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Design of constructed wetland systems for cold climates

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Abstract: This study was conducted in order to treat domestic wastewater in Karaurgan village which is located in Sarikamis, a district of the city Kars and on which the most severe weather conditions of Turkey prevail. Karaurgan village which consists of two neighborhoods and one center is located 38 km from the district Sarikamis. During the time when work is carried out (2007), the population of the village is approximately 750 and the number of households is around 750. It has been recorded that the domestic wastewater that originates from the village is discharged directly into the stream even without being retained in a septic tank. This stream that is also known as Karaurgan stream is one of tributaries of Aras river. The treatment system project that has been designed specifically for this village in order to ensure hygiene and prevent other environmental problems caused by domestic wastewater comprises 2 parts. Imhoff tank system that is known as the pre-treatment constitutes the first part while SFS-h or HF (submerged horizontal flow) which is known to be less problematic under cold climate conditions constitutes the other. It is planned that if the required treatment conditions are met within the scope of treatment system, the wastewater treated will be used as water source for irrigating forage plants. It is planned that minimum BOD_5 removal rate be 92% according to the treatment system project designed.

Key words: Cold climates, constructed wetlands, CW design approach, low cost treatment

Soğuk iklimler için yapay sulakalan sistemi dizayn yaklaşımı

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Özet: Bu çalışma Türkiye'nin en sert iklim koşullarının hüküm sürdüğü alanlardan biri olan Kars ili Sarıkamış ilçesi Karaurgan köyü evsel atıksularının arıtılması amacıyla gerçekleştirilmiştir. İki mahalle ve bir merkezden oluşan Karaurgan köyünün Sarıkamış ilçesine uzaklığı 38 km'dir. Çalışma döneminde (2007) köy nüfusu yaklaşık 750 olup hane sayısı ise 130 civarındadır. Köyden kaynaklanan evsel atıksular herhangi bir foseptikte dahi alıkonmadan doğrudan dereye deşarj edildiği kaydedilmiştir. Karaurgan deresi olarak bilinen bu dere Aras nehrinin yan kollarından biridir. Evsel atıksuların özellikle hijyen açısından ve yarattığı diğer çevre sorunlarının önlenmesi amacıyla bu Köy için projelendirilen arıtma sistemi 2 kısımdan oluşmaktadır. Bunlardan ilki ön arıtım olarak imhoff tank sistemi, diğeri ise soğuk iklimlerde daha az sorunlu olarak bilinen SFS-h ya da HF (submerged horizontal flow) olarak bilinen sistemidir. Arıtma sistemi gerekli arıtma koşullarını sağlaması durumunda oluşan arıtılmış atıksuların yem bitkileri yetiştiriciliğinde sulama suyu olarak kullanılması planlanmıştır. Hazırlanan arıtma sistemi projesinde minimum BOD_5 giderim oranı %92 olarak planlanmıştır.

Anahtar kelimeler: Soğuk iklim, yapay sulakalanlar, CW dizayn yaklaşımı, düşük maliyetli arıtım

