Environmental Engineering and Management Journal March 2010, Vol. 9, No.3, 385-391
http://omicron.ch.tuiasi.ro/EEMJ/

"Gheorghe Asachi" Technical University of Iasi, Romania

ASSESSMENT OF JAJROOD RIVER WATERSHED MICROBIAL POLLUTION: SOURCES AND FATES

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Abstract

The Jajrood River watershed is one of the main drinking water resources of Tehran, the capital city of Iran. In addition it provides many recreational usages. However, a variety of microbial pollutions is commonly perceived in the Jajrood River, among them a high concentration of coliform group bacteria that has caused strong concerns. In this article, different aspects of microbial pollution as well as the main microbial pollution sources in the region are discussed. Coliform group bacterial die-off rates have been evaluated as the key parameters that govern bacterial fate in the watershed and were estimated using both laboratory and field data investigations. The high values of the bacterial die-off rates cause significant reduction in the bacteria population naturally. According to the first order decay equation, around 74% of the microbial pollution from domestic wastewater of the 3 main cities in the study area would be attenuated naturally before arrivals to the watershed outlet. In addition, around 98.1% of the microbial population of the animal excretion in the surface area would be decayed naturally. By investigating both sources and fates in the Jajrood River watershed, our knowledge about coliform group bacteria dynamics in this watershed would be enhanced. Therefore, microbial pollution can be managed in a sustainable way by evaluation and use of natural capacity of bacteria die-off in the environment. The derived values for bacterial die-off rates can be a useful reference in microbial studies and modeling attempts.

Key words: coliform group bacteria, die-off rate, Jajrood River, microbial pollution, source and fate

1. Introduction

Water-born diseases are an increasing concern nowadays. Microbial pollutions are becoming a worldwide problem, both in developed and developing countries. Between 1920 and 2002, at least 1870 outbreaks were reported in the United States that were associated with drinking water, an average of 22.5 per year. The average annual number of water-born disease outbreaks ranged from a low of 11.1 during 1951–1960 to as many as 32.4 outbreaks during 1971–1980. In the most recent 12-year period (1991–2002), 207 outbreaks and 433 947 illnesses were reported (Craun et al., