MATEMATIKA, MJIM, Volume 39, Number 2, 191–212

Mathematical Assessment of the Wastewater Stabilization Ponds for the Geographical Regions of Turkey

[1,2]Hafiz Qasim Ali[*] and [2]Osman Üçüncü

[1]Department of Civil Engineering, Karadeniz Technical University
61000, Trabzon, Türkiye

[2]Department of Civil Engineering, The University of Lahore
54590, Lahore, Pakistan

[*]Corresponding author: qasim.ali@ce.uol.edu.pk

Article history
Received: 6 April 2023
Received in revised form: 8 August 2023
Accepted: 13 August 2023
Published on line: 31 August 2023

Abstract Wastewater stabilization ponds (WSPs) are used worldwide to treat wastewater from industrial and domestic sources because they are the most economical. However, the two main disadvantages are the colossal area required for the treatment facility and limited control over the effluent quality. The study compares pond designs with various baffle wall numbers and lengths in various configurations of ponds. The number of baffle walls analyzed was increased in even numbers from 0 to 10, and their length increased from 50% to 90% with a 10% increase every time. This study also examines how temperature affects treatment efficiency in various climatic regions of Turkey. The results reveal that increasing the number and length of baffle walls reduces design area and detention time and improves the effluent quality. It was also discovered that regions with warmer climates need less area and detention time than those with colder climates to remove a similar pollution load. In all regions except the Eastern Anatolia region, two out of three configurations analyzed in this study satisfied the country's class-B irrigation standards for eliminating fecal coliform and BOD_5. Based on the analyses, configuration 1 (Anaerobic, facultative, and maturation ponds), having six baffle walls with 70% length, is the optimum and suitable option for all regions. Lastly, comparing this research's outcome with experimental results is recommended.

Keywords Assessment; Baffle Walls; Geographical Regions; Climatic Conditions; Wastewater Stabilization Ponds

Mathematics Subject Classification 62H12, 47N10, 90C47

1 Introduction

Water is essential to almost every form of life on Earth. Only 3% of the earth's water is freshwater, and only one-thousandth of that is drinkable. This minimal resource is under pressure due to the dramatic rise in population and industrialization [1]. This situation highlights the need to explore other sources of water. Wastewater treatment can make a significant impact on protecting freshwater sources. High, upper-middle, and lower-middle-income countries treat 70%, 38%, and 28% of wastewater, respectively, while low-income countries treat 8% [2]. Turkey is classified as an upper-middle-income country based on the most recent data provided by the World Bank to categorize the income levels of nations [3]. In Turkey, 60.8% of the population benefits from a wastewater collection and treatment system that provides at least a secondary level of treatment. However, this figure exceeds 90% in countries such as the Netherlands, England, Denmark, Latvia, Luxembourg, Estonia, Sweden, Malta, Switzerland, Austria, and Germany [4]. According to information from the Turkish Statistical Institute, the level of advanced treatment provided to wastewater in 2018 was 47.90%; however, the percentages for biological, physical, and natural treatment were 27.6%, 24.20%, and 0.20%, respectively [5]. These stats highlight Turkey's need for more wastewater treatment plants based on natural processes.

If Turkey puts more money into cleaning up its wastewater, it can get enough water to reuse in agriculture, which uses much water. In 2013, Turkey was listed as one of the top ten agricultural producers in the world by the Food and Agriculture Organization (FAO). In 1950, agriculture's contribution to the Gross Domestic Product (GDP) was 34%; by 2015, it had fallen to 6.8% due to policy shifts and neglect [6]. Nowadays, 73% (32 billion m^3) of Turkey's total annual water consumption is in irrigation [7]. According to the goals and estimates, yearly irrigation water demand is expected to reach 72 billion m^3 by 2023 [7]. In the coming years, it is necessary to investigate alternative water sources, primarily water reuse after treatment. This research has analyzed the effectiveness of the most economical wastewater treatment method, i.e., wastewater stabilization ponds (WSPs) for various climatic regions of Turkey.

Conventional wastewater treatment methods in high-income countries are energy-intensive; in the United States, for example, they consume 1-4% of total energy production [8]. The aeration process in biological wastewater treatment accounts for much of this energy demand [9]. In contrast, natural wastewater treatment systems require no or minimal units of energy for their operation. Energy-saving methods must be applied because the Middle East is one of the world's most water-stressed regions [10]. Turkey, a country in the Middle East, has much potential for sustainable development. If it implements proper wastewater management, treatment, disposal, and reuse processes and policies. This research aims to provide treated water that satisfies the class-B standards for reuse in irrigation [11].

A centralized wastewater treatment system collects, transports, treats, and disposes of the wastewater generated by large populations in a single location. The system provides high-quality effluent that meets the requirements of regulatory agencies [12]. However, this system cannot be used in middle-income countries. The primary reasons are; the high maintenance costs and the low number of treatment plants [2]. Dispersed and rural communities can benefit from decentralized wastewater treatment plants that collect, transport, treat, dispose of, and reuse their wastewater [13]. However, many communities need more resources and expertise to build or maintain these systems, which require careful planning and policy implementation [2]. Wastewater treatment through WSPs does not require skilled labor to construct, operate and maintain. So they are the most suitable option for such communities [14-15].

Wastewater treatment through WSPs is a natural system Cakmak and Apaydin [16] that can be used in the semi-centralized or centralized sewerage system serving towns or cities. It can also be used as an onsite treatment system for a single entity, such as a slaughterhouse, hospital, community center, etc. [17]. To lessen the impact of industrialization on developing nations, wastewater treatment methods must keep pace with the sector's rapid growth [12]. The use of WSPs systems that treat domestic and industrial wastewater is rising, particularly in countries with expanding manufacturing sectors. Industrial wastewater, extra water from irrigation of crops, mine wastewater, oil and gas industry effluent, landfill leachate, and groundwater are all treated through WSPs. Industrial applications for wastewater stabilization ponds include treating wastewater for sectors like food and beverage processing, pulp and paper manufacturing, and textile production at a low cost with high efficiency [4-6].

The provision of WSPs has three primary objectives: removing organic matter, nutrients, and pathogenic microorganisms from wastewater [18]. However, environmental factors such as temperature, wind, cloudiness, etc., affect their removal efficiency [19-20]. Among these environmental factors, temperature has the most significant impact [21-22]. The disadvantages of WSPs include the need for a large area, limited control over the effluents' quality, and specific soil requirements [16]. The study also focuses on minimizing the required area and increasing pollutant removal efficiency. As mentioned above, temperature is vital in many biological wastewater treatment processes. At average temperatures, land requirements are reduced, the conversion process increases, removal efficiency improves, and the utilization of the wastewater treatment process is possible [21]. WSPs can be used in low-temperature areas, but the land requirements will increase, and the removal efficiency in the winter season may be reduced [21]. Another essential role in natural wastewater treatment is that of microorganisms. The microorganisms require specific conditions to survive and reproduce (such as adequate oxygen and nutrients) [23]. The process of design involved in this study considers all these factors.

WSPs have three fundamental hydraulic models: complete mix, dispersed flow, and plug flow [24]. Dispersed flow, a model between complete mix and plug flow, was selected for the investigation involved in this research. Both emerging and developed nations face the challenge of water contamination. Anthropogenic activities that produce water also produce new chemical classes. Organic and inorganic substances, pathogenic organisms, plant nutrients, and oxygen-demanding molecules are examples of typical pollutant groups [25]. Adding baffle walls (BWs) transforms their flow regime from a complete mix to a plug flow. Researchers may read the articles and the book to learn the fundamental concepts regarding BWs [17-18, 26]. Olukkani and Ducoste have also summarized different studies about how the number and length of BWs in WSPs affect their work. The authors have also listed many other books and articles in their research [27].

This study focuses on the mathematical analysis of various configurations and arrangements mentioned below. The arrangements of the BWs in facultative ponds (FPs) are (0,2,4,6,8 and 10) in number and (0.5, 0.6, 0.7, 0.8, and 0.9) in length. i. Configuration 1: A sequence of anaerobic, facultative, and maturation ponds ii. Configuration 2: A sequence of facultative and maturation ponds iii. Configuration 3: Just facultative pond with (4 and 10) BWs of varying duration, as described above; see Figure 1. Because WSPs primarily rely on natural processes to treat wastewater, they are highly susceptible to changes in climate and location [28]. No study analyzed WSPs that covered any country's climatic and geographical regions, according to the research. This research will address this lacuna in the literature. The research objectives are: 1. To investigate the impact on the design area and detention time (D_T) of increasing the number and length of BWs. At the same time, meeting irrigation standards for the contaminants under consideration, namely fecal coliform and BOD_5. 2. Analyze the effect of temperature change in seven geographical regions of Turkey on the design area and D_T. 3. To give suggestions and recommendations if any of the above combinations fail to meet the effluent standards and WSPs design criteria.

