeable Pavement

The utilization of permeable pavements is another effective approach adopted by the ETUT to mitigate the impact of runoff on sewer systems. By incorporating permeable pavement, the ETUT aims to significantly reduce the volume of runoff that flows into the sewer system, thereby allowing groundwater supplies to be replenished. This approach is instrumental in promoting sustainable water management practices and minimizing the adverse effects of storm water runoff.

2.1.3 Cisterns

Cisterns play a vital role in ETUT's rainwater collection infrastructure. These water storage systems are utilized to store rainwater, which can be subsequently utilized for non-potable uses, such as irrigation. By harnessing rainwater through cisterns, the ETUT aims to reduce dependency on other water sources for non-drinking purposes, thereby conserving valuable freshwater resources.

2.1.4 Disconnection of Downspouts

The strategic disconnection of downspouts is an integral part of ETUT's rainwater collection strategy [3]. Instead of allowing runoff from roofs to directly enter the sewer system, downspouts are redirected to designated areas, such as rain gardens and cisterns, where the collected water can be effectively utilized. This approach ensures that rainwater is efficiently harvested and contributes to sustainable management of water resources.

The ETUT recognizes the significance of implementing comprehensive rainwater collection methods and is committed to promoting sustainable water management practices through the adoption of these innovative strategies.

2.2 The Fountain Water Recycling System at ETUT Campus

At the ETUT, the fountain water recycling system exemplifies a commitment to sustainability through innovative water management practices [3]. This closed-loop system is designed to efficiently collect, purify, and reuse water from fountains across the campus. The intricate design of the system incorporates various components, including pumps, filters, and ultraviolet (UV) sterilizers, ensuring that the water is treated to the highest standards before being reintroduced into the fountain network. The fountain water recycling system at the ETUT follows a systematic process to ensure recycled water quality and safety.

2.2.1 Water Collection

The system was initiated by collecting water from fountains across campus in a designated storage tank. This initial step set the stage for subsequent purification.

2.2.2 Filtration Stage

The collected water passes through a series of advanced filters aimed at removing suspended solids and impurities, thus significantly enhancing water quality. This filtration step plays a crucial role in the preparation of water for subsequent sterilization.

2.2.3 UV Sterilization

Following filtration, the water underwent UV sterilization, which is a highly effective method for eliminating harmful bacteria and viruses present in the water. UV light treatment ensures that the water meets stringent health and safety standards, safeguarding the well-being of the campus community.

2.2.4 Storage for Reuse

Sterilized and purified water is then stored in a secondary tank and ready for reuse in fountains. This storage mechanism ensures a constant and sustainable supply of clean water for vibrant fountain displays across campus [3].

The implementation of the fountain water recycling system at the ETUT not only promotes water conservation but also significantly reduces the demand for freshwater resources. By recycling water from the fountains, the ETUT minimizes water waste and contributes to the overall sustainability goals of the campus. The closed-loop system exemplifies a proactive approach towards responsible water management, aligning with the university's dedication to environmental stewardship.

The incorporation of advanced technologies such as pumps, filters, and UV sterilizers underscores ETUT's commitment to utilizing cutting-edge solutions for sustainable water reuse. The progressive design of the system highlights the university's emphasis on innovation and efficiency, thereby setting a benchmark for water recycling initiatives in educational institutions.

2.3 Water Efficient Appliances Usage

The recent upgrades of the ETUT to its restrooms demonstrate a commendable commitment to water conservation. By implementing a combination of low-flow fixtures and sensor-activated technology, university has achieved significant reductions in water usage, benefiting both the environment and community.

2.3.1 Low-flow showerheads and Small-Flow Faucet Nozzles

Traditional showerheads and faucets can use upwards of 2.5 gallons per minute (gpm). These high flow rates translate to a significant amount of water wasted during everyday activities such as showering, brushing teeth, and washing hands. The university's installation of low-flow showerheads (typically using 1.5 gpm or less) and small-flow faucet nozzles can reduce water usage by up to 50%. This reduction translates to substantial water savings over time without compromising hygiene. Low-flow showerheads often achieve this water reduction using innovative spray patterns that maintain water pressure and a satisfying showering experience [3].