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1. Introduction

Studies show that constructed wetland systems are operable under all climate conditions (Biohabitats, 2021). However; taking some measures regarding isolation and opting for design approaches that are more protective against cold weather rather than conventional design help us to increase treatment efficiency. It has been reported that the reason why constructed wetland systems are less popular in North America is because conventional constructed wetland systems freeze under such climate conditions (Wallace et al., 2001). In the same study (Wallace et al., 2001), it is reported that, through mulching of a treatment system, significant success has been achieved in terms of resistance against freezing and treatment performance has increased and BOD_5 removal rate exceeded 90% in the second year especially following engagement of the system (Wallace et al., 2001). In Norway where the average temperature drops below -10°C during winter, BOD_5 removal rate in two different constructed wetland systems built for treatment of domestic wastewater ranged between 85 and 93% and 'e-coliform' removal rate was 99.9% (Maehlum et al., 1995). In a study conducted about effects of seasonal changes on performance of hybrid constructed wetlands, it is reported that TN, NH_4-N and NO^{-3}-N efficiency is reduced starting from January and until the end of March (Mietto et al., 2015). In the same study (Mietto et al., 2015), has established that 14.2 °C is the breaking point for TN and NO_3-N removal (Mietto et al., 2015). In a study conducted about a constructed wetland system in which different plants are used within the temperature range of 12-28 °C, a linear relationship has been established between increase in temperature and nitrification efficiency and it has been shown that growth rate of rhizosphere is higher in the root than that in non-root parts (Peng et al., 2014). This shows that oxygen level in plant's root is much higher than that in other parts of the plant and is an indicator of oxygen-carrying mechanism in a plant's root. Results obtained from a constructed wetland system operated at -4 °C and below for 2 years in Tianjin city that is located on the northern region of China have been found to be satisfactory and it has been established that effluent concentrations for BOD_5, TN and TP parameters are below 20, 15 and 0.6 mg l^{-1} respectively (Yin and Shen, 1995). In another study in which performance of different types of constructed wetlands that operated under cold climate conditions were examined in detail, it is reported that these systems that are implemented on several parts of the world have BOD_5 removal performance that is over approximately 70% and TN removal performance over approximately 45% (Wang, et al., 2017). Different techniques which are cost-effective and profitable are used to increase treatment efficiency during winter in places where cold climate conditions prevail. According to one of these techniques, heat that is produced during composting of animal manure (pig) raises wastewater temperature in constructed wetland system from the range of 9.2–13.6 °C to 15.7–21.7 °C (Zhang, et al., 2015). This, without doubt, contributes to treatment efficiency in terms of several parameters. Under cold climate conditions, treatment efficiency of not only wetland systems but also other conventional wastewater treatment systems is decreased. If sufficient space is found and a wetland system is added behind the conventional wastewater treatment systems (generally for secondary treatment systems) in order to prevent this, treatment efficiency can be increased significantly. The removal on the first year of a constructed wetland system of 21 ha built for the purpose of improving nitrogen removal by 50% in the wastewater treatment system of a Swedish town with population of 12500 was 720 kg ha^{-1} (Wittgren and Tobiason, 1995). P removal rate of 90% is foreseen by use of sand, that is rich in calcium and iron, as different approach method and as a filling material for the purpose of increasing treatment efficiency in wetland systems during the winter (Jenssen et al., 2005). It is known that constructed wetland systems are used successfully for treating wastewater that originates from several fields besides domestic wastewater treatment. One of these is treatment of polluted river water. In a place with cold climate conditions, COD and TN removal was approximately 92% and 56% respectively in a horizontal flow constructed wetland system through which polluted river water is treated by use of *Potamogeton crispus* plant (Fan et al., 2016).

According to the literature review and field studies, there are 2 studies planned or implemented for cold climate conditions in Turkey. One of them is a constructed wetland system designed for Demirgeçit village in Erzurum province. The study is the Subsurface Flow System, which is designed for 350 people and includes a bulrush plant (Kuslu, 2019). In this designed system, no insulation against freezing is taken into account. However, the root depth of the selected plant is relatively shorter. This may leave the root zone relatively weak against freezing in cold climates. Another study was carried out in Kotandüzü village of Erzurum province. The constructed wetland system applied here is the “Vertical Flow System”. Since the system is vertical flow, it has been observed in the field studies that the wastewater pipes are out of service in freezing winter conditions.

The purpose of this study is to treat domestic wastewater in Karaurgan village that is located in a rural area through a system with low initial investment cost and low operational cost and to determine the treatment level of constructed wetland systems in this region that is one of the coldest parts of Turkey.

