Using Constructed Wetlands to Clean Wastewater from Various Sources

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Abstract. Biological wastewater treatment systems have been used for many years. Constructed wetlands are one such system. Constructed wetlands are a modern bio-engineered system which can remove many forms of pollutants from wastewater from various sources. Thanks to the varied forms and configurations of such systems, they harmoniously blend in to existing landscapes and do not disturb elements of harmony in the environment. The goal of this work is to review existing publications and research into the use of constructed wetlands in various regions to remove a wide range of pollutants from wastewater. It was determined that constructed wetlands are effective in treating urban surface runoff, industrial wastewater, and agricultural wastewater. Wetlands can effectively remove many pollutants: heavy metals (iron, copper, nickel, zinc, boron), biological contaminants, food industry waste, glycol, hydrocarbons, mineral nitrogen compounds, chlorine, radionuclides, and more. Constructed wetlands can serve as an inexpensive and easy-to-maintain solution for wastewater treatment which does not require the use of chemical or energy-intensive processes, can ensure the output of wastewater of the required quality while performing decorative and aesthetic functions, and improve the microclimate and condition of recreational areas and parks.

Keywords: Constructed wetlands · Wetlands · Wastewater · Biological wastewater treatment

1 Introduction

Constructed wetlands are modern bio-engineering systems which have been used for many years for informal wastewater treatment. There is archaeological evidence of the use of prototypes of modern wetlands in China in 2000 BC. In 1950, at the Max Planck Institute, German professor and hydrobotanist Kathe Seidel began to study the properties of wetlands used to remove a certain volume of pollutants. Later, she was joined by Reinhold Kickuth from the University of Goettingen, but the researchers subsequently began to study this issue separately, as rivals.

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In 1953, Kathe Seidel put forth Max-Planck institute–process cleaning systems, consisting of four or five stages of purification, each of which consisted of several consecutive and parallel ponds. In the mid-1960s, Reinhold Kickuth presented the root zone method. An artificial (constructed) wetland based on the root zone method was built in Othfresen (Germany) in 1974. Irrigation fields first appeared in CIS territories in Odessa (1887), then in Kiev (1894), and the Lyublinsk irrigation fields appeared in Moscow in 1898. Currently there are more than 2500 operational constructed wetlands across the world [1].

There are four types of constructed wetlands: surface, horizontal, vertical infiltration, and mixed. Each type has its advantages and disadvantages; the dominating form of pollutant in a given area determines which of these wetlands will be chosen. Figure 1 shows horizontal and vertical constructed wetlands.

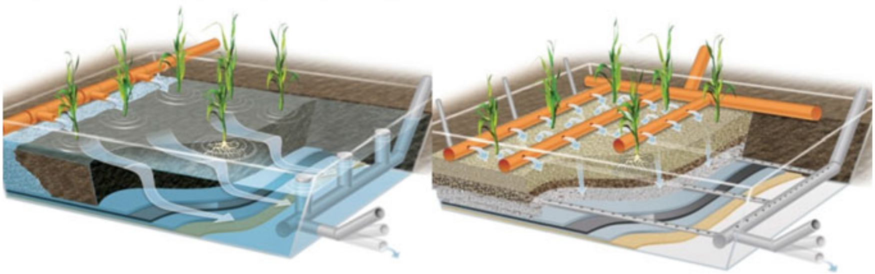

Fig. 1 Horizontal (left) and vertical flow (right) constructed wetlands [2]

The various types of constructed wetlands allows for them to be effectively integrated into various conditions. Modern systems can be placed in confined spaces without losing efficiency of wastewater treatment. For example, cone-shaped infiltration constructed wetlands have been installed on 113 m2, while treating wastewater with the same efficiency as horizontal constructed wetlands taking up 309 m2 of territory [3].

The form and configuration of the system depends on various conditions and should be chosen with respect to the climactic, topographic, geological, and hydrological characteristics of the territory and the ecological characteristics of the flora [4].

In the further evolution of these systems, various useful models were created to improve performance [5].

The experience of building constructed wetlands in various cold-weather countries, including the West (Sweden, Finland, Norway, Canada) and Russia has shown that these systems do not lose efficiency even in the winter; there is an insignificant decrease in the activity of the systems [6].

The main advantages of constructed wetlands is their low energy use, high level of purification, environmental friendliness, and ability to accumulate various types of pollutants [7].

2 International Use Cases

A large number of these systems have been built across the world. The technology has been widely used in Europe, Asia, and America. They are used to treat wastewater containing pollutants from various sources: urban surface runoff and industrial and agricultural runoff.

Constructed wetlands are widely used to treat wastewater in urban territories.

In 1998, a system was implemented to treat village wastewater in the municipality of Roussillon in the south of France. The reed beds completely blend in to the valley, which is visited by many tourists. The wastewater treatment system has a capacity of 1320 people in the peak summer season and 550 people in the off-season [8].