2.3.2 Dual-Flush Toilets

Toilets are one of the biggest culprits of bathroom water usage. Traditional toilets can use up to 5 gallons per flush, regardless of the waste being eliminated. Dual-flush toilets address this issue by offering two flush options: full flush for solid waste and partial flush for liquid waste. The partial flush typically uses approximately 1.5 gallons, significantly reducing water consumption for situations where a full flush is not necessary. Studies suggest that dual-flush toilets can achieve a 25% reduction in water usage compared with traditional toilets. This reduction can have a major impact on a university's overall water consumption, especially considering the high number of restroom facilities.

2.3.3 Sensor-Activated Faucets

Sensor-activated faucets eliminate the possibility of water being left to run unintentionally. These faucets use infrared sensors to detect hand movements, automatically turning on the water flow when needed and shutting off when the hands are removed. This technology prevents water waste that can occur because people forget to turn off their faucets. Sensor-activated faucets are particularly beneficial in high-traffic areas where the risk of unintentional water waste is higher.

2.3.4 The Combined Impact and Looking Forward

The ETUT's multi-pronged approach to water conservation, by implementing low-flow fixtures, dual-flush toilets, and sensor-activated faucets, has the potential to significantly reduce the overall water footprint. A 50% reduction in showerhead flow and a 25% reduction in toilet flush volume, combined with the water savings from sensor-activated faucets, can lead to substantial daily water conservation. This not only benefits the environment by reducing water extraction and treatment needs, but it can also lead to cost savings for the university [3].

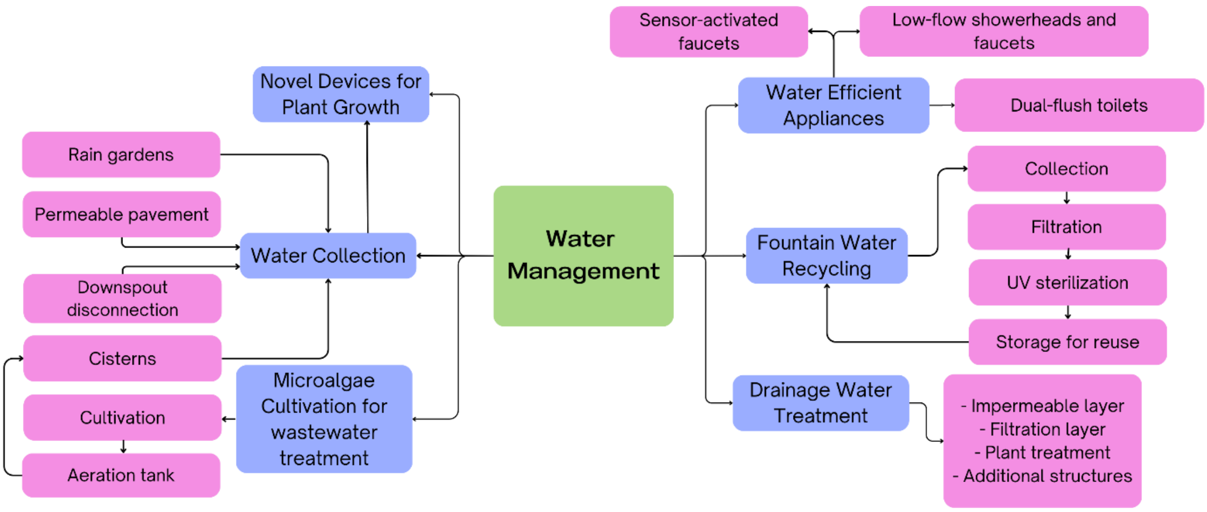

Figure 1. Water management system of ETUT

The university's commitment to water conservation serves as a positive example for other institutions and communities (*Figure 1*). By implementing water management strategies, they are demonstrating environmental responsibility and inspiring others to follow suit. Looking forward, the university could explore further water-saving measures such as rainwater harvesting for toilet flushing and irrigation, and installing water-efficient landscaping on campus. These additional efforts can further solidify their commitment to sustainability and water conservation.

2.4 Novel devices for plant growth

2.4.1 Background

Turkmenistan is in a temperate desert zone. The region has a dry and sharp continental climate. In Turkmenistan, the average annual precipitation is low, and evaporation is high [9]. This leads to an increase in natural water loss. Therefore, the possibility of using novel devices in growing fruit and ornamental trees is being studied, and research is being conducted at the

Oguz Han University of Engineering and Technology of Turkmenistan. The advanced device for plant growth performs a function similar to that of a natural phenomenon and is capable of collecting precipitation (Figure 2). It has the substantial benefit of enhancing water efficiency as compared to traditional drip irrigation methods [9].