2. Material and Method

2.1. Description of the studied area

Karaurgan village is a settlement unit that is situated on the east side of Turkey (“40°24’ 40. 50’’ N, “42° 27’ 91.19’’ E and the altitude of 1855 m) (Figure 1). The village with approximate population of 750 and where continental climate conditions prevail. According to General Directorate of Meteorology data for 2021, its climate type is categorized as cold for winter (-8.42), mild for summer (16.09) based on Trewartha climate classification and its rainfall effectiveness index is indicated as very humid based on Erinç climate classification.

The village encompasses several institutions such as a boarding primary school, high school, police station, Agricultural Credit Cooperative and a health care center. Images of the village are included on Figure 2.

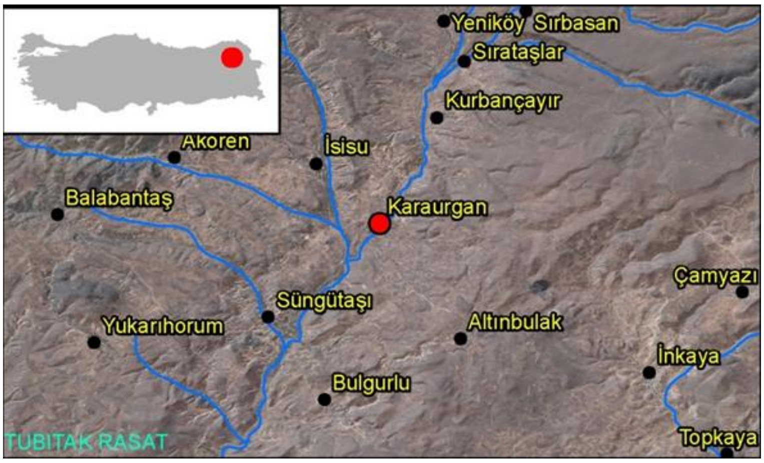

Figure 1. The studied area (Karaurgan village)

Figure 2. Images from the village of Karaurgan in the winter period
(*Photo: Osman Ağar/SÜRKAL*)

In this study treatment system is designed after taking into consideration several criteria including climate conditions of the village, current population, socio-economic level, whether there is any sewage system, whether the treated wastewater will be utilized or for which purpose, whether there is enough space of treatment, whether there are any analysis results obtained for wastewater and water consumption level of the village.

3. Result and Discussions

Sewage system was not available in Karaurgan village when the study was initiated. Therefore, a measured analysis result and flow rate values are not available. However, construction and engagement of a sewage system has been planned by the relevant competent authorities, primarily SÜRKAL (Sustainable Rural and Urban Development Association) until the planned wastewater treatment system is built. Nevertheless, as the village comprises two neighborhoods and a center, it has been planned that sewage system be connected to the treatment system through 4 main lines. It is planned that wastewater be directed to sand filtration before being discharged into the treatment system. It is considered that they will be discharged into 'imhoff' tank that will function as a means of precipitation and pre-treatment, thereafter. The reason why imhoff tank is preferred is because its operation and treatment performance is much easier than other similar systems. It is designed in a way that a certain amount of treated water that leaves the Imhoff tank is discharged into constructed wetland system which is the principal system. It is foreseen that treated wastewater be used to irrigate agricultural fields of 400 da which belongs to the village and where forage plants are grown mostly. As wastewater flow rate has never been measured for Karaurgan village, flow rate per person is considered as 100 l d^{-1}. It is much lower in reality. All of the other design parameters are given on Table 1. Imhoff tank and constructed wetland system designs are shown on Figure 3, Figure 4 and Figure 5 respectively.

