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LAND BASED SOURCES POLLUTION MANAGEMENT IN A SUB-BASIN CATCHMENT AREA OF A FRESHWATER LAKE: A CASE STUDY

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Abstract

This study has been conducted in Hoyran, a sub-basin of Lake Egirdir which is the second largest freshwater lake of Turkey. Total population of this sub-basin is approximately 35000 people. Untreated domestic wastewater is discharged into the main drainage channel which passes through sub-basin together with the agricultural return flow. This main drainage channel carries domestic wastewater and agricultural return flow directly to Lake Egirdir. The main purpose of our study is to enable treatment of domestic wastewater and agricultural return flow through sustainable systems. In this study, it has been planned that wastewater of 6 settlement units to be treated through constructed wetland systems which will be built individually. This study aims to treat wastewater of 2 settlement units and agricultural return flow through riverine constructed wetland that is planned to be built inside the main drainage channel. Removal of organic compounds has been taken as basis for treatment systems designed within the scope of this study. In this regard, average Biological Oxygen Demand (BOD_5) values measured at wastewater discharge points of settlement units ranges between 200 and 350 mg/L. Additionally, other parameters which are analyzed in the main drainage channel are Dissolved Oxygen (DO), pH, Electricity Conductivity (EC), Chemical Oxygen Demand (COD), Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS). Average values of these parameters are 2.7; 7.8; 724; 500; 63.2; 12.2; and 174 mg/L, respectively. When these planned systems were constructed, the targeted range of BOD_5 removal rate was 76-99.9%.

Keywords: catchment, freshwater, lake, pollution

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1. Introduction

It is quite difficult to manage classical biological wastewater treatment systems due to factors such as initial investment costs, requirement for qualified personnel, chemical substance and electricity consumption. Therefore; sustainable treatment technologies with lower cost, which do not consume electrical power and chemical substance and which do not require qualified personnel are recommended in rural areas. In this study, socio-economic structure of the field studied is evaluated. When the general structure of settlements was reviewed, it was determined that the main source of revenue is agriculture and economic and academic level is mostly satisfactory. Especially cherry production has been recorded as one of the most important source of revenue within the agricultural sector. It has also been determined that municipalities situated in the basin have been making great effort to resolve the domestic wastewater issue in order to preserve the lake and the environment. However, as the municipalities situated within the basin do not have a strong economic structure, they have not yet constructed a treatment system that consumes electricity and chemical substance. Moreover, it is

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another economic burden to employ qualified stuff who can operate a classical treatment system in the municipalities situated within the basin. Therefore, this study differs from others in the sense that propose a sustainable treatment system, as an alternative, that does not consume electrical power and chemical substance. Moreover, this study also addresses the qualities of the most suitable treatment systems in this basin and similar fields where agricultural activities are carried out intensively. As such, it was also put forth that a drainage channel can be turned into a system through which agricultural return flows can be treated. In other words, the way how domestic wastewater which is discharged into the main drainage channel after getting treated through CWs in this sub-basin becomes subject to an additional treatment together with ‘agricultural return flow’ that is planned to be treated through ‘riverine wetland’ which will be constructed again in this drainage channel. As such, both domestic wastewater and agricultural return flow will be treated together before they reach Lake Egirdir. One of the most important and distinctive features of this study consist in the fact that ‘riverine constructed wetland’ that is planned to be constructed in the main drainage channel is 3500 m long. This feature is quite different from popular systems.

Lake Egirdir is located within Antalya Basin which is situated in the south of Turkey and is the second biggest freshwater lake that is drinkable (Fig. 1). This study has been conducted in the sub-basin of Lake Egirdir and which is named as Hoyran (Fig. 2). This sub-basin has 14 settlement units. Among these, domestic wastewater and agricultural return flows of the settlement units Uluborlu, Uluğbey, Senirkent, Yassıören, Büyükkabaca, Ortayazı, Dereköy, Küçük Kabaca affect Lake Egirdir directly. Therefore, detailed field works have been conducted and natural domestic wastewater treatment systems have been designed for 8 settlement units that affect the lake directly. On-site treatment systems have been recommended or constructed for the remaining 6 settlement units. As such, effects of these 6 settlement units have been taken under control. It is essential that the Egirdir Lake, which is very valuable for Turkey and the region in which it is located, is used at the maximum rate in the future by preserving its potable water feature. In order to achieve this goal, it is important to treat the domestic and agricultural return waters in this Hoyran sub-basin, the second polluting zone of the lake.