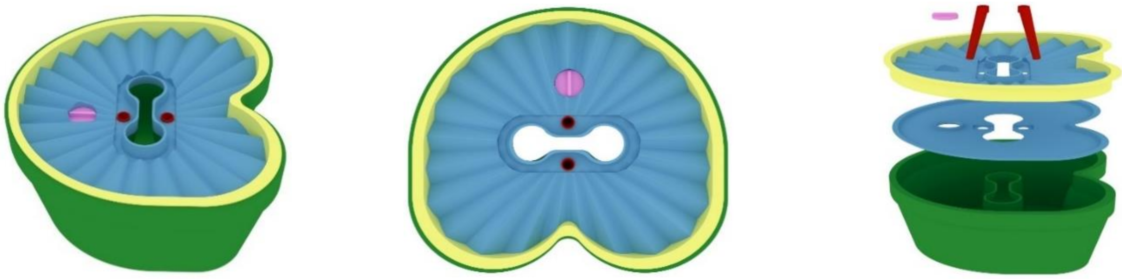

Figure 2. Structure of the novel device for plant growth

2.4.2 Materials and Method

This study was conducted in the experimental area of ETUT. Three plots (1 × 5 m each) were allocated for planting apple and biota-tree seedlings. The area of each experimental site was 5 m^2, and the total area of the experimental site was 15 m^2.

Figure 3. Planted tree plots: a) Plot 1, trees watered with a novel device; b) Plot 2, trees watered with drip irrigation; and c) Plot 3, trees watered with conventional irrigation.

Each tree in plot 1 was watered 2 times during its first year of growing in a novel device, that is, 21 liters at planting (5 liters for tree planting, 16 liters for the novel device) and 16 liters in June-July month, for a total of 37 liters of water per year. Plot 2 was watered by drip irrigation, which consumed 90 liters of water and plot 3 with conventional methods.

Trees in the plot 3 were given 5 liters of water every 5 days from May to August month of the year, and an average of 120 liters of water was consumed per year (*Figure 4*).

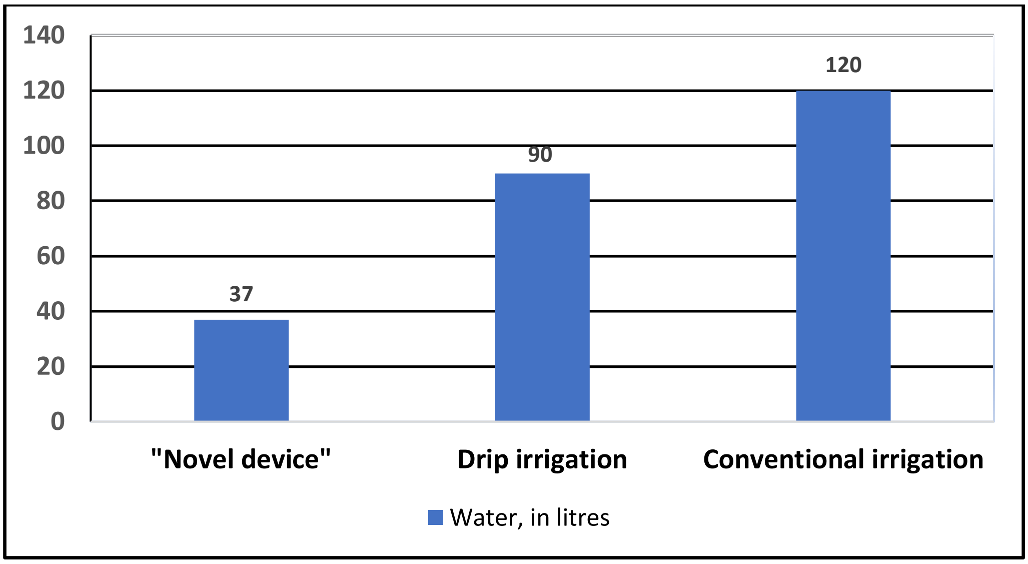

Figure 4. Comparison of the amount of water consumed to grow trees in different irrigation methods (per tree).

Further, the influence of the efficiency of irrigation methods on the biometric parameters of trees was determined. The diameter of the stem and the growth length of the seedling were measured [9] (*Table 1*).