In 2011, a project was implemented in Chincha, Peru to build a two-stage wetland system to treat the domestic wastewater of 55 residents and staff of the Hogar de Ancianos Sta. Ana y San Joaquín y Asociación Ayuda Me Perú Retirement Home [9]. Constructed wetlands have also been successfully applied to treat wastewater in Provincial domain Huizingen, Belgium. The wetland is designed to treat domestic wastewater from a toilet building which serves up to 30 people. The treated wastewater flows into a basin with a reverse osmosis unit, where drinking water is produced from the wastewater and supplies a small fountain. The rest is discharged into a pond [10].

In Cuba, water treated by constructed wetlands is used for utilities (including flushing toilets); in Israel, treated wastewater is used for desert landscaping [11].

In addition to municipal wastewater treatment, these systems are widely used for wastewater treatment in various industrial applications.

In the Jebel Ali Free Zone, Dubai, UAE, at the seafood processing plant of Kulimer Seafood Ltd., a constructed wetland has been implemented to treat wastewater from fish and shellfish cleaning in a wetland planted with papyrus. This wastewater is reused after ozonation at the plant [12].

At the end of 2010, IRIDRA designed a wetland in Val delle Rose (Cecchi Val delle Rose, Grosseto, Italy) to provide a new winery with a treatment system. A similar system had already been successfully used for wastewater treatment at another winery operated by the same client (Casa Vitivinicola Cecchi & F.). Monitoring of this installation allowed for the operations to be optimized, both in terms of the treatment and purification and the owner's wishes for improved maintenance [13].

Constructed wetlands are widely used in the food industry to treat runoff of various origins. De Moerenaar is an artisanal cheese factory near the west coast of Belgium which produces a variety of local cheeses. Wastewater from the cheese factory and the dairy farm that supplies the milk is treated in an aerated wetland of 240 m2 [14].

In 2017, a 1650 m2 two-stage aerated wetland was put into operation to treat wastewater at Frupeco (Fruit Peeling Company) in Lendelde, Belgium, which processes various types of fruit for fruit salads and packaged fruit for restaurants and grocery stores [15].

Dufftown Distillery, owned by Diageo (Scotland, UK), produces 4 million liters of whisky per year. The distillery produces wastewater containing significant amounts of copper, which is leached from the distillation cubes during distillation and treatment. An 800 m2 horizontal reed treatment system was designed and constructed to remove soluble copper from the distillery wastewater [16].

Wetlands can be used to solve airport wastewater problems. The Mayfield Wastewater Treatment Plant was commissioned in 2001 and designed to treat runoff from the southern catchment area of Heathrow Airport, London, UK. The runoff is contaminated with glycols from de-icing. Treatment of glycol contaminated runoff is a challenge faced by every airport in winter in cold climate areas [17].

Constructed wetlands have proven themselves effective for the treatment of very specific wastewater. For example, the treatment of wastewater from a firefighting training center at an international airport (Teeside Airport in County Durham, UK) [18].

Wetlands are capable of providing efficient treatment of urban surface runoff: from parking lots (shopping centers, city facilities, etc.), from gas stations, and from sidewalks. The IKEA warehouse in Peterborough (Peterborough, UK) works as a distribution center for IKEA outlets in the region. The warehouse itself is of considerable size and forms a significant catchment for rainfall. The runoff from the warehouse generated during rainfall requires treatment before being returned to the environment [19].

The city of Genk, Belgium has an effective constructed wetland that treats runoff from a 1-hectare sidewalk and water from street washing [20].

A constructed wetland is an environmentally-sound technology to prevent the eutrophication of water bodies as a result of anthropogenic activity. This technology can launch the biological self-cleaning of water bodies. This includes preventing the massive, uncontrolled spread of phytoplankton and restoring the oxygen regime. Including flowers in the wetlands achieves decorative and aesthetic goals while improving the microclimate and the condition of recreation areas and parks [21].

A number of modern studies aim to utilize constructed wetlands to restore recreational resources. In this case, constructed wetlands are used as a regeneration area—they support the efficient clarification and treatment of water; contribute to the restoration of the ecosystem of the recreational area; and minimize costs, as no additional equipment is required [22]. Due to the production and release of wastewater from many nearby enterprises, thermal power station TETs-1 at Lake Kaban (Kazan, Republic of Tatarstan) became unsuitable for lounging and bathing. A project developed by the Russian-Chinese consortium Turenscape + MAP architects, a cascade phyto-purification system entitled “Elastic Band. An Immortal Legend of Kazan”, was chosen to treat water at the site. A unified concept was created for the development of the embankments of the Kaban lake system: the Upper, Middle, and Lower lakes, starting from the channel adjacent to Bulak and up to the site where the Sabantui of the Privolzhsky district is located. It has been proposed to supplement the lake embankments with floating gardens (constructed wetlands). The Lower Lake Kaban phyto-purification facilities are located across several tiers. Water is supplied to the facilities through a 15-m channel. Wastewater, having passed through a system of water cascades with planted plants, is purified before entering Lake Kaban [23].