In order to protect the lake from agricultural, domestic and industrial wastewater pollution, several studies were conducted in the Lake Egirdir basin which is a home to intensive agricultural activities. Examination of the studies has shown that, based on the characteristics of the field of study, the most sustainable method for agricultural and domestic wastewater treatment is natural wastewater treatment systems. Among the natural wastewater treatment systems, constructed wetlands (CW) have been preferred as they are regarded as the most popular and feasible ones.

As is known, constructed wetland (CW) systems have been used as eco-engineering treatment method for decades to treat water of very different characteristics from mine drainage waters to domestic wastewater (Wu et al., 2015). These systems are considered as natural systems which provide multi-directional service in social, economic and environmental terms (Thorslund et al., 2017).

First trials of ‘constructed wetland’ began in 1950s in Germany by use of Wetland macrophytes (Vymazal, 2010). These systems are being used mostly for treatment of domestic wastewater for many years and several important researches in this field have gained momentum especially since 1990s and books and guidelines started to be published within less than 10 years (AMS MAN, 2017; Brix et al., 2000; Brix, 1997; CH2M HILL Canada Limited, 2014; Ellis et al., 2003; Haberl et al., 2003; Kivaisi, 2001; Sundaravadivel and Vigneswaran, 2001; Tanner and Kloosterman, 1997; Vymazal, 2005).

Fig. 1. Lake Egirdir basin

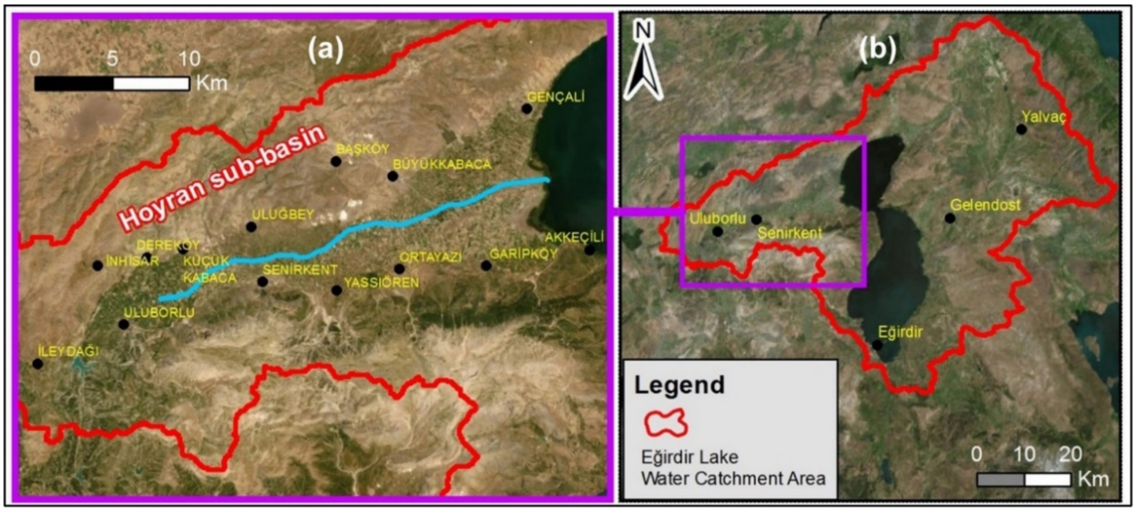

Fig. 2. (a) The main drainage channel passing through Hoyran sub-basin center and (b) Hoyran sub-basin

Consequently, CWs can be regarded as a treatment method being feasible alternative to conventional treatment systems (Zhang et al., 2014).

These systems are effective in nitrate removals rather than N removal. Removal rates are 90% and exceed 60% for total N (Beutel et al., 2009). Average treatment yields of different plants used in a constructed wetland model study and built for treatment of urban stormwater are 67, 87, and 62% per day for NO^{-}_{3}, NH^{+}_{4}, and PO_4^{3-} respectively (Johengen and LaRock, 1993). Removal rates of 43% to 67% were achieved by increasing hydraulic loading for removal of organic substance that arises from earth particles in agricultural stormwater (Braskerud, 2002).