Table 1. Diameter and stem length of trees grown under different irrigation methods

Irrigation method	**Plants**	**Diameter, cm**	**Length of seedling, cm**
Novel device	An apple tree	1,11	110,5
	Biota tree	1,91	129,0
Drip irrigation	An apple tree	1,09	110,0
	Biota tree	1,80	115,0
Conventional irrigation	An apple tree	1,14	114,0
	Biota tree	1,85	126,0

2.4.3 Result and Discussion

The results of the study demonstrate significant water savings using novel devices compared to drip and traditional irrigation methods. As presented in Table 1, while no major differences were observed in the diameter and height of the tree stems across all plots, the key finding is the considerable reduction in water consumption. Specifically, trees irrigated with the novel device utilized 37 liters of water per year, approximately 2.4 times lower than the 90 liters consumed through drip irrigation and 3.2 times lower than the 120 liters used in traditional methods [9].

These findings highlight the effectiveness of the novel device in maximizing water efficiency, particularly under Turkmenistan's arid conditions, where water scarcity is a critical issue. This device reduces natural water loss due to evaporation and mimics natural precipitation processes, capturing and storing water more effectively. The device's ability to operate efficiently in the high-evaporation environment of Turkmenistan explains its practical applicability in expanding forest areas.

Additionally, the economic benefits of adopting this novel device were calculated. From the second year onwards, the cost of maintaining trees with this device was 4 times lower than that of trees maintained through drip irrigation and conventional methods. This cost-efficiency is attributed to the reduced need for frequent watering and the reduced infrastructure required for water delivery, such as hoses and pumps for drip irrigation.

Moreover, the biometric parameters of the trees, such as stem diameter and growth length, indicated that the novel device does not negatively affect the growth rate of the trees compared to traditional methods. While the trees irrigated with the device had similar growth patterns to those using drip and conventional irrigation, the novel technology provides the additional benefit of reducing water use and economic inputs without compromising tree health and development.

In terms of ecological impact, the deployment of this novel device across larger areas could significantly contribute to the expansion of forest zones. With more water available for planting, there is potential to increase forested areas, leading to improvements in the microclimate, stabilization of groundwater levels, and enhancement of soil reclamation. This would positively affect the ecological balance by boosting biodiversity and fostering healthier ecosystems.

The long-term impacts of this technology on water sustainability and reforestation efforts in arid and semi-arid regions like Turkmenistan are promising. Not only does it hold the potential to double water savings compared to drip irrigation, but it can also achieve threefold savings when compared to conventional irrigation methods. Thus, the adoption of novel devices for plant growth could significantly advance sustainable water management and ecological restoration efforts in water-scarce regions.

2.5 Drainage water treatment

2.5.1 Background

Turkmenistan, situated at the heart of the Eurasian continent, is characterized by its distance from the world's oceans and it's predominantly desert and semi-desert climate within a temperate zone. The vast majority of its landmass, approximately 80%, is covered by the Karakum desert. Therefore, the population largely resides in oases, primarily in river valleys and foothills where surface and underground streams are present. Despite its arid nature, the Karakum desert plays a pivotal role in Turkmenistan's economy, particularly in the fuel and energy sector, owing to its abundant hydrocarbon resources.

The Karakum desert boasts a surprisingly diverse array of flora and fauna compared to other deserts globally. This biodiversity is crucial for supporting animal husbandry activities in the desert. Additionally, the expanse of arable land within the Karakum desert exceeds 15 million hectares, presenting opportunities for agricultural development. The President of Turkmenistan has demonstrated an unwavering commitment to transforming the nation, including the vast desert landscape into a flourishing oasis through effective utilization of the country's water resources. A prime example of this commitment is the construction of the "Altyn Asyr" Turkmen Lake in the Garashor Basin, located in the northwest region of Turkmenistan. This ambitious project, outlined in the "Social and Economic Development

Program of the President of Turkmenistan for 2019-2025", has not only enhanced the ecological conditions of the desert but also facilitated irrigation improvements for cultivated lands [4].

The Turkmen lake known as "Altyn Asyr" spans approximately 103 kilometers in length and 18.6 kilometers in width, with a volumetric capacity reaching 132 cubic kilometers. The lake receives saline water from two significant drainage networks: The Main Salt Drainage, stretching across 720 kilometers in total length, and the Dashoguz drainage system, which spans approximately 381 kilometers.