Table 1. Design parameters for the treatment system

Design parameters	Accepted and calculated values	Units
Number of population	750	*pe (person equivalent)*
Qmn (Mean daily flow)	75	$m^3 d^{-1}$
Inlet organic load (after Imhoff tank) as BOD_5	250	$mg\ l^{-1}$
Imhoff tank volume	53,5	m^3
Wastewater retention time (Imhoff tank)	17	*hour*
Organic load per capita	25	$grBOD_5\ pe.d^{-1}$
Water minimum temperature	4	*°C*
Water height in the bed (HF)	0.70	m
Hydraulic gradient of the SFS-h or HF beds (S)	0.010	-
Slope of the beds	1	%
Porosity of the filling media (n)	0.35	*Ø 8 mm*
Theoretical hydraulic conductivity (ks)	500	$m^3\ m\text{-}^2\ d^{-1}$
BOD effluent after SFS-h	20	$m\ l^{-1}$
Removal with water temp= 4° C as BOD_5	92	*%*
Total hydraulic residence time (SFS-h)	2,3	*d*
Configuration	3 HF Beds	*3 parallel lines-1 stage*
Area of a single bed	600	m^2
Width	30	*m*
Length	20	*m*
Inlet depth	0,55	*m*
Outlet depth	0,85	*m*
Proposed minimum insulation cover (depends on the material)	25	*cm*
Total area	1800	m^2

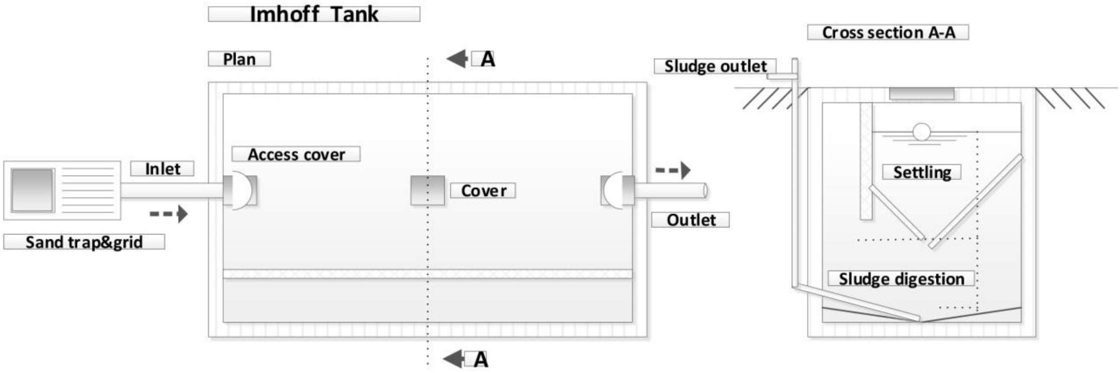

Figure 3. Imhoff tank system required for pre-treatment

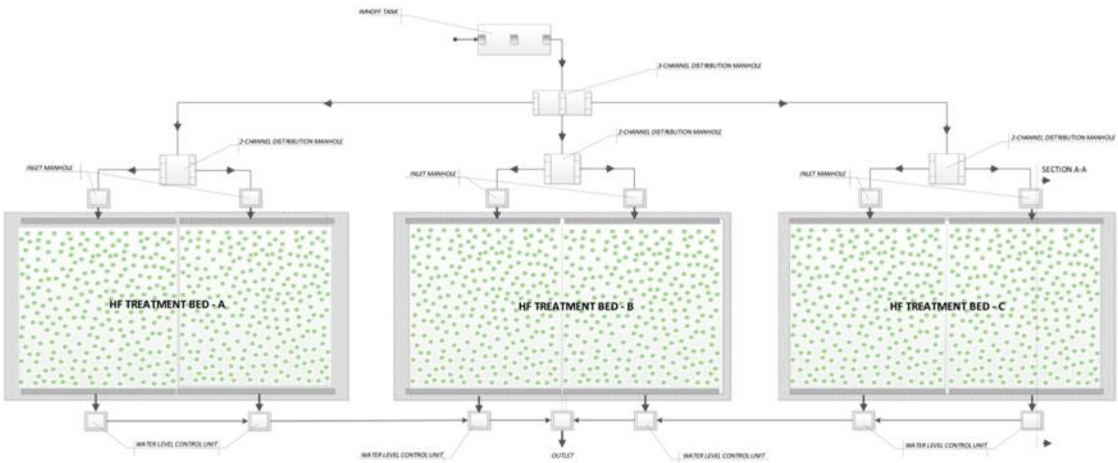

Figure 4. SFS-h or HF Constructed wetland system (Plan view)