Riverine wetland systems' are also one of the most effective methods for removal of diffuse pollutions. For example, first attempts were made through constructed wetlands in 1970s for removal of pesticides, which are among diffuse pollutions; however, they became popular in 2000s. In the studies conducted during such years, it was determined that the pesticides with the highest removal rate were organochlorine, strobilurin/strobin, organophosphate and pyrethroid group, while those with the lowest removal rate were triazinone, aryloxy alkanoic acid and urea (Vymazal and Brezinova, 2015).

It is indicated that combinations of pond - CWs systems used for treatment of urban stormwater remove high amount of TSS besides pre-treatment and storage and prevents occlusion of CWs. Aside from that, it has been reported that combination of Vertical Flow Constructed Wetland (VFCWs) and Horizontal Flow Constructed Wetlands (HFCWs) can result in more effective N removal (Li et al., 2010). However; high degree nitrate removal performance should not be expected in treatment of agricultural return flows with low C/N rate (Wu et al., 2014). However, in some studies, it is indicated that usage of CWs led to an effective N removal and, as such, agricultural nitrogen and nitrate in 'non-point sources' were removed significantly (Hernandez and Mitsch, 2007; Poe et al., 2003). It has been underlined that constructed and restored wetlands have significant potential in minimization of nutrients in agricultural drainage waters. However, while both of these systems are effective in N removal, they are not always effective in P removal (Ballantine and Tanner, 2010). As a result, when all the systems are generally evaluated, wetlands act as an effective nutrient pool for years in the absence of excessive nutrient loading (Mitsch et al., 2005).

Nevertheless, as this study aims maximum efficiency, both domestic and diffuse pollution were treated together in the same treatment bed by use of riverine wetland systems. Specifically, the main problem in treatment of agricultural stormwater with low C/N rate, which contains high amount of nitrate, is insufficient C source because removal of effective amount of N requires denitrification.

However, agricultural stormwater contains only small amount of C source which is required for denitrification and this leads to insufficient denitrification. As this system that is studied also encompasses domestic wastewater, there is not any problem in terms of C source. As such, high amount of N removal is possible.

The novelty of this study consist in combining different ecological treatment methods and creating a model which puts forth feasible and sustainable treatment systems that can be suitable for Lake Egirdir and other critical areas with similar features.

2. Method

First of all, the points into which domestic wastewater of settlement units are discharged were determined in the field of study (Fig. 3). At such points, both wastewater flows were measured and parameters of wastewaters were measured on site. Flow rate measurement has been carried out as "measuring the flowing volume for a certain period of time", which is a kind of method specified in the regulations (RG, 1991). Apart from that, wastewater samples required for the determination of other parameters were taken in accordance with the principles given in RG (1991).

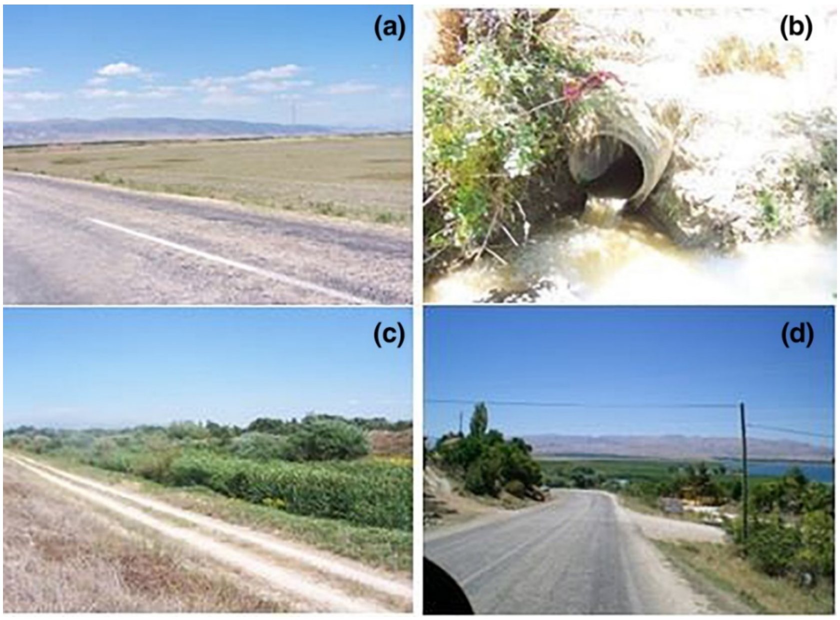

Fig. 3. Some pictures from the studied area: (a) Tokat location; (b) Ulugbey wastewater discharge point; (c) A view of the main drainage channel and the secondary road next to it; (d) Kayaagzı location