Turkmen Lake "Altyn Asyr" holds significant importance in bolstering the economic potential of the country, fostering the growth of agricultural and livestock industries, augmenting food production, and ensuring consistent food security for the nation. Additionally, it plays a vital role in enhancing the socio-economic conditions of the population and generating employment opportunities, with plans underway to construct numerous new cities and settlements along its shores shortly.

An artificial reservoir "Altyn Asyr" is constructed in the Karakum desert to gather rainwater, and drainage water. These waters collected from the Turkmen Lake will be subjected to specialized purification and desalination processes before being utilized as a recycled water source [10].

The agricultural drainage water is a vital component in the agricultural sector, referring to the runoff and excess water removed from fields through drainage systems. This water carries various substances such as fertilizers, pesticides, and sediments that have been applied to the fields during irrigation or other agricultural activities. The management of agricultural drainage water is significant for maintaining soil health, water quality, and crop productivity. Whether through natural or artificial drainage systems, the control and treatment of agricultural drainage water play a significant role in sustainable agriculture practices and environmental stewardship [5, 10].

This study highlights the utilization of constructed wetlands for drainage water treatment. This approach, which leverages biological cleaning methods, holds promise for addressing water pollution challenges and promoting regional agricultural development.

2.5.2 Materials and Method

The function of plant species within drainage systems in the process of drainage water purification has been investigated in the study. The study was carried out at the experimental section of the Institute of General and Applied Biology of the Oguz Han Engineering and Technology University of Turkmenistan.

The treatment of drainage water has been realized by creating vertical flow (VF) constructed wetlands. The constructed wetland consists of four parts:

- Impermeable layer;
- Filtration layer;
- Plants;
- Additional structures for water distribution through the wetland area.

The wetland has three reservoirs. Between the reservoirs is a concrete wall. The first and second reservoir beds were filled with a 40 cm coarse gravel layer, 50 cm sandy soil, and 10 cm clay soil. At the top of the layer drainage macrophytes such as common reed (*Phragmites Communis*), cattail (*Typha L.*), and other macrophytes were planted. The density of plants is on average 50 plants per 1 m^2. The flow rate in the river is about 0.01 m/h.

The cleaning efficiency of the VF constructed wetland was determined throughout the study. Water samples were taken from 2 points of the drain at the same time. Water samples were analyzed in the laboratory of the “Ecological Biotechnology” research center [5].

2.5.3 Results and Discussion

The results from the vertical flow (VF) constructed wetlands demonstrated a significant improvement in the quality of drainage water. After the water passed through the different layers of the wetland, a marked reduction in harmful substances was observed. The levels of chlorine ions decreased by nearly 50%, while the concentration of bicarbonate ions dropped to 25 mg/l, showing the system's ability to reduce salinity. Notably, the pH levels were also moderated, which is a critical factor in ensuring water suitability for agricultural purposes. However, calcium and magnesium ion concentrations remained unchanged, which may indicate the need for further refinement of the system to address these elements, especially in areas where water hardness is a concern (*Table 2*) [5].

Table 2. Drainage water test results

Tested indicators of the content of drainage water	Water content from point 1, mg/l	Water content from point 2, mg/l
HCO 3 -	518.5	494.1
Cl -	1198.99	725.71
Ca 2+	180.36	180.36
Mg 2+	103.3	103.3
pH	8.5	8.1
Hardness	17.5	17.5

The use of an impermeable layer and filtration layer in the wetland design is crucial for controlling water movement and ensuring pollutants do not escape into surrounding environments. The coarse gravel layer aids in mechanical filtration, trapping sediments and larger particles, while the sandy and clay soils create a gradient that enhances water purification through both biological and chemical processes. This stratified structure enables the system to manage water flow rates effectively, preventing stagnation and encouraging the active filtration of pollutants [5].

The plant species, primarily *Phragmites Communis* (Common reed) and *Typha L.* (Cattail), played an instrumental role in the biological cleaning process. These macrophytes are well known for their phytoremediation capabilities, actively absorbing pollutants and nutrients from the water. Their dense root systems create microenvironments that facilitate microbial activity, further breaking down contaminants. In this study, a plant density of 50 plants per square meter optimized the purification process by ensuring adequate coverage and interaction between the water and plant roots.

The ability of the VF-constructed wetland to reduce chlorine and bicarbonate ion concentrations significantly makes it an ideal for water treatment in regions where salinity is a problem, such as Turkmenistan. This reduction in salinity will enhance soil health over time, reducing the risk of soil degradation due to salt accumulation, which is a common problem in areas with high evaporation rates and intensive irrigation practices.