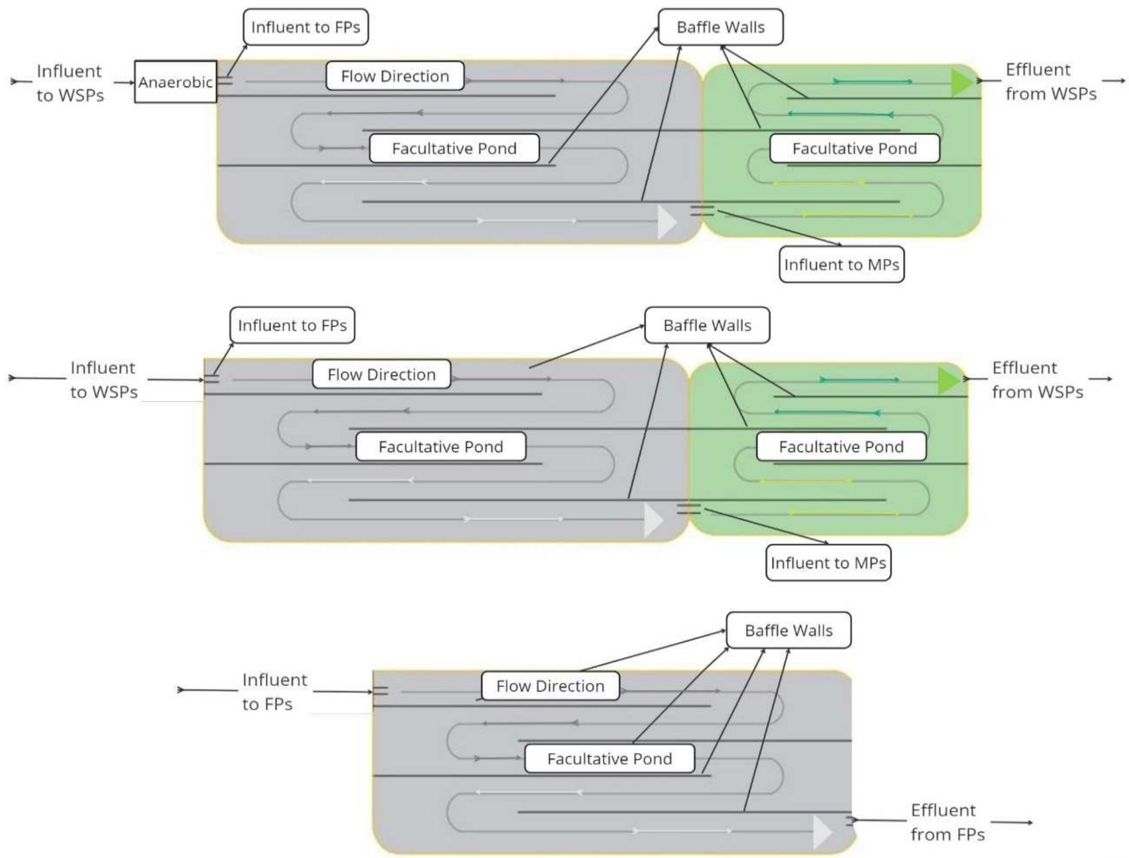

Figure 1: Configuration 1 with 4 baffle walls in both FPs and MPs

2 Materials and Methods

The Anaerobic ponds (APs) were designed using Marais' technique. Similarly, the Yanez method was followed to design the remaining two ponds, i.e., facultative and maturation ponds (MPs). The idea of configuration and arrangements for the analysis and design procedure was taken from Martinez et al. [18]. Their work is extended with 54 additional analyses performed for each region. There were 420 analyses performed in this study in the seven climatic regions of Turkey [18]. The idea for the distribution of the whole country into seven geographical and climatic regions was derived from Gulsen et al. [29]. The authors divided the country into 4 parts, northern, southern, eastern and western. However, in this research, the country is divided into seven climatic regions to get a more precise picture for the application of WSPs.

2.1 Anaerobic Ponds

The constants and variable input values are presented in Table 1.

The design procedure followed for the design of APs in this research is discussed by Martinez et al. [18, Equation (1) to (17)]. Some changes made in the procedure are discussed below. The inflow

Table 1: Variable and Constant Input Values

Constant input values	Variable input values
(Population (N), $(BOD_5)_i$, and fecal coliform (N_i) MPN/100 mL), depth of the Pond (d_p), and wastewater generation rate in liters per capita per day (LPCD).	The temperature in each region's coldest month over the past ten years, expressed as the monthly average temperature (Tavg) in degrees Celsius, Flow (Q_i) in m^3/day, and evaporation (e_p) in mm/day.

rate can be calculated using Equation (1) below [18].

$$\text{Inflow rate } (Q_i) \text{ in } m^3/\text{day} = \frac{N \times \text{LPCD}}{1000} \tag{1}$$

As the study includes various climatic regions, the determination of volumetric load (see Equation (2)) and BOD_5 removal efficiency (see Equation (3)) was different, as in Table 2, based on the temperature in that particular region [30].

Table 2: Determination of Volumetric Load and BOD_5 Removal

Temperature (T_{avg} °C)	Volumetric load = λ_v (g BOD_5/m^3.d) (2)	BOD_5 removal (%) (3)
<10	100	40
10-20	$20 \times T_{avg}$ - 100	$2 \times T_{avg} + 20$
20-25	$10 \times T_{avg} + 100$	$2 \times T_{avg} + 20$
>25	350	70

2.2 Facultative Ponds (FPs)

Yanez's method for the dispersed flow in the FPs was followed for the design [18]. The whole design procedure for the design of FPs is also discussed by Martinez et al. [18, Equation (18) to (27)]. Some changes made in the design procedure, based on the requirements of this research, are discussed in the following section. Furthermore, Below mentioned are the effluent values obtained from the design of the APs and used as influent values for the design of the FPs. Effluent BOD_5, corrected by evaporation = $(BOD_5)_e = (BOD_5)_i$, effluent fecal coliform, corrected by evaporation (MPN/100 mL) = $N_e = N_i$, Temperature in each region's coldest month over the past ten years, expressed as the monthly average temperature (Tavg) in degrees Celsius, outflow from the WSPs (m^3/d) = $Q_e = Q_i$, and evaporation (e_p) in mm/day.

The formula for determining the maximum surface loading rate differed based on each region's temperature. The maximum surface loading rate was the same for regions with a temperature ≤ 8 ℃ (applicable to 4/7 regions of Turkey), that is, 80 kg/h.d. It was calculated using the formula below in the remaining three regions. The formula considers various safety variables to produce an equation for the design of FPs applicable globally [31].

$$\lambda \,\text{s (kg/h.d)} = 350 \times (1.107 - 0.002 \times T_{\text{avg}})^{T_{\text{avg}}-20} \tag{4}$$

The coefficient of bacterial decrease, $(K_b)_{\text{Tavg}}$, varied from one region to the next, depending on the depth of FPs and MPs as well as the coldest average monthly temperature of the region. The bacterial reduction coefficient is calculated as mentioned below [24].

$$(K_b)_{Tavg} = (K_b)_{20} \times \theta^{Tavg-20} \tag{5}$$

where, $(Kb)_{20}$ is the bacterial reduction coefficient at 20 C and calculated using Equation (5), given below [24]. and the value of θ was considered constant. Marais used 1.19, but Yanez said the value is too high and should be 1.07 [24]. Lastly, it is essential to remember that the baffle walls (BWs) in FPs were parallel to the length of the ponds to achieve higher efficiency, as mentioned by Olukanni and Ducoste [27].

$$(Kb)_{20} = 0.542H^{-1.259} \tag{6}$$

2.3 Maturation Ponds (MPs)

Yanez's method for the dispersed flow was followed to design the MPs as in the FPs [18]. The design procedure followed was also discussed by Martinez et al. [18, Equation (28) to (29)]. The changes made to the design procedure are discussed above in the design of FPs. Moreover, effluent values obtained from the design of the FPs were used as influent values for the design of the MPs, wherever needed. The method for selecting D_T in MPs was hit and trial; the value was added manually in the design sheet. While finalizing it, two things were ensured: 1. Effluent requirements must align with Turkey's class B guidelines for irrigation. 2. Minimum possible volume and, ultimately, the surface area must be achieved because the depth of the ponds was constant, i.e., 1 m. It is crucial here to notice that the width of the MPs was taken as equivalent to the FPs. The length was then calculated by repeating the same procedure mentioned in the FPs.

2.4 Application of the Method

A wastewater treatment plant was designed for rural communities in each region of Turkey, using the aforementioned configurations and arrangements, where the sewerage system is already provided. WSPs are primarily preferred in places having hot climates and less than 2000 populations [32]. The settlements in Turkey with less than 2000 population are considered villages, 2000-20000 are towns, and above 20000 are cities [33]. A constant value of 1200 persons in all the regions was taken to assess the WSPs, a typical rural area population for all regions of Turkey. The wastewater generation rate used in this study was considered to be 80% percent of the water supply in the respective region [34]. The calculated wastewater generation rate was 179 LPCD in four out of seven regions of Turkey, i.e., Black Sea, Mediterranean, Eastern Anatolia, and Southeastern Anatolia [34]. However, in the other three regions, this rate was 151, 166, and 191 for Marmara, Aegean, and Central Anatolia, respectively [34]. Figure 2 shows the flow chart for the analysis and design procedure of WSPs.

The typical concentrations of fecal coliform and BOD_5 used in this study from a domestic source were 10^7 (MPN/100 ml) and 200 (mg/l), respectively [35]. Values of evaporation and temperature, shown in Figure 3, are the average of the coldest month in the respective region. These values were calculated from the meteorological data of the last ten years (2012-2021), taken from the General Directorate of Meteorology in Trabzon, Turkey. To determine the quality of the effluents from WSPs, to be used for unrestricted irrigation, the concentrations specified by Yasar et al. [11] were considered. In this, effluents are categorized into classes: Class A and Class B. The concentrations of BOD_5, and fecal coliform in the former must be less than or equal to 20 (mg/L) and 0 (MPN/100 mL), respectively. These concentrations are difficult to achieve through WSPs. However, in the latter, the concentrations are 30 mg/l and 200 (MPN/100 mL), respectively, which can be achieved by treating the wastewater through WSPs only. Due to the stated reason, Class B standards were considered for the analysis of this research.