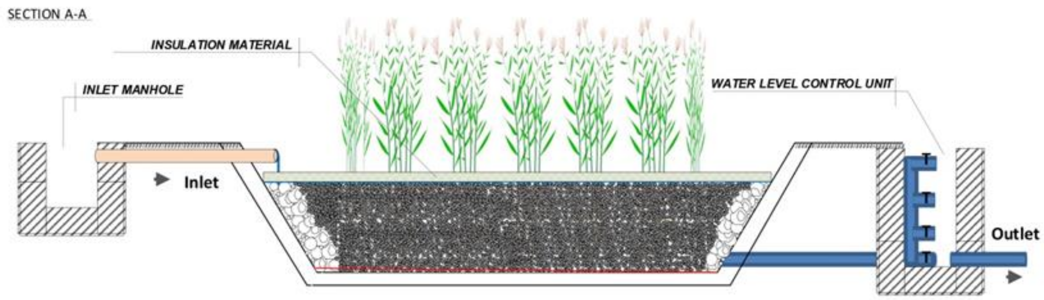

Figure 5. SFS-h or HF Constructed wetland system (Section A-A view)

Constructed wetland system designed and known as SFS-h or HF (submerged horizontal flow) is a natural treatment system according to which mainly gravel filling material of specific diameters that help plants to adhere is available in the treatment bed and into which wastewater that is subject to pre-treatment the least (or kept in the settling tank for at least 2 hours) is planned to be discharged. The plant that is planned to be used in this system is *Phragmites australis* the supreme performance of which has been proved even under the most extreme climate conditions. It is foreseen that the treatment system bed be coated definitely with an impermeable material. While HDPE (High Density Polyethylene) or LDPE (Low Density Polyethylene) geomembranes can be used to ensure impermeability in the treatment bed, based on economic conditions or availability of materials, compressed clay with thickness of 10 cm approximately can be also as impermeable.

Meeting isolation conditions as much as possible in order to keep treatment performance at a certain level in cold climates would affect treatment efficiency directly. Therefore, coating treatment bed with various plant wastes (fodder, straw etc.) after construction of the treatment system and growth of the treatment plant determined for the system would increase isolation coefficient. Besides that, it is thought that leaves, seeds and similar residuals that arise from treatment plants would create a layer on the surface in time and, as such, contribute to the isolation. Moreover; it is foreseen that snow thickness that increases in the region where snowfall is heavy will prevent icing and therefore ensure natural isolation.

4. Conclusions

In this study, it has been considered that if the construction of treatment system is completed, performance of constructed wetland systems under cold climate conditions will have been examined for the first time in Turkey. As such, it is thought that it will be useful in terms of improving the system by evaluating the data obtained from this system, implementing different hybrid constructed wetland systems, determining its effects as water source for irrigation and, consequently, enhancing widespread impact of the system. Other benefits that are expected to be driven from implementing the project are as follows:

- Domestic wastewater will have been treated by use of the most suitable method under regional conditions.
- It will be a model system that can be applied to all settlements with a population of less than 2000 in the region.
- As domestic wastewater will be utilized for agricultural fields during irrigation time and the recipient medium in other times, environmental damage will have been prevented.

- Pathogen organisms in domestic wastewater will have been reduced below a certain level and it will be useful for both public health and environmental health.
- Problem of odor that is caused by wastewater will have been eliminated.
- Visual pollution caused by wastewater will have been prevented.
- Health problems that arise from flies and other vectors originating from wastewater will have been minimized.

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Ethics committee: This article is not a study that requires ethics committee approval.

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