Moreover, while calcium and magnesium ion levels remained unchanged, this outcome suggests that further research could explore additional layers or biological treatments that could target these ions. Future work may incorporate anion exchange resins or other filtration technologies that could complement the current design, focusing on capturing ions that are not affected by the existing wetland processes.

The integration of constructed wetlands into the water management system at ETUT offers not only environmental benefits but also economic and agricultural advantages. By treating and reusing drainage water, the need for freshwater resources is minimized, making this approach both cost-effective and sustainable. The treated water, while still containing certain ions, can be reused for irrigating non-sensitive crops, further enhancing resource efficiency in the region.

In the context of Turkmenistan's broader water scarcity challenges, the successful implementation of VF-constructed wetlands represents a significant advancement in tackling water pollution and promoting the reuse of treated drainage water in agriculture. This approach could be scaled up to larger regions, particularly in the Karakum Desert, where water is a limiting factor for agricultural development. Additionally, by addressing the issue of salinity, the method contributes to the long-term sustainability of both agriculture and the environment.

Overall, if constructed wetlands combined with desalination technologies, could offer a comprehensive solution to water shortages in arid zones, further supporting the nation's agricultural expansion goals. Additionally, the ecological benefits include the creation of new habitats for wildlife, improved biodiversity, and enhanced landscape aesthetics, aligning with Turkmenistan's broader efforts to transform its desert regions into productive, sustainable ecosystems.

2.6 Microalgae cultivation

2.6.1 Background

Microalgae also represent important CO_2 consumers and primary producers – being the basis of the food chain in aquatic environments. They represent one of the most efficient converters of solar energy to biomass.

In nature, water blooms develop in eutrophic reservoirs where phytoplankton populations are only occasionally mixed by wind or flux. In these situations, biomass concentrations are much below 1 g of dry matter per liter. For centuries, natural blooms of the cyanobacterium *Spirulina* (now referred to as *Arthrospira*) were harvested in selective environments of alkaline soda lakes in Chad, Mexico, or Myanmar, and used as food. On the other hand, the present nutrient enrichment of surface waters, through several factors such as human waste, industrial effluents, and agricultural fertilizers, has caused massive developments of dangerous microalgal blooms; these represent an ecological threat due to the potential deterioration of water quality and create serious environmental problems [6].

Although several microalgal strains are cultivated worldwide for different purposes, for example, as a health food, feed additives, or as a source of bioactive compounds for pharmacology, cosmetics, or diagnostic products. The bulk of annual biomass production is represented by only three species: the cyanobacterium Spirulina and the green algae *Chlorella* and *Dunaliella*.

2.6.2 Light

Light is the most important factor for microalgal growth. The amount of photon energy received by each cell is a combination of several factors: photon flux density, cell density, length of optical path (thickness of culture layer), and rate of mixing. The light captured by photosynthetic pigments is roughly 10 times higher under full sunlight (2000 mmol photons m^2 s^1) than that required to saturate growth. In other words, up to 90% of the photons captured in full sunlight by chlorophyll and other pigments are not being used for photosynthesis and instead must be dissipated as heat and fluorescence. Consequently, the efficiency of light utilization usually drops from a theoretical value of 20% (based on photosynthetically active irradiance) to lower than 4%, roughly corresponding to an annual biomass yield of about 40 t ha^{-1} [6].

2.6.3 Temperature

After light, temperature is the most important parameter to measure and control the microalgal culture. Some microalgal strains tolerate a broad temperature range between 15 and 35^0 C (e.g., *Chlorella* and *Spirulina*), while *Haematococcus* usually requires a more rigorous regulation between 25 and 27^0 C. However, for the majority of freshwater microalgae, the optimum temperature ranges between 25 and 30^0 C [6].

2.6.4 Culture Monitoring and Maintenance

Successful cultivation requires continuous monitoring of physicochemical parameters, that is, pH, temperature, oxygen concentration, and nutrient status. The basic biological method used is a microscopic examination to detect morphological changes and contamination by other microalgae and protozoa. Nutrient status can be followed by monitoring the concentration of nitrogen, using it as a measure for adding proportional amounts of other nutrients. In the mass cultivation of microalgae, monocultures are usually required for biomass exploitation. The appearance of 'contaminants' (other microalgae as well as protozoa, bacteria, or fungi) might indicate that the cultivated culture has come under stress. Contaminants often represent one of the major limitations of large-scale production in microalgal cultures, particularly with strains that cannot be grown in a selective medium outdoors. For the cultivation of some microalgae (e.g., *Haematococcus*), the use of a closed system becomes mandatory [6].