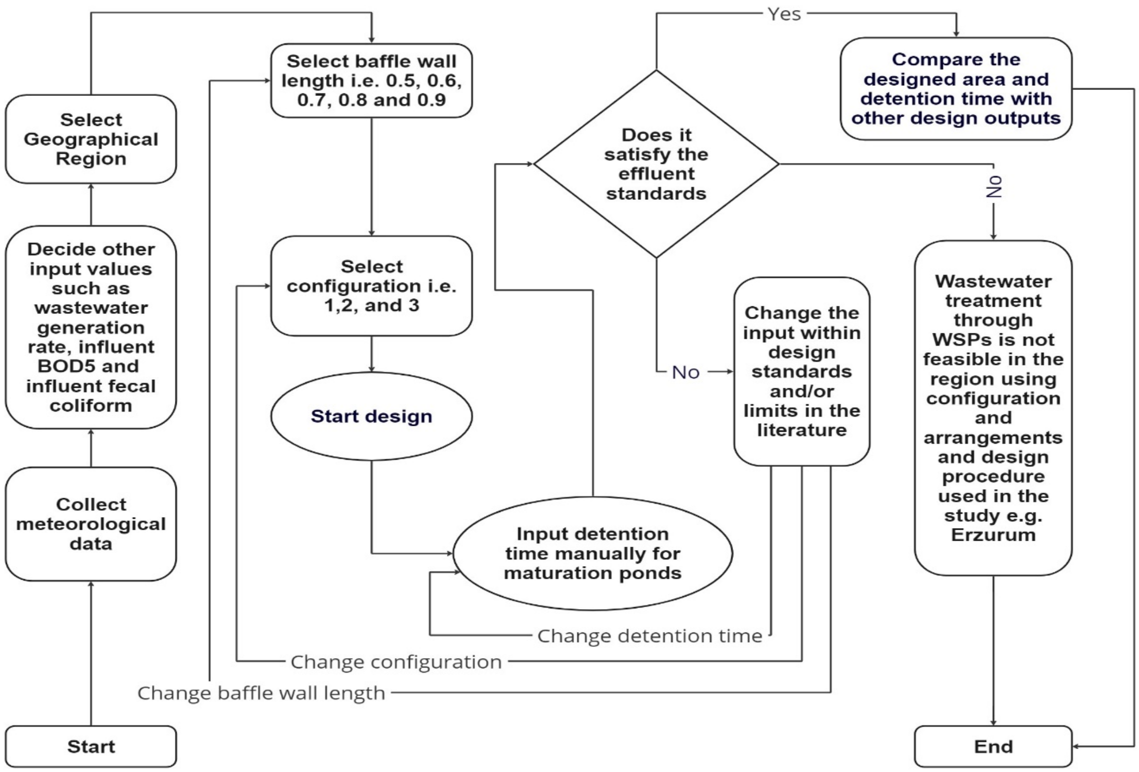

Figure 2: Flow Chart of the Analysis Performed.

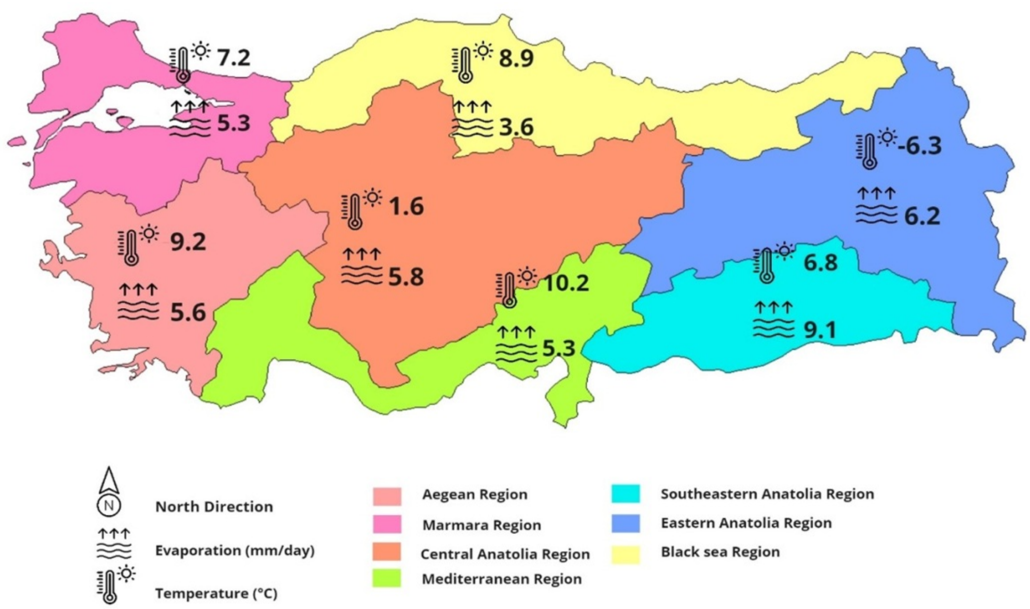

Figure 3: Geographical Regions of Turkey with their Design Input Data for WSPs

3 Results and Discussions

Generally, it can be seen that increasing the number of BWs significantly reduced the design area and D_T requirements by up to four BWs in all regions of Turkey, see Appendix A. With adding more BWs, the area, and D_T decrease at a comparable rate within each length of BWs, as demonstrated by Martinez et al. [18]. As the number of BWs increases from 0 to 4, the area reduces by around 550 square meters. The area reduces by approximately 150 square meters when the number increases from 2 to 4. The area reduces to approximately 100 square meters when the number increases from 6 to 8. All regions observed less than 100-meter squares reduction in the area with further addition of the BWs. Moreover, as the length of the BWs increases, it was also found that the requirement of both area and D_T decreases, see A.

Table 4-10 in Appendix A presents the findings of 420 analyses, 60 for each region. According to the Turkish Water Pollution Control Regulation for irrigation, configurations 1 and 2 are in compliance [11]. Consistent with Martinez et al. [18], configuration 3 gives the smallest area; however, effluents do not fulfill the criteria for BOD_5 and fecal coliform, which were examined in this study. This demonstrates why WSPs effluent can only be used for unrestricted irrigation once MPs are provided [24].

3.1 Effect of BWs on the Area of WSPs

Temperature and surface loading rate affect the reduction of area. The surface loading rate for four out of seven regions is constant, at 80 kg/ha.d, because in these regions average temperature of the coldest month is below 8 °C, see Figure 3. Configuration 2 gives more area than Configuration 1, the reason is the absence of APs. They have more depth that reduces the pollutant load (BOD_5 and fecal coliforms) in proceeding ponds, as in configuration 1. The volumetric loading rate depends on temperature and only affects the area and D_T of APs, which is only included in configuration 1. Six of the seven regions have an average coldest month temperature below 10 °C, see Figure 1. Due to this reason, they have different formulae for volumetric loading than the Mediterranean region, which has an average coldest month temperature over 10 °C. As a result, regions with a high average temperature in the coldest month require less WSPs area. On the other hand, low-temperature zones need a greater area to remove similar concentrations of impurities. An equal area for the Aegean and the Mediterranean is because less wastewater generation nullifies the effect of the decrease in temperature in the Aegean.

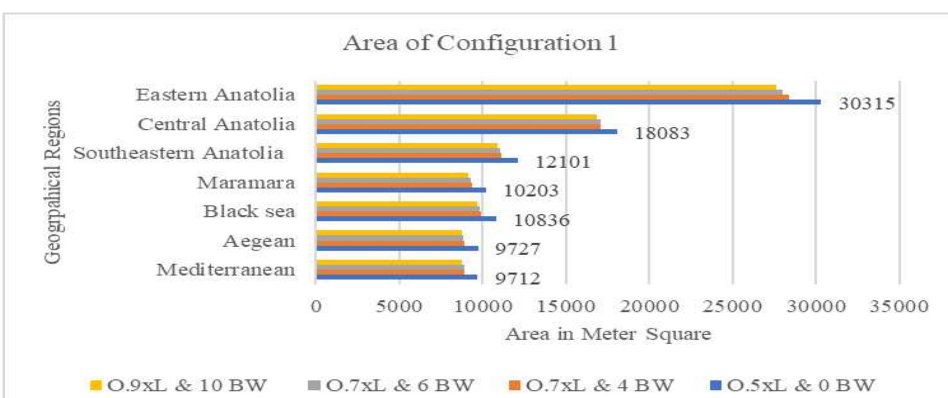

Figure 4: Area of Configuration 1 in Seven Geographical Regions of Turkey

Figure 4 depicts the pattern of differences in the wastewater treatment plant area utilizing configuration 1 for all seven regions of Turkey as the number and length of BWs changes. When the number of BWs is zero, and the length is minimal, 0.5 x L in the FPs, the area is maximum for all regions. The impact of change in the length of the BWs is only relevant to BWs in MPs at this point. It is also clear that four BWs with a length of 0.70 x L significantly reduce the necessary area, but adding more BWs or increasing their length does not reduce the area considerably. As mentioned above Figure 5 shows the area requirement in Configuration 2 is more for all regions than in Configuration 1. It is also clear that zero BWs with 0.5 x L length gives a higher area, and when BWs are added paired with their increased length, the area decreases. There is an apparent decrease in the area on adding 2 BWs with 0.7 x L length and follows the same trend of no significant decrease as in configuration 1 on further additions.