Table 1. Analyzed parameters and their analysis methods

Analysis parameters	*Sampler container*	*Min. Sample amount (milliliter)*	*Sample protection*	*Max. recommended storage time*	*Analysis method*
pH	-	20 - 100	On-site analysis	2 hours	(*) SM- 4500- H^+ B Elektrometric
Temperature (^{0}C)	(**) P/G	---	On-site analysis	---	Thermometer
EC (µS/cm)	P/G	500	+4 ^{0}C	28 days	SM-2510 B Lab. Method
DO(O_2 mg/L)	C	300	On-site analysis		SM- 4500- O G Membrane Electrod
TSS (mg/L)	P/G	500	+4 ^{0}C	2 days	SM- 2540 D Gravimetric
TN (mg/L)	P/G	500	pH<2 with H_2SO_4	1-6 months	SM-4500- $N_{org.}$ B+SM-4110 B Ion Chromotography
Toplam P (mg/L)	P/G	100	pH<2 with H_2SO_4	30 days	SM- 4500 P D Tin Chloride
BOD_5 (mg/L)	P/G	200	+4 ^{0}C	1 day	SM- 5210 B (5- Day BOD test)
COD (mg/L)	P/G	100	pH<2 with H_2SO_4	7 days	SM- 5220 B Open Refluks

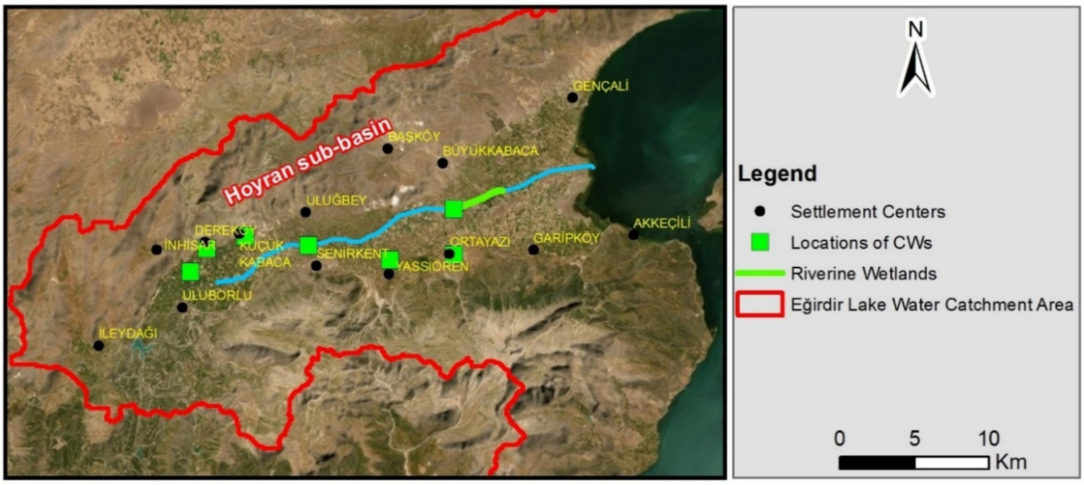

Fig. 4. Locations of natural treatment systems required for each settlement

Table 2. The types of treatment systems planned for each settlement and their initial investment costs

Settlements name	*Population*	*Pre-treatment type*	*Designed treatment system*	*Current cost ($)*
Uluborlu	10500	Imhoff tank	Horizontal Sub-surface Flow Constructed Wetland System	448898
Ulugbey	1500	Imhoff tank	Horizontal Sub-surface Flow Constructed Wetland System	140121
Senirkent	13000	Imhoff tank	Riverine wetland / On-stream wetland	560386
Yassioren	2000	Imhoff tank	Horizontal Sub-surface Flow Constructed Wetland System	70537
Buyukkabaca	6000	Imhoff tank	Riverine wetland / On-stream wetland	249030
Derekoy	500	Imhoff tank	Horizontal Sub-surface Flow Constructed Wetland System	21248
Ortayazi	500	Imhoff tank	Horizontal Sub-surface Flow Constructed Wetland System	21248
Kucukkabaca	500	Imhoff tank	Horizontal Sub-surface Flow Constructed Wetland System	31872

For this purpose, the sample containers were rinsed 2-3 times with the sample to be taken. Each sample was subjected to separate storage and preservation according to the type of analysis processed. The samples taken were delivered to the accredited laboratories of TUBTAK MRC as soon as possible considering the periods in the relevant regulation and analyzed according to the Standard Methods (APHA, 1998). Information on analysis methods are given in Table 1.