A sufficient mixing of the microalgal suspension is necessary to ensure nutrient diffusion and a homogeneous light supply to the cells, as well as to prevent the accumulation of oxygen in the culture, particularly when they are grown in a closed system. Indeed, excessive oxygen accumulation in a culture can promote photoinhibition of photosynthesis and a decline in growth. On the other hand, excessive mixing can cause hydrodynamic or sheer stress to the cells, and consequently a similar reduction of productivity [6].

Biophysical and biochemical monitoring methods generally reflect the status of the cells' photosynthetic apparatus and are used to adjust the appropriate cultivation conditions for the production of biomass or certain compounds. The concentration of dissolved oxygen measured by an oxygen electrode is considered a reliable and sensitive indicator of photosynthetic activity in microalgal cultures [6].

2.6.5 Cultivation Systems

Closed type of cultivation systems for microalgae have been designed and constructed through the study. The choice of a suitable cultivation system and the adjustment of the cultivation regime must be worked out for each productive strain. In every cultivation system, several basic features must be considered: illumination, circulation, and gas exchange (supply of CO_2 and O_2 degassing).

Two basic approaches to microalgal mass production are used: the first applies to cultivation in open reservoirs large in area, while the second represents closed vessels – photobioreactors or fermentors. In this study, the term photobioreactor is used for closed cultivation systems using artificial illumination. Generally, production from an open pond culture is cheaper than from a culture in closed photobioreactors, but the use of the open pond is limited to a relatively small number of microalgal species. From a commercial point of view, the price of the final product is crucial [6].

These closed, controlled systems provide the necessary light, temperature, and nutrient conditions to maximize the growth and productivity of the microalgae. The use of bioreactor technology ensures efficient and reliable cultivation processes, leading to high-quality microalgae biomass for wastewater treatment.

Figure 5. Microalgae cultivation

The utilization of photobioreactors for microalgae cultivation aligns with the research center's commitment to environmental sustainability. By harnessing the natural capabilities of microalgae to purify wastewater, the center is contributing to the preservation of aquatic ecosystems and the overall conservation of water resources. This approach also reduces the reliance on traditional, energy-intensive wastewater treatment methods, thereby lowering the ecological footprint of the facility (*Figure 5*).

The cultivation of microalgae in photobioreactors is a significant achievement for the research center. Microalgae are known for their ability to thrive in wastewater environments and effectively remove contaminants such as nitrogen and phosphorus [7]. This breakthrough represents a sustainable and environmentally friendly approach to wastewater treatment, offering a promising solution to water pollution challenges.

The objective of the study was to explore the effectiveness of various microalgae strains in removing nutrients (nitrogen, phosphorus) from agricultural runoff wastewater, while also assessing the biomass yield for potential biofuel and bioproduct applications.

2.6.6 Materials and Method

Microalgae strains (*Chlorella vulgaris* and *Spirulina platensis*) were cultivated in both an open pond system and a closed photobioreactor under controlled environmental conditions. Each system was filled with 10 liters of wastewater collected from agricultural runoff rich in nitrogen and phosphorus. The photobioreactor was designed to maintain optimal light (12:12 light-dark cycle) and temperature (25-30°C), while the open pond relied on natural sunlight and ambient temperatures.

Sampling was done every three days over 14 days, and the following parameters were monitored. Nitrogen (N) and phosphorus (P) levels were measured using standard colorimetric methods. Microalgal growth was determined by measuring dry weight (g/L) after filtering and drying biomass samples. pH, dissolved oxygen (DO), and heavy metal content were monitored to assess changes in water quality.

2.6.7 Results and Discussion

The results showed significant removal of nutrients, particularly nitrogen and phosphorus, from the wastewater by the microalgae. All strains demonstrated efficient nutrient uptake, with *Chlorella vulgaris* showing the highest removal rate for nitrogen, achieving a reduction of 70% by two weeks. *Spirulina platensis* performed similarly in phosphorus removal, with a 60% reduction over the same period.

Biomass production varied among the strains, with *Chlorella vulgaris* reaching a peak biomass of 2.8 g/L by the end of the experiment in the photobioreactor, compared to 1.9 g/L in the open pond system. This indicates that the closed system provided more stable growth conditions. *Spirulina platensis* also produced substantial biomass, but its yield were slightly lower.