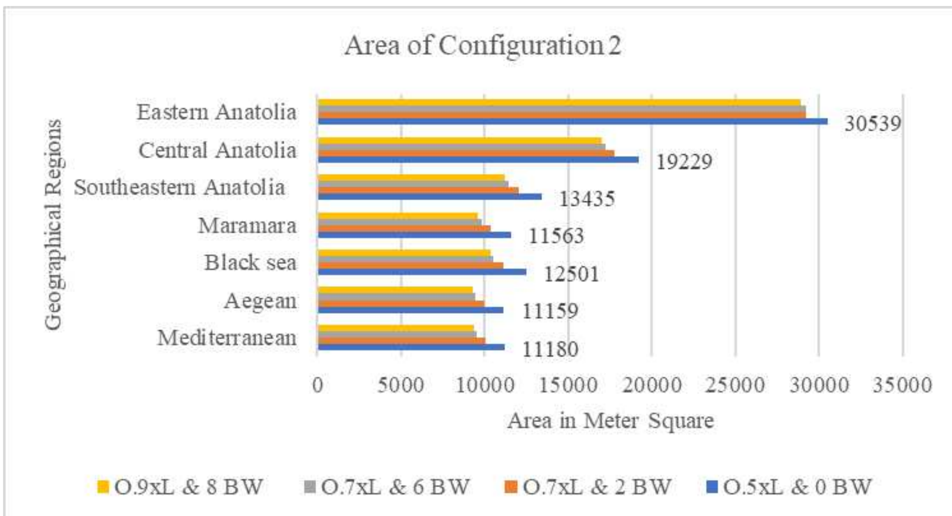

Figure 5: Area of Configuration 2 in Seven Geographical Regions of Turkey

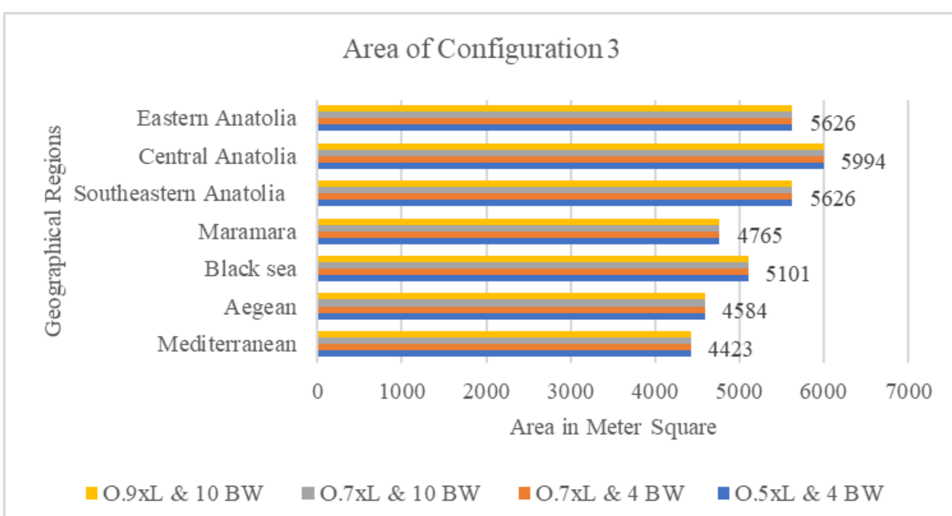

Figure 6. Area of Configuration 3 in Seven Geographical Regions of Turkey

Configuration 3 shows no effect of variations in the number and length of BWs on the area of WSPs; see Figure 6. It is significant to mention here that the variation in length and the number of baffle walls also does not affect the removal of BOD_5 see Table 11 in Appendix B. However, it reduces the fecal coliforms within the regions, see Table 12 in Appendix B. As the graph shows, the area increases with a region-wise decrease in temperature, but two regions deviate from the trend, Aegean and Marmara. The reason behind this deviation is a reduction in wastewater generation rate in respective regions, i.e., 151 LPCD for Marmara, compared with 179 LPCD for the Black Sea region [34]. Similarly, 179 LPCD in eastern Anatolia compared to 191 LPCD in central Anatolia [34]. Moreover, it can also be noticed that the areas of Southeastern Anatolia, and Eastern Anatolia, regions were equal in this configuration, see Appendix A. This is because the same input values of BOD_5, surface loading rate, and wastewater generation rate are involved in calculating the area for configuration 3. After the analysis and design of WSPs for all regions, it can be seen that the minimum and maximum area values are 4423 and 30539 m^2, see Appendix A. The total design area of configuration 1 in 4 regions is below, in 2 regions is within the range, and in only one (the Eastern Anatolia region) it is above the feasible range as per Turkish standards for the design area of WSPs, i.e., 10-15 m^2/person [11].

3.2 Effect of BWs on the D_T of WSPs

Figure 7 shows the decrease in D_T by increasing the number and length of BWs in all seven geographical regions of Turkey for configuration 1. When the BWs number is zero, and the length is 0.5 x L, D_T is maximum, keeping in mind that this length is for MPs. A sharp decrease in D_T can be observed with 4 BWs and 0.7 x L length in all regions. However, a minimal decrease can be observed after further addition in the number and length of BWs. The data clearly shows that the D_T is greatest in the coldest area and least in the warmest.

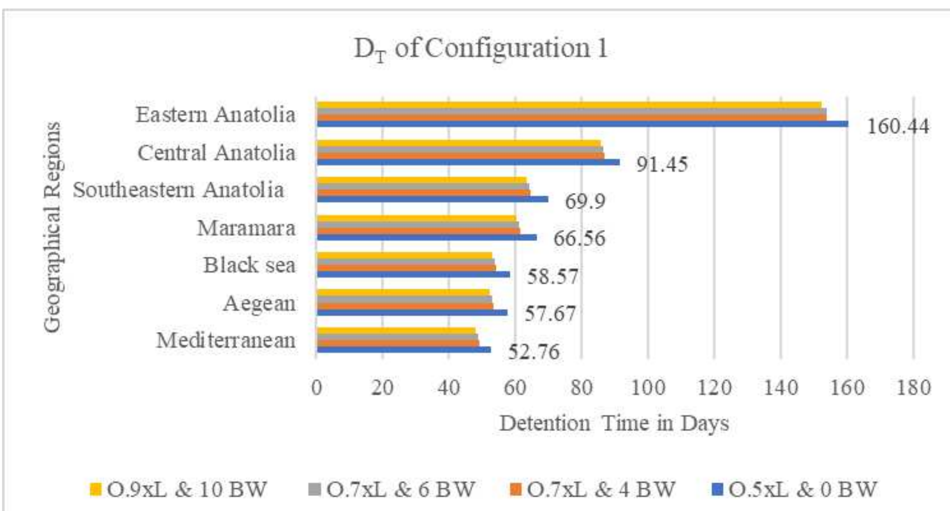

Figure 7: Detention Time of Configuration 1 in Seven Geographical Regions of Turkey

Figure 8 shows the decreasing D_T trend for all of Turkey's regions for configuration 2. There is a difference that configuration 2 gives a significant decrease in D_T at 2 BWs with 0.7 x L length compared to 4 BWs and 0.7 x L in configuration 1. It can also be observed that 6 BWs with 0.7 x L gives a considerable decrease in all seven regions because the increase in the number of BWs is 4, as compared to 2 in configuration 1. This configuration follows the same pattern as configuration 1: the region having highest temperature need lowest D_T, and the region having lowest temperature need highest D_T. In configuration 3, increasing the number and length of BWs shows no change in D_T, in any region but an increase in the removal of fecal coliforms, see Figure 9. At the same time, it can be observed that the temperature affects D_T for the first four regions from the bottom in Figure 9. There is an increase in D_T for these four regions in increasing order, from the Mediterranean, which has less D_T, to Marmara, a comparatively lower average temperature region with more D_T. The increase in D_T is due to the decrease in surface loading rate and the decrease in these regions' average temperature. Afterward, there is no effect of temperature on D_T because the surface loading rate is constant for the remaining regions.

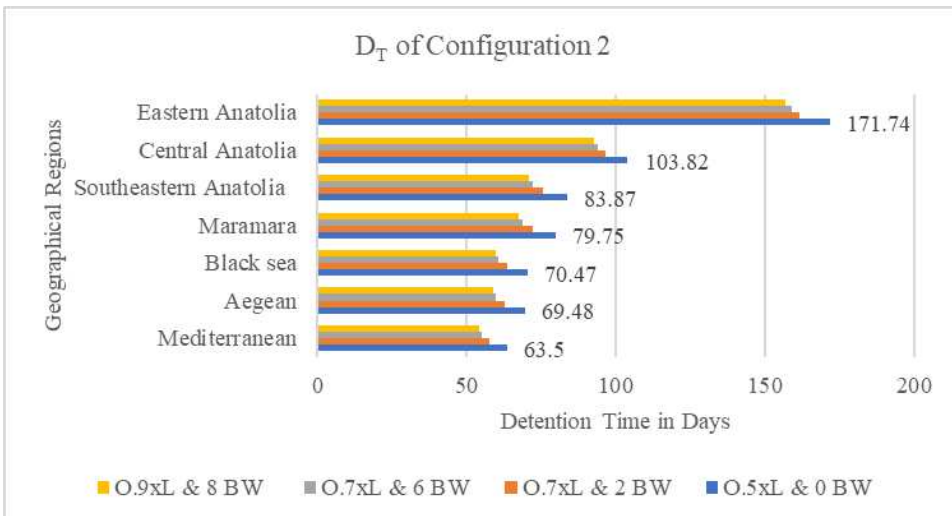

Figure 8: Detention Time of Configuration 2 in Seven Geographical Regions of Turkey

While observing the overall requirement for area and D_T within the regions, it is clear that there is no reduction for both facultative and APs but in MPs. D_T for FPs is constant in two out of three configurations because it depends on the values of surface loading rate and influent BOD_5, which are taken constant for four out of seven regions with temperatures less than $8°C$. Moreover, the variable design flow does not affect D_T because both volume and discharge are dependent on it. However, in configuration 1, the value of D_T is a little less because the APs reduce the influent pollutant load for FPs. The usual D_T range is 18-20 days for MPs that is not achieved in any region, see Table 13 in Appendix B, but the value is very close in five out of seven regions in accordance with the literature [11]. However, the calculated value of D_T in this research is within the 0.1 to 114 days range in six out of seven regions [17]. The primary reason behindnon-compliance with standards is strict effluent standards compared to WHO guidelines [11]. Factors affecting D_T include dissolved oxygen, pH, solar radiation, physical configuration, and BOD_5 loads [18]. The total minimum and maximum calculated D_T values in seven regions are 29.30 and 171.74 days, respectively.