Locations of natural treatment systems were determined for each settlement unit by use of field works and satellite images (Fig. 4). In determining the location of treatment systems, many criteria such as slope, transportation, distance to settlements, etc. have been taken into account. It was ensured that the areas determined for treatment were flat or somewhat flat. It was ensured that the preferred location of riverine wetland system could get both domestic wastewater and agricultural return flow. However, the most important material to be used in treatment beds for the construction of constructed wetland systems is gravel It is recommended that the gravel should be relatively round and collected from rivers. However, it is not always possible to find sufficient amount of river gravel for this purpose in the regions where the construction of the treatment systems is planned. For this reason, it has been assessed that crushed stones used in the construction of highways can also be used for this purpose. The crushed stone can be used if they staisfy the criteria indicated in Table 3. In the future, if the number of construction sites of such systems increases, it may be necessary to develop systems that can produce crushed stone in a round or oval shape with a grain diameter of 5-8 mm. The plants that are planned to be used in the treatment systems are Phragmites australis species which can be found in abundance in the region.

These types of plants can grow in all climatic conditions and their performance is better than other plants. For this reason, it is the most preferred plant species in the world for this purpose. It is quite easy to grow Phragmites australis in an artificial wetland systems. In these systems, which are planned to be built, it is aimed to plant 4-10 plant seedlings per square meter especially in early April. It is known that this number will increase at least 10 times after a year. Qualified personnel are not required for maintenance of the treatment systems planned to be built. For this reason, it has been evaluated that the personnel who will undertake the maintenance of the treatment systems will be able to perform maintenance operations after a short training period. It is also planned that this work can be done with the personnel to be provided from the municipalities discharging wastewater to the treatment system.

In addition to that, implementations of constructed wetland systems on different parts of the world were examined on site. Generally current natural treatment systems in Italy, which have the same climate conditions, were examined and evaluated within the scope of this study. Similar systems which were examined in Germany before were evaluated within the scope of this study. The entire data obtained was evaluated and treatment systems that can be suitable for each settlement unit were designed accordingly.

3. Results and discussion

According to measurements made at points where wastewater of settlement units is discharged, per capita daily flow value ranges between 92 and 100 liters. Average BOD_5 and COD values analyzed to be used for designing natural wastewater treatment systems in the 8 settlement units in the basin are within the range of 250 and 500 mg/L respectively. The types of treatment systems planned for each settlement and the initial investment costs are shown in Table 2.

Wastewater treatment systems designed comprise 2 sections. The first section is Imhoff tank which functions as a means of pre-treatment and the second section is constructed wetland or riverine constructed wetland system (Fig. 5, Fig. 6 and Fig. 7). Here the striking detail that is significant is the size of one of Imhoff tanks. This pre-treatment system that is designed for 10500 people is the largest Imhoff tank that has been designed so far in Turkey. As such, it was planned that wastewaters that were pre-treated with Imhoff tank would be treated, in the following phase, together with agricultural return flow in ‘constructed wetlands’ and ‘riverine constructed wetlands’ and would be discharged into the lake after it was treated. Besides that, the distance between the lake and the exit point of the treatment system that was planned to be in the closest proximity to the lake is around 6.3 km and all wastewaters can be polished additionally because it reaches up to the lake together with plants that naturally grow inside the main drainage channel which has a slight slope less than 1%. This will enable additional polishing of treated wastewaters.

Parameters as to design of 'constructed wetlands' and 'riverine constructed wetlands' are given on Table 3. Besides that, Table 3 shows the detailed parameters used for design of constructed wetland system of Uluborlu settlement unit that has a population of 10500 people. Design approach shown on Table 3 was also used for other settlement units. Reed et al. (1995) equation was used in the design calculation in Table 3. Treatment efficiencies at 3 different temperature levels determined depending on the climatic conditions in the study area were obtained by using this equation. The general form of the method is given by Eqs. (1-2):

$$ln(C_i / C_e) = K_T . t \quad (1)$$

$$t = (As.y.n)/Q \quad (2)$$

where: t = hydraulic retention time, in days; As = superficial area of the bed; Ce = outlet concentration; Ci = Inlet concentration; K_T = removal rate constant at T °C; y = average depth of the treatment bed; n = porosity (as percentage); Q = daily mean hydraulic load.