The pH levels in both systems remained stable (7.5-8.0), ensuring that the microalgae maintained optimal growth conditions without causing significant changes to water acidity. Dissolved oxygen levels increased over time, indicating healthy photosynthetic activity, particularly in the closed system, where DO reached 8 mg/L. Heavy metals were largely unaffected, suggesting that additional measures may be required to target specific contaminants such as lead and mercury.

The results indicate that microalgae cultivation in photobioreactors provides an efficient method for wastewater treatment, with the added benefit of biomass production. This biomass can be used for biofuels, animal feed, and other valuable products, adding economic value to the process. The reduction in nutrient levels suggests that this method can mitigate eutrophication in affected water bodies.

Moreover, the cultivation of microalgae in wastewater provides an eco-friendly solution by reducing reliance on chemical treatments and minimizing the carbon footprint of conventional wastewater treatment methods.

3. Regulatory Compliance and Continuous Improvement

ETUT’s commitment to sustainability extends beyond innovative practices to include compliance with national water regulations. The university adheres to the Water Code of Turkmenistan and drinking water standards, ensuring the provision of safe drinking water and the protection of water resources. ETUT’s compliance with these regulations underscores its dedication to environmental stewardship and responsible water management practices. Additionally, the university actively participates in regional and international initiatives aimed at addressing water-related challenges, contributing to global efforts to achieve water security and sustainability. By integrating sustainability principles into its institutional framework and operations, ETUT demonstrates leadership in environmental conservation and sets a precedent for other educational institutions to follow. Regular monitoring and evaluation of water consumption data enable ETUT to assess policy effectiveness and drive continuous improvement in its water conservation program. Through transparency and accountability, ETUT aims to foster a culture of sustainability within university's community and inspire other communities to adopt similar practices [8].

Monitoring and evaluation of Water consumption data at ETUT involves a systematic approach to track, analyze, and assess the university's water usage patterns. Here is how this process unfolds:

1. Data collection. ETUT collects water consumption data from various sources across its campus, including meters installed in buildings, irrigation systems, and water storage facilities. This data includes information on the volume of water used, the frequency of usage, and the purposes for which water is utilized.
2. Analysis. The collected data is analyzed to identify trends, patterns, and anomalies in water consumption. This analysis may involve comparing current usage data to historical records, assessing seasonal variations, and identifying areas of high water consumption and potential leaks.
3. Performance metrics. ETUT establishes key performance indicators (KPIs) to measure the effectiveness of water conservation efforts. These KPIs include metrics such as water consumption per capita, water use intensity per square foot of campus area, and the percentage of recycled water used for non-potable purposes.
4. Benchmarking. ETUT benchmarks its water consumption data against industry standards, best practices, and peer institutions to assess performance and identify areas for improvement. This benchmarking process helps ETUT identify opportunities to optimize water use and reduce waste.
5. Stakeholder engagement. ETUT engages with stakeholders, including students, faculty, staff, and local communities, to gather feedback and insights on water usage patterns and conservation initiatives. This collaboration fosters a sense of ownership and responsibility among the university community and promotes collective action toward sustainable water management.
6. Continuous improvement. Based on the findings from the monitoring and evaluation process, ETUT develops and implements targeted interventions to improve water efficiency, reduce consumption, and minimize environmental impact. These interventions include infrastructure upgrades, behavior change campaigns, and educational programs aimed at raising awareness about water conservation.

In a consequence, by continuously monitoring and evaluating its water consumption data, ETUT can effectively manage its water resources, minimize waste, and contribute to a more sustainable future.

4. Conclusion

ETUT demonstrates a strong dedication to sustainable water management and environmental stewardship through various initiatives. The utilization of rainwater collection systems is actively contributing to the conservation and responsible utilization of water resources. By harnessing the potential of water recycling, ETUT demonstrates a steadfast dedication to creating a greener and more efficient campus ecosystem. Innovative tree-growing technologies focus on water savings and ecological balance. Additionally, the installation of photobioreactors for microalgae cultivation at the research center signals a significant step in wastewater treatment and biotechnological advancements. Further, continuously monitoring and evaluating its water consumption data enables ETUT to efficiently manage water resources, reduce waste, and enhance sustainability efforts for the future. Together, these endeavors underscore the ETUT's commitment to addressing complex environmental challenges through cutting-edge science and technology.

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