The influent value of fecal coliform taken in this study is 10^7, while the range for fecal coliform for domestic wastewater is 10^6 to 10^8. So, if this value is reduced and taken as 10^6, all of the results would comply with the international standards for area and D_T. Little higher influent BOD_5 value could also reduce the fecal coliform load in MPs, reducing the overall requirement of both area and D_T and meeting the effluent standards [20]. It can be observed from Appendix A that the design area and D_T for the region having maximum temperature, i.e., the rural area near Antalya city in

Mediterranean Anatolia, is minimal, Appendix A. Similarly, it is maximum in the region having the lowest temperature, i.e., the rural area near Erzurum city in eastern Anatolia, see Appendix A, confirming the comment made by Alisawi [21].

Overall, the maximum reduction in D_T and area is around 20% in configurations 1 and 2, but in configuration 3, this reduction is about 50% in D_T and 60% in the area, see Appendix A. This percentage is calculated between configuration 2 with 0 BWs and other configurations with or without adding BWs. As mentioned in the literature, the major disadvantage of WSPs is the requirement of the area. The percentage reduction mentioned above is essential for acquiring the land and developing the infrastructure.

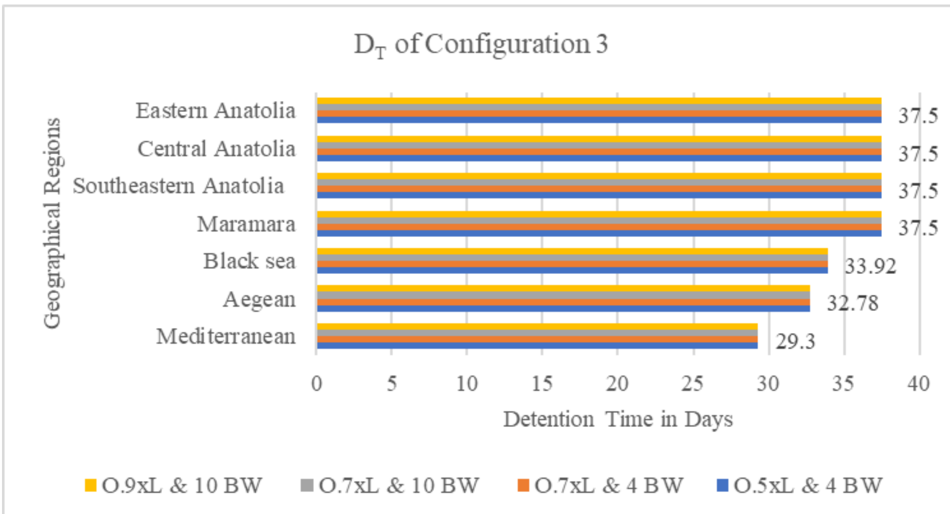

Figure 9: Detention Time of Configuration 3 in Seven Geographical Regions of Turkey

3.3 Removal Efficiency of BOD_5

The BOD_5 removal efficiency is above 95% in configurations 1 and 2. However, in the case of configuration 3, it is around 80%, except for two regions; central Anatolia (rural areas near Ankara), where it is around 70%, and the Eastern Anatolia region (rural areas near Erzurum city), where it is around 50%, see Table 14 in Appendix B. The results obtained in six out of seven regions for BOD_5 removal efficiency are in the range of 70% to 80%, similar to Martinez et al. [18].

3.4 Removal Efficiency of Fecal Coliforms

In the case of fecal coliform removal, the trend is the same, i.e., more reduction is observed in the first two configurations and less in the third configuration with a percentage removal of more than 99, see Table 15 in Appendix B [18]. To obtain higher removal efficiency and lower D_T in WSPs, the dispersion number must be achieved in the range of 0.1 to 0.3. The desired dispersion number is possible with a length-width ratio greater than 5. However, the analysis used a length-width ratio equivalent to 3 [17]. Another possible solution to achieve higher removal efficiency is to reduce the depth of the pond, which will increase the surface area for the same inflow volume.

Based on the discussion of the results and considering local factors such as temperature, evaporation, and wastewater generation rate, the suggested configuration for all regions is Configuration 1, with three ponds in series and 6 BWs with their 0.7 x L. The possible variations that can be explored in the same design procedure are the involvement of the cost of both area and BWs, variable influent BOD_5 and fecal coliform concentrations, variable depth of all ponds within their design criteria, and variable population by keeping a constant temperature, evaporation and wastewater generation rates in each region.

4 Conclusions and Recommendation

Based on the discussion above, it is concluded that the design area and D_T of the WSPs can be reduced: 1. By increasing the length and number of BWs in the first two configurations. 2. By adding APs as in configuration 1. 3. An increase in length and number of BWs in FPs does not affect its area, but the reduction in the area of MPs in the first two configurations because of the reduced fecal coliform load. 4. Higher temperature also decreases the design area and DT requirement.

The number and length of BWs increased the efficiency of removing fecal coliforms. This increased removal efficiency is beneficial for wastewater generated from domestic and industrial sources. The design area and D_T are reduced to meet Turkey's desired effluent standards in the first two configurations. Configuration 3 does not provide effluents that meet the permitted limits set by the Turkish authorities. It can also be concluded that high-quality effluent necessitates more area and D_T than low-quality effluent. Configuration 3 provides the smallest area, but it should only be used if MPs are added to meet the irrigation standards of Turkey. So, keeping in mind the above context, there is no doubt that configuration 1 with 0.7 x L baffle wall length and 6 BWs is the most feasible option. Beyond this arrangement, there is only a small decrease in design D_T and area, due to which further addition of BWs becomes uneconomical.

As the number of BWs varied in even numbers, it is suggested that another study be conducted with odd numbers of BWs. Additionally, it is recommended that the analysis be performed with a 0.05 variation in wall length instead of the 0.1 used in this study to obtain more precise results. For the rural areas near Ankara and Erzurum, where D_T is significantly higher than normal. Therefore, it is recommended that wastewater treatment based on WSPs be carried out by providing only APs with the intermittent flow, as in the arctic regions. Another suggestion is to conduct research on real-time data from the treatment plant to compare the findings and then scale them up appropriately. Finally, optimization studies of the design must be carried out using various methods available in the literature.

Acknowledgment

The researchers involved in this study pays their deepest thank to the Regional Directorate of Meteorology, Trabzon, for supplying the meteorological data needed for this analysis.

Appendices

Appendix A is presented at the end of this article. Moreover, the corresponding author will gladly provide the tables of design calculations and a summary of results (Appendix B) used to write this article.

Declaration Statement

The writers stated that there were no conflicts of interest.

Acronyms

Table 3: List of Acronyms Used in the Manuscript

Qi	Inflow in (m^3/day) to the WSPs system
BWs	Baffle Walls
D_T	Detention time
N_{BWs}	Number of Baffle walls
T_{avg} ℃	The average monthly temperature during the coldest month in each region
λ_v	Volumetric load in (g BOD_5/m^3.d)
λ_s	Maximum surface loading rate
N	Number of persons in each region
LPCD	Liters per capita per day
dp	Depth of pond
$(K_b)_{Tavg}$	Bacterial reduction coefficient at average monthly temperature during the coldest month in each region
$(K_b)_{20}$	Bacterial reduction coefficient at 20 ℃
e_p	Evaporation in mm/day
BOD_5	Five days' biochemical oxygen demand
C	Configuration

References

[1] Ali, H. Q., and Farooq, A. Characterization of Heavy Metals in Waste Stabilization Ponds: A Case study of Waste Stabilization Ponds at Chokera, Faisalabad. *6th International Student Symposium Proceedings. Engineering Sciences. December 05-06,* UDEF, Sakarya University. Turkey. 2020. 110-117. http://www.internationalstudentsymposium.com/news/

[2] Akao, P. K., Singh, B., Kaur, P., Sor, A., Avni, A., Dhir, A., Verma, S., Kapoor, S., Phutela, U.G., Satpute, S. Coupled microalgal–bacterial biofilm for enhanced wastewater treatment without energy investment. *Journal of Water Process Engineering*. 2021. 41: 102029. https://doi.org/10.1016/j.jwpe.2021.102029