As it can be seen on Table 3, organic substance removal (BOD removal) was taken as a basis for design of systems. It was calculated that treatment efficiency could be realized as approximately 76% even when the wastewater temperature was 6 °C under the harshest winter conditions. In addition to that, while the treatment efficiency is expected to be approximately 98% during spring and autumn months, it was calculated that such value would be around 99% during summer months.

According to results of studies conducted before in Lake Egirdir basin, nitrogen and phosphor loads that originate from point and nonpoint sources were calculated as 1514.4 and 150 tons/year, respectively (Gunes, 2008). Approximately 30% of such pollutants that reach the lake originates from Hoyran sub-basin. When the treatment data that is explained above and indicated on Table 2 is considered for resolving such problem, it can be seen that construction of these systems designed lead to significant decrease in pollutant load that reaches the lake. In another study that was conducted specifically for this issue, it was indicated that 'diffuse pollutions' in the region, except for 'atmospheric deposition', can be taken under control by 50% at minimum through the systems that are recommended within the scope of this study (Gunes, 2008).

According to this study and previous studies, the most suitable treatment systems for rural areas are natural wastewater treatment systems that offer low initial investment and low operating costs. In order to ensure low initial investment costs, it is important to choose places that are not used as agricultural field in rural areas because compared to conventional wastewater treatment systems, natural treatment systems occupy an immense space. For this reason, as in this study, it is recommended to choose drainage channels or areas that are not used in agricultural production as much as possible as a treatment system location. Initial investment costs of treatment systems calculated within the scope of this study are given on Table 2 as an example.

Table 3. Sizing criteria of constructed wetland systems in Lake Egirdir watershed

Design parameters	***Measured or calculated values***	***Units***
Number of Population equivalent	10500	pe
Qmn (Mean daily flow)	1000	m^3/d
Max daily flow = 3Qmn	3000	m^3/d
Max hourly flow with peak coefficient 3,38	141	m^3/h
Per capita daily flow	95	l/pe.d
Organic load per capita	24	$grBOD_5$/pe.d
Water minimum temperature	6	°C
Water height in the bed (HF)	0.70	m
Hydraulic gradient of the HF beds (S)	0.010	
Slope of the beds	1	%
Porosity of the filling media (n)	0.35	Gravel diameters 8 mm
Theoretical hydraulic conductivity (ks)	500	m^3/m^2 d
Inlet organic load (after primary treatment) as BOD_5	250	mgO_2/lt
Removal (%) with water temp= 6° C as BOD_5	92.7	%
Removal (%) with water temp= 14° C as BOD_5	98.5	%
Removal (%) with water temp= 24° C as BOD_5	99.94	%
Total superficial area	21900	m^2
Configuration	10 HF beds	5 parallel lines – 2 stages each
Geometry of each bed		
Area of a single bed	2190	m^2
Width	73	m
Length	30	m
Inlet depth	0.55	m
Outlet depth	0.85	m