Zero emissions are a common goal for sustainable development, especially for industrial production. Tertiary treatment of constructed wetlands may be a suitable solution to close the loop. The constructed wetlands at Changshu Advanced Materials Industrial Park, Haiyu City, Jiangsu Province, China, are not just for water reclamation. They serve as a landing pad for people seeking nature and endangered species in an industrialized area. Created as a beautiful park, the wetland provides recreation while also serving as a buffer strip between chemical plants and urban areas. The Wetlands Visitor Center, with its rooftop and water level terraces, offers a stunning new view [24].

One of the most serious environmental hazards that must be addressed is the generation of wastewater by mining and mineral processing. In addition to wastewater generated directly from smelting and refining, existing pollutants also contaminate groundwater. Abandoned mines also pose a threat—water passes freely through the tunnels and accumulates existing pollution. Studies conducted by a number of Russian institutes clearly demonstrate the effectiveness of these facilities in removing pollutants from wastewater, including iron (common reed planted in an area irrigated with polluted wastewater accumulates 4 times more iron at the end of the growing season than reed not irrigated with the same water) [25, 26].

Quarry wastewater is very often contaminated by mineral nitrogen compounds, which are produced by blasting using nitrogen compounds. A study conducted on a retention pond collecting mine waters from the vast territory of the Kirovogorsky quarry of AO OLCON (mining and processing plant in Olenegorsk, Murmansk region) resulted in the development of an innovative technology for mining wastewater treatment. After implementing floating wetlands, ammonium nitrogen content in the water at the outlet of the sedimentation tank decreased from 3.7 times (July) to 2.1 times (October); nitrite nitrogen content throughout the experiment was below the threshold [27, 28].

A group of researchers performed laboratory experiments and developed a new method of constructing floating constructed wetlands which can extract radionuclides (cesium-137 with activity of 1.5 kBq/l.) from wastewater [7]. There are publications proving that higher aquatic plants are able to extract uranium, radium, and thorium from wastewater [1].

Properly selected remediation agents can achieve the extraction of various heavy metals from wastewater, including copper, nickel, iron, zinc, and boron ions [1, 4]. In addition, experiments on increasing the level of purification have been carried out [29].

In 2021, Zhitnitsa Kryma APH and the Biopositive Construction and Resource Conservation engineering center of V. I. Vernadsky Crimean Federal University presented the Constructed Wetlands project, which includes an environmentally-friendly and cost-effective technology for wastewater treatment. This system can return about 100 million m3 of water which has entered the sewerage system (no less than three volumes of Simferopol reservoir). After treatment, the water will meet the requirements of the State Sanitary and Epidemiological Rules and Hygienic Standards of the Russian Federation [11].

Water scarcity from arid and semi-arid regions forces researchers to look for alternative means of extracting and utilizing water. One excellent alternative is to use treated municipal wastewater for irrigation. From 1991 to 1995, several experiments on macrophytes and artificial wetlands were conducted in the laboratory of the ECOSERVICE Scientific Consulting Center in Tashkent, Uzbekistan. A riverbed and floating constructed wetland with macrophytes were designed and built. These systems proved to be highly effective in removing pollution within a few days after installation. A bioengineered infiltration structure (BIC) with macrophytes was installed in 2000 in Karakalpakstan, located in the semi-arid northwest of Uzbekistan to provide drinking water to small communities. Concentrations of total nitrogen, phosphorus, and organic matter were reduced 10–100 times. Chemical analyses showed that 22–38% of organic pollutants were removed in the BIC pond and the remaining 62–78% were removed in the filtration zone via the biological activity of macrophytes and biocenosis. Floating structures were used in the drainage channel to prevent soil erosion and improve water quality [30].

In Turkmenistan, researchers conducted experiments on using wetlands to treat lake Altyn Asyr and its drainage reservoirs at the Ecological Biotechnology R&D center of the Oguz Khan Engineering and Technical Institute. In their studies, wastewater was passed through a 100 m long wetland. As a result, chlorine ions were reduced by 2 times and the concentration of bicarbonate ions was reduced to 25 mg/l, which allows treated water to be used to grow fodder plants and create forest areas in the Karakums [27].

3 Conclusion

The literature analysis has shown that constructed wetlands are a modern highly effective biological system which can be used to treat wastewater from various sources. For effective operation, the correct species, form, and variety of native plants must be chosen.

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