[3] Öztürk, A. C., and Tiftikçigil, B. Y. Assessment of the possibility of a middle-income trap in Turkey. *Journal of Life Economics*. 2020. 7: 331–348. https://doi.org/10.15637/jlecon.7.025

[4] Collivignarelli, M. C., Abbà, A., Frattarola, A., Carnevale Miino, M., Padovani, S., Katsoyiannis, I., and Torretta, V. Legislation for the reuse of biosolids on agricultural land in Europe: Overview. *Sustainability*. 2019. 11(21), 6015. https://doi.org/10.3390/su11216015

[5] Zöhre, K. Özdemir, I. and James, A.M.R. Effectiveness of microplastics removal in wastewater treatment plants: A critical analysis of wastewater treatment processes. *Journal of Environmental Chemical Engineering*, 2022. 10(3).107831. https://doi.org/10.1016/j.jece.2022.107831

[6] Ersoy, E., and Ugurlu, A. The potential of Turkey's province-based livestock sector to mitigate GHG emissions through biogas production. *Journal of Environmental Management*. 2020. 255: 109858. https://doi.org/10.1016/j.jenvman.2019.109858

[7] Nas, B., Uyanik, S., Aygün, A., Doğan, S., Erul, G., Nas, K.B., Turgut, S., Cop, M., Dolu, T. Wastewater reuse in turkey: from present status to future potential. *Water Supply. 2020.* 20: 73–82. https://doi.org/10.2166/ws.2019.136

[8] Longo, S., d'Antoni, B.M., Bongards, M., Chaparro, A., Cronrath, A., Fatone, F., Lema, J.M., Mauricio-Iglesias, M., Soares, A., and Hospido, A., Monitoring and diagnosis of energy consumption in wastewater treatment plants. a state of the art and proposals for improvement. *Applied Energy*. 2016. 179: 1251–1268. https://doi.org/10.1016/j.apenergy.2016.07.043

[9] Dong, Y., He, W., Liang, D., Li, C., Liu, G., Liu, J., Ren, N., and Feng, Y. Operation strategy of cubic-meter scale microbial electrochemistry system in a municipal wastewater treatment plant. *Journal of Power Sources*. 2019. 441: 227124. https://doi.org/10.1016/j.jpowsour.2019.227124

[10] Stefanakis, A. I. Constructed wetlands for sustainable wastewater treatment in hot and arid climates: opportunities, challenges and case studies in the middle east. *Water*. 2020. 12: 1665. https://doi.org/10.3390/w12061665

[11] Yasar, A., Can Dogan, E., Ayberk, H. S., & Aydiner, C. Water Recovery from Urban Wastewater for Irrigation using Ultrafiltration and Nanofiltration: Optimization and Performance. *CLEAN–Soil, Air, Water*. 2022. 50(12). 2200280. https://doi.org/10.1002/clen.202200280

[12] Hu, W., Tian, J., Zang, N., Gao, Y., and Chen, L. Study of the development and performance of centralized wastewater treatment plants in Chinese industrial parks. *Journal of Cleaner Production*. 2019. 214: 939–951. https://doi.org/10.1016/j.jclepro.2018.12.247

[13] Arias, A., Rama, M., Gonz alez-Garc ia, S., Feijoo, G., and Moreira, M.T. Environmental analysis of servicing centralised and decentralised wastewater treatment for population living in neighbourhoods. *Journal of Water Process Engineering*. 2020. 37: 101469. https://doi.org/10.1016/j.jwpe.2020.101469

[14] Ali, H. Q., Farooq, A., Ahmad, M., Ahmed, M. L., and Akhtar, M. Effect of climatic conditions on treatment efficiency of wastewater stabilization ponds at Chokera, Faisalabad. *Mehran University Research Journal of Engineering and Technology. 2021.* 40(1): 75-81. https://doi.org/10.22581/muet1982.2101.07

[15] Sunarsih, S., Sasongko, D. P., & Sutrisno, S. Process improvement on domestic wastewater treatment stabilization ponds by using mathematical optimization approach. *MATEMATIKA: Malaysian Journal of Industrial and Applied Mathematics*. 2019. 35(2): 171-176. https://doi.org/10.11113/matematika.v35.n2.1157

[16] Cakmak, B., and Apaydin, H. Advances in the management of the wastewater in turkey, natural treatment or constructed wetlands. *Spanish Journal of Agricultural Research*. 2010. 1: 188–201. https://dialnet.unirioja.es/servlet/articulo?codigo=3158829

[17] Verbyla, M., Sperling, V. M., and Maiga, Y. *Waste stabilization ponds. Global Water Pathogens Project. Part 4 - Management of Risk from Excreta and Wastewater*. UNESCO Report. Michigan State University. 2017. DOI: 10.14321/waterpathogens.65

[18] Martinez, F. C., Salazar, A. D., Rojas, A.L., Rojas, R.L., and Sifuentes, A.C.U. Elimination of fecal coliforms in stabilization lagoons with different arrangements. *Far East Journal of Applied Mathematics*. 2012. 69: 87–110. http://www.pphmj.com/journals/fjam.htm

[19] Shen, X., Xu, M., Li, M., Zhao, Y., and Shao, X. Response of sediment bacterial communities to the drainage of wastewater from aquaculture ponds in different seasons. *Science of The Total Environment*. 2020. 717: 137180. https://doi.org/10.1016/j.scitotenv.2020.137180

[20] Ali, H. Q., and Üçüncü, O. Impact of Baffle Walls on Area and Hydraulic Detention Time Needed for Wastewater Stabilization Ponds at Different Pollutant Loads. *International Journal of Environmental Pollution and Environmental Modelling.* 2022. 5(2), 99-108. https://dergipark.org.tr/en/pub/ijepem/issue/71152/1148838

[21] Alisawi, H. A. O. Performance of wastewater treatment during variable temperature. *Applied Water Science*, 2020. 10: 1-6. https://doi.org/10.1007/s13201-020-1171-x

[22] Ali, H. Q., and ÜÇÜNCÜ, O. Optimizing the amount of concrete for the construction of wastewater stabilization ponds: A case study of Ayvadere, Trabzon, Türkiye. *Environmental Research and Technology*. 2022. 5(3), 278-288. https://doi.org/10.35208/ert.1141587

[23] Liu, L., Hall, G., and Champagne, P. Disinfection processes and mechanisms in wastewater stabilization ponds: a review. *Environmental Reviews*. 2018. 26: 417–429. https://doi.org/10.3390/w8010005

[24] Sperling, V. M. *Waste Stabilization Ponds, Biological Wastewater Treatment Series*. London: IWA Publishers. 2007. https://www.iwapublishing.com/books/9781843391630/waste-stabilisation-ponds

[25] Ali, H. Q., Farooq, A., and Ahmed, M. Monitoring the wastewater treatment efficiency of oxidation ponds at Chokera, Faisalabad. *Mehran University Research Journal of Engineering and Technology.* 2017. 36(4), 987-994. https://doi.org/10.22581/muet1982.1704.23

[26] Ali, H. Q., and Üçüncü, O. Mathematical modeling and optimization of wastewater stabilization ponds using nonlinear programming. *Mehran University Research Journal of Engineering and Technology*. 2023. 42(1), 198-206. https://doi.org/10.22581/muet1982.2301.18

[27] Olukanni, D. O., and Ducoste, J. J. Optimization of waste stabilization pond design for developing nations using computational fluid dynamics. *Ecological Engineering*. 2011. 37: 1878–1888. https://doi.org/10.1016/j.ecoleng.2011.06.003

[28] Liu, L., Hall, G., and Champagne, P. Effects of environmental factors on the disinfection performance of a wastewater stabilization pond operated in a temperate climate. *Water*. 2015. 8(5). https://doi.org/10.3390/w8010005

[29] Gulsen, H., Turan, M., and Altay, A. The application of an empirical design model in the development of facultative pond design criteria for Turkey. *Environmental Technology*. 2000. 21: 1363–1369. https://doi.org/10.1080/09593332208618174

[30] Valero, M. A. C. *Nitrogen Transformation Pathways and Removal Mechanisms in Domestic Wastewater Treatment by Maturation Ponds*. Ph.D. thesis. University of Leeds, England, 40-42, 2008. https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.493562

[31] Mara, D. *Domestic Wastewater Treatment in Developing Countries*, 1st edition, London: Routledge Publishers. 2003. https://doi.org/10.4324/9781849771023

[32] Yılmaz, G., Şahinkaya, E., Uyanik, S., Hale, U., and Akyüz, İ. Yatay yüzey altı akışlı yapay sulak alan sistemlerinin kullanılmasıyla stabilizasyon havuzu çıkış suyu kalitesinin iyileştirilmesi. Harran Tarım ve Gıda Bilimleri Dergisi, 2010. 14: 3-11. https://dergipark.org.tr/en/pub/harranziraat/issue/18433/194179

[33] Özden, M. Environmental awareness and attitudes of student teachers: An empirical research. *International Research in Geographical and Environmental Education*. 2008. 17: 40–55. https://doi.org/10.2167/irgee227.0

[34] https://data.tuik.gov.tr/Bulten/Index?p=Belediye-Su-Istatistikleri-2018-30668. Access date: 26.01.2022.