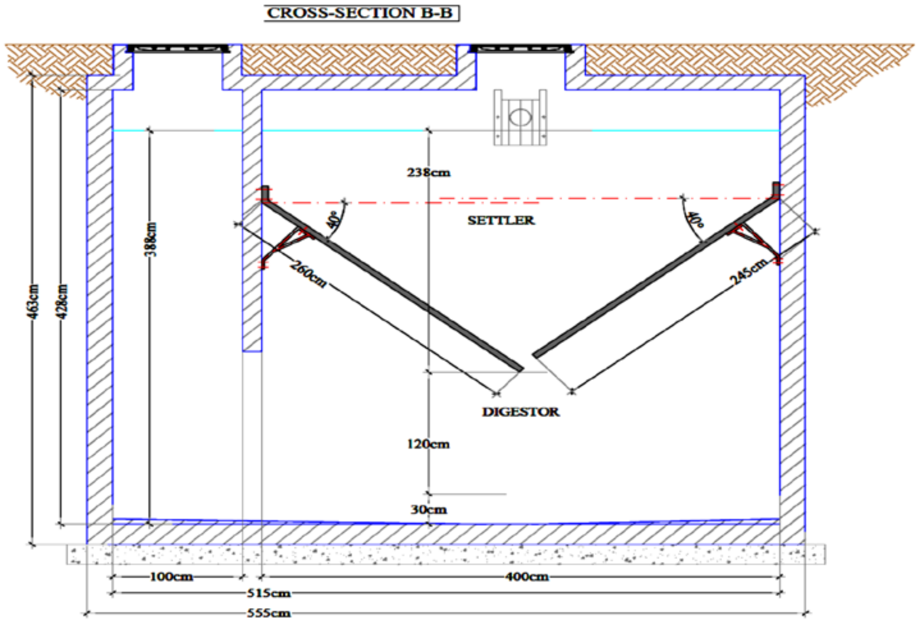

Fig. 5. Imhoff tank systems planned for the residential units

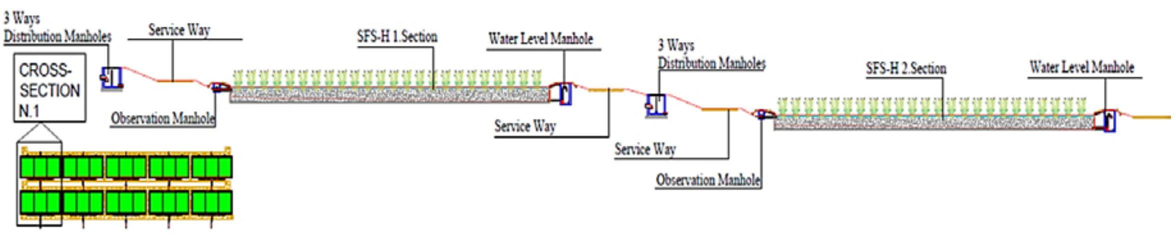

Fig. 6. Constructed wetland system designed for 6 residential units

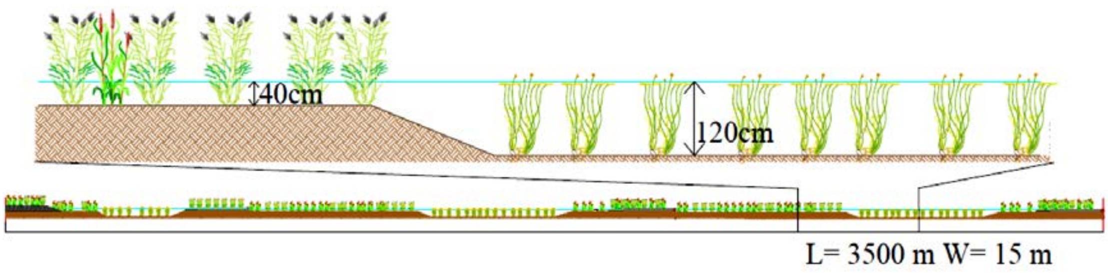

Fig. 7. Riverine constructed wetland system

4. Conclusions

The most suitable method for treatment of domestic wastewater that originates from rural areas and agricultural return flow is, without question, natural treatment systems. It has been shown within the scope of this study that removal rate of organic load that exists in domestic wastewater by use of natural treatment systems may range between 77% and 99% depending on conditions. Apart from that, 'riverine constructed wetland system' that is one of the potential treatment systems, that will be constructed in Hoyran basin, is one of the effective methods for removing 'diffuse pollutions' which originate especially from agricultural fields. Therefore, as it was shown in previous studies conducted for removal of 'nutrients' such as nitrogen and phosphor that comes from this sub-basin together with diffuse pollution, minimum 50% success can be achieved. This result indicates that it will make great contribution to making sure that the lake qualifies as drinkable water in the future. As a result, it is important to use domestic wastewater which originates from lake and dam basins as a source of drinkable water in rural areas and to utilize agricultural return flow by use of ecological treatment methods. Re-utilization of such water after treatment, as the conditions may allow, can be considered as one of the most ideal methods for sensitive ecosystems such as the one addressed in this study. Sensitive ecosystems can be preserved not only by constructing treatment systems but also making ecological agricultural techniques more popular in such areas and establishing other waste minimization management systems. No doubt that one of the most important factors in this one and similar areas is raising awareness of manufacturers and society, giving relevant trainings, ensuring continuity of such trainings and putting incentives into practice as required.

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