[35] George, I., Crop, P., and Servais, P. Fecal coliform removal in wastewater treatment plants studied by plate counts and enzymatic methods. *Water Research*. 2002. 36: 2607–2617. https://doi.org/10.1016/S0043-1354(01)00475-4

Appendix A

Table 4: Summary of the Results for the Rural Area Near Antalya City (Mediterranean Region)

Sr. No.	C	BWs in FPs	Length of the Baffle wall									
			0.5		0.6		0.7		0.8		0.9	
			D_T(d)	Area (m^2)	D_T(d)	Area (m^2)	D_T(d)	Area (m^2)	D_T(d)	Area (m^2)	D_T(d)	Area (m^2)
1	C 1	0 BW	52.76	9712	52.37	9631	52.07	9569	51.84	9521	51.65	9482
2	C 2	0 BW	63.50	11180	62.88	11059	62.40	10964	62.05	10896	61.75	10837
3	C 1	2 BW	50.74	9294	50.17	9176	49.74	9087	49.39	9014	49.13	8960
4	C 2	2 BW	59.36	10367	58.38	10175	57.62	10025	57.02	9907	56.54	9813
5	C 1	4 BW	49.84	9107	49.36	9008	49.00	8933	48.74	8879	48.52	8834
6	C 3	4 BW	29.30	4423	29.30	4423	29.30	4423	29.30	4423	29.30	4423
7	C 1	6 BW	49.49	9035	49.06	8946	48.75	8882	48.52	8834	48.33	8795
8	C 2	6 BW	56.30	9766	55.63	9634	55.15	9540	54.77	9465	54.47	9406
9	C 1	8 BW	49.35	9006	48.94	8921	48.63	8857	48.41	8811	48.23	8774
10	C 2	8 BW	55.87	9681	55.27	9563	54.82	9475	54.50	9412	54.22	9357
11	C 1	10 BW	49.26	8987	48.87	8906	48.58	8846	48.37	8803	48.18	8764
12	C 3	10 BW	29.30	4423	29.30	4423	29.30	4423	29.30	4423	29.30	4423

Table 5: Summary of the Results for the Rural Area Near İzmir City (Aegean Region)

Sr. No.	C	BWs in FPs	Length of the Baffle wall									
			0.5		0.6		0.7		0.8		0.9	
			D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)
1	C 1	0 BW	57.67	9727	57.20	9638	56.87	9576	56.60	9525	56.40	9487
2	C 2	0 BW	69.48	11159	68.73	11025	68.23	10936	67.83	10865	67.50	10806
3	C 1	2 BW	55.32	9282	54.67	9159	54.17	9065	53.79	8993	53.47	8932
4	C 2	2 BW	64.75	10316	63.58	10108	62.73	9956	62.08	9841	61.55	9746
5	C 1	4 BW	54.27	9084	53.72	8980	53.32	8904	53.00	8843	52.77	8800
6	C 3	4 BW	32.78	4584	32.78	4584	32.78	4584	32.78	4584	32.78	4584
7	C 1	6 BW	53.87	9008	53.37	8913	53.02	8847	52.75	8796	52.52	8752
8	C 2	6 BW	61.18	9680	60.43	9547	59.88	9449	59.48	9378	59.13	9315
9	C 1	8 BW	53.67	8970	53.22	8885	52.87	8819	52.62	8771	52.42	8733
10	C 2	8 BW	60.68	9591	60.00	9470	59.53	9387	59.13	9315	58.84	9264
11	C 1	10 BW	53.57	8951	53.12	8866	52.77	8800	52.55	8758	52.37	8724
12	C 3	10 BW	32.78	4584	32.78	4584	32.78	4584	32.78	4584	32.78	4584

Table 6: Summary of the Results for the Rural Area Near Trabzon City (Black Sea Region)

Sr. No.	C	BW in FPs	Length of the Baffle wall									
			0.5		0.6		0.7		0.8		0.9	
			D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)
1	C 1	0 BW	58.57	10836	58.10	10738	57.77	10669	57.52	10616	57.31	10572
2	C 2	0 BW	70.47	12501	69.78	12362	69.28	12261	68.89	12183	68.57	12118
3	C 1	2 BW	56.17	10333	55.49	10190	55.00	10088	54.62	10008	54.31	9943
4	C 2	2 BW	65.66	11532	64.54	11307	63.69	11136	63.02	11001	62.47	10890
5	C 1	4 BW	55.05	10098	54.51	9985	54.11	9901	53.82	9840	53.58	9790
6	C 3	4 BW	33.92	5101	33.92	5101	33.92	5101	33.92	5101	33.92	5101
7	C 1	6 BW	54.65	10014	54.15	9909	53.81	9838	53.53	9779	53.32	9735
8	C 2	6 BW	61.99	10794	61.26	10647	60.72	10538	60.31	10455	59.99	10391
9	C 1	8 BW	54.44	9970	53.99	9876	53.67	9808	53.42	9756	53.22	9714
10	C 2	8 BW	61.47	10689	60.82	10558	60.34	10461	59.99	10391	59.69	10331
11	C 1	10 BW	54.34	9949	53.90	9857	53.59	9792	53.34	9739	53.15	9699
12	C 3	10 BW	33.92	5101	33.92	5101	33.92	5101	33.92	5101	33.92	5101

Table 7: Summary of the Results for the Rural Area Near İstanbul City (Marmara Region)

Sr. No.	C	BW in FPs	Length of the Baffle wall									
			0.5		0.6		0.7		0.8		0.5	
			D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)
1	C 1	0 BW	66.56	10203	66.02	10110	65.63	10044	65.30	9987	65.07	9948
2	C 2	0 BW	79.75	11563	78.92	11431	78.32	11335	77.83	11256	77.44	11194
3	C 1	2 BW	63.88	9745	63.12	9615	62.53	9514	62.08	9437	61.73	9377
4	C 2	2 BW	74.32	10695	73.02	10487	72.03	10329	71.25	10204	70.62	10103
5	C 1	4 BW	62.65	9534	62.02	9427	61.53	9343	61.18	9283	60.89	9234
6	C 3	4 BW	37.50	4765	37.50	4765	37.50	4765	37.50	4765	37.50	4765
7	C 1	6 BW	62.18	9454	61.62	9358	61.19	9285	60.87	9230	60.62	9187
8	C 2	6 BW	70.22	10039	69.35	9900	68.73	9801	68.23	9721	67.85	9660
9	C 1	8 BW	61.99	9422	61.45	9329	61.04	9259	60.73	9206	60.50	9167
10	C 2	8 BW	69.65	9948	68.88	9825	68.29	9730	67.87	9663	67.50	9604
11	C 1	10 BW	61.87	9401	61.34	9311	60.95	9244	60.67	9196	60.43	9155
12	C 3	10 BW	37.50	4765	37.50	4765	37.50	4765	37.50	4765	37.50	4765

Table 8: Summary of the Results for the Rural Area Near Sanliurfa City (Southeastern Anatolia Region)

Sr. No.	C	BW in FPs	Length of the Baffle wall									
			0.5		0.6		0.7		0.8		0.9	
			D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)
1	C 1	0 BW	69.90	12101	69.27	11983	68.80	11894	68.45	11828	68.	11777
2	C 2	0 BW	83.87	13435	82.85	13264	82.10	13139	81.50	13038	81.06	12964
3	C 1	2 BW	67.13	11579	66.25	11413	65.60	11291	65.10	11197	64.70	11121
4	C 2	2 BW	78.14	12475	76.63	12222	75.50	12033	74.63	11888	73.92	11769
5	C 1	4 BW	65.86	11340	65.13	11202	64.60	11103	64.20	11027	63.87	10965
6	C 3	4 BW	37.50	5626	37.50	5626	37.50	5626	37.50	5626	37.50	5626
7	C 1	6 BW	65.39	11251	64.73	11127	64.25	11037	63.87	10965	63.59	10912
8	C 2	6 BW	73.88	11762	72.87	11593	72.10	11464	71.52	11367	71.09	11295
9	C 1	8 BW	65.17	11210	64.55	11093	64.08	11005	63.73	10939	63.45	10886
10	C 2	8 BW	73.29	11663	72.35	11506	71.67	11392	71.15	11305	70.75	11238
11	C 1	10 BW	65.04	11185	64.45	11074	64.00	10990	63.65	10924	63.40	10876
12	C 3	10 BW	37.50	5626	37.50	5626	37.50	5626	37.50	5626	37.50	5626

Table 9: Summary of the Results for the Rural Area Near Ankara City (Central Anatolia Region)

Sr. No.	C	BW in FPs	Length of the Baffle wall									
			0.5		0.6		0.7		0.8		0.9	
			D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)
1	C 1	0 BW	91.45	18083	66.20	17944	90.32	17842	89.92	17756	89.66	17701
2	C 2	0 BW	103.82	19229	102.79	19024	102.00	18867	101.43	18754	100.96	18660
3	C 1	2 BW	89.13	17588	88.29	17408	87.63	17267	87.15	17165	86.78	17086
4	C 2	2 BW	98.90	18250	97.45	17962	96.33	17739	95.50	17574	94.82	17439
5	C 1	4 BW	88.18	17385	87.45	17229	86.90	17111	86.48	17021	86.15	16951
6	C 3	4 BW	37.50	5994	37.50	5994	37.50	5994	37.50	5994	37.50	5994
7	C 1	6 BW	87.83	17310	87.15	17165	86.63	17054	86.26	16974	85.95	16908
8	C 2	6 BW	95.68	17610	94.60	17395	93.80	17236	93.21	17119	92.73	17023
9	C 1	8 BW	87.67	17276	87.03	17139	86.53	17032	86.15	16951	85.85	16887
10	C 2	8 BW	95.23	17521	94.24	17324	93.50	17177	92.93	17063	92.47	16972
11	C 1	10 BW	87.60	17261	86.96	17124	86.48	17021	86.11	16942	85.82	16880
12	C 3	10 BW	37.50	5994	37.50	5994	37.50	5994	37.50	5994	37.50	5994

Table 10: Summary of the Results for the Rural Area Near Erzurum City (Eastern Anatolia Region)

Sr. No.	C	BW in FPs	Length of the Baffle wall									
			0.5		0.6		0.7		0.8		0.9	
			D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)	D_T (d)	Area (m^2)
1	C 1	0 BW	160.44	30539	159.00	30253	157.85	30025	157.10	29876	156.50	29757
2	C 2	0 BW	171.74	30315	169.35	29876	167.75	29583	166.50	29353	165.60	29188
3	C 1	2 BW	157.44	29943	155.90	29638	154.75	29409	153.90	29241	153.30	29122
4	C 2	2 BW	165.49	29168	163.00	28711	161.30	28398	160.00	28160	158.90	27958
5	C 1	4 BW	156.47	29751	155.05	29469	153.98	29257	153.30	29122	152.70	29002
6	C 3	4 BW	37.50	5626	37.50	5626	37.50	5626	37.50	5626	37.50	5626
7	C 1	6 BW	156.10	29677	154.80	29419	153.82	29225	153.10	29082	152.50	28963
8	C 2	6 BW	162.40	28600	160.45	28242	159.00	27976	158.00	27793	157.15	27637
9	C 1	8 BW	155.98	29654	154.60	29380	153.72	29205	153.00	29062	152.40	28943
10	C 2	8 BW	162.05	28536	160.10	28178	158.80	27939	157.75	27747	157.00	27609
11	C 1	10 BW	155.90	29638	154.55	29370	153.60	29181	152.90	29042	152.40	28943
12	C 3	10 BW	37.50	5626	37.50	5626	37.50	5626	37.50	5626	37.50	5626

APPENDIX B

Table 11: Typical Representation of the Effect of Variation in BWs Length and Numbers on BOD Removal in Various Climatic Regions

Sr. No.	C	BWs in FPs	Aegean		Mediterranean		Black Sea		Marmara		Southeastern Anatolia		Eastern Anatolia		Central Anatolia	
			Length of the Baffle Wall													
			0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9
1	C 1	0 BW	7	7	7	7	6	6	7	7	10	10	73	64	12	13
2	C 2	0 BW	8	8	8	8	7	7	8	9	13	13	93	77	16	16
3	C 1	2 BW	7	7	7	7	6	7	7	8	10	10	66	58	13	13
4	C 2	2 BW	9	9	8	9	8	8	9	10	13	13	77	66	16	16
5	C 1	4 BW	7	7	7	7	6	7	8	8	10	10	64	57	13	13
6	C 3	4 BW	40	40	40	40	37	37	41	41	48	48	94	94	60	60
7	C 1	6 BW	7	7	7	7	7	7	8	8	10	10	63	57	13	13
8	C 2	6 BW	9	10	9	9	8	9	10	10	13	14	72	64	16	16
9	C 1	8 BW	7	7	7	7	7	7	8	8	10	10	63	57	13	13
10	C 2	8 BW	9	10	9	9	8	9	10	10	13	14	71	64	16	16
11	C 1	10 BW	7	7	7	7	7	7	8	8	10	10	62	57	13	13
12	C 3	10 BW	40	40	40	40	37	37	41	41	48	48	94	94	60	60

Table 12: Typical Representation of the Effect of Variation in BWs Length and Numbers on Fecal Coliform Removal in Various Climatic Regions

Sr. No.	C	BWs in FPs	Aegean		Mediterranean		Black Sea		Marmara		Southeastern Anatolia		Eastern Anatolia		Central Anatolia	
			Length of the Baffle Wall													
			0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9
1	C 1	0 BW	170	170	170	170	170	170	170	170	170	170	170	170	170	170
2	C 2	0 BW	170	170	170	170	170	170	170	170	170	170	170	170	170	170
3	C 1	2 BW	170	170	170	170	170	170	170	170	170	170	170	170	170	170
4	C 2	2 BW	170	170	170	170	170	170	170	170	170	170	170	170	170	170
5	C 1	4 BW	170	170	170	170	170	170	170	170	170	170	170	170	170	170
6	C 3	4 BW	8355	5180	10737	6877	7286	4470	8495	5270	11347	7182	501443	452644	66892	51682
7	C 1	6 BW	170	170	170	170	170	170	170	170	170	170	170	170	170	170
8	C 2	6 BW	170	170	170	170	170	170	170	170	170	170	170	170	170	170
9	C 1	8 BW	170	170	170	170	170	170	170	170	170	170	170	170	170	170
10	C 2	8 BW	170	170	170	170	170	170	170	170	170	170	170	170	170	170
11	C 1	10 BW	170	170	170	170	170	170	170	170	170	170	170	170	170	170
12	C 3	10 BW	3176	2726	4373	3799	2707	2314	3233	2775	4506	3897	412559	401738	40289	37396

Table 13: Typical Representative Values of D_T in MPs after Variation in BWs Length and Numbers in Various Climatic Regions of Turkey

Sr. No.	C	BWs in FPs	Aegean		Mediterranean		Black Sea		Marmara		Southeastern Anatolia		Eastern Anatolia		Central Anatolia	
			Length of the Baffle Wall													
			0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9
1	C 1	0 BW	36	34.73	33.37	32.26	36.22	34.96	42.06	40.57	45.4	43.68	135.94	132	66.95	65.16
2	C 2	0 BW	36.7	34.72	34.2	32.45	36.55	34.65	42.25	39.94	46.37	43.56	134.24	128.1	66.32	63.46
3	C 1	2 BW	33.65	31.8	31.35	29.74	33.82	31.96	39.38	37.23	42.63	40.2	132.94	128.8	64.63	62.28
4	C 2	2 BW	31.97	28.77	30.06	27.24	31.74	28.55	36.82	33.12	40.64	36.42	127.99	121.4	61.4	57.32
5	C 1	4 BW	32.6	31.1	30.45	29.13	32.7	31.23	38.15	36.39	41.36	39.37	131.97	128.2	63.68	61.65
6	C 3	4 BW	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	C 1	6 BW	32.2	30.85	30.1	28.94	32.3	30.97	37.68	36.12	40.89	39.09	131.6	128	63.33	61.45
8	C 2	6 BW	28.4	26.35	27	25.17	28.07	26.07	37.72	30.35	36.38	33.59	124.9	119.65	58.18	55.23
9	C 1	8 BW	32	30.75	29.96	28.84	32.09	30.87	37.49	36	40.67	38.95	131.48	127.9	63.17	61.35
10	C 2	8 BW	27.9	26.06	26.57	24.92	27.55	25.77	32.15	30	35.79	33.25	124.55	119.5	57.73	54.97
11	C 1	10 BW	31.9	30.7	29.87	28.79	31.99	30.8	37.37	35.93	40.54	38.9	131.4	127.9	63.1	61.32
12	C 3	10 BW	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 14: Typical Percentage Removal of BOD with Variation in BWs Length and Numbers in Various Climatic Regions of Turkey

Sr. No.	C	BWs in FPs	Aegean		Mediterranean		Black Sea		Marmara		Southeastern Anatolia		Eastern Anatolia		Central Anatolia	
			Length of the Baffle Wall													
			0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9
1	C 1	0 BW	97	97	97	97	97	97	96	96	95	95	64	68	94	94
2	C 2	0 BW	96	96	96	96	97	96	96	96	94	94	53	61	92	92
3	C 1	2 BW	97	96	97	96	97	97	96	96	95	95	67	71	94	94
4	C 2	2 BW	96	95	96	96	96	96	95	95	94	93	61	67	92	92
5	C 1	4 BW	96	96	97	96	97	97	96	96	95	95	68	71	94	94
6	C 3	4 BW	80	80	80	80	81	81	79	79	76	76	53	53	70	70
7	C 1	6 BW	96	96	97	96	97	97	96	96	95	95	69	72	94	94
8	C 2	6 BW	95	95	96	95	96	96	95	95	93	93	64	68	92	92
9	C 1	8 BW	96	96	97	96	97	97	96	96	95	95	69	72	94	94
10	C 2	8 BW	95	95	96	95	96	96	95	95	93	93	64	68	92	92
11	C 1	10 BW	96	96	96	96	97	97	96	96	95	95	69	72	94	94
12	C 3	10 BW	80	80	80	80	81	81	79	79	76	76	53	53	70	70

Table 15: Typical Percentage Removal of Fecal Coliforms with Variation in BWs Length and Numbers in Various Climatic Regions of Turkey

Sr. No.	C	BWs in FPs	Aegean		Mediterranean		Black Sea		Marmara		Southeastern Anatolia		Eastern Anatolia		Central Anatolia	
			Length of the Baffle Wall													
			0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9
1	C 1	0 BW	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98
2	C 2	0 BW	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98
3	C 1	2 BW	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98
4	C 2	2 BW	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98
5	C 1	4 BW	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98
6	C 3	4 BW	99.16	99.48	98.93	99.31	99.27	99.55	99.15	99.47	98.87	99.28	49.86	54.74	93.31	94.83
7	C 1	6 BW	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98
8	C 2	6 BW	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98
9	C 1	8 BW	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98
10	C 2	8 BW	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98
11	C 1	10 BW	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98	99.98
12	C 3	10 BW	99.68	99.73	99.56	99.62	99.73	99.77	99.68	99.72	99.55	99.61	58.74	59.83	95.97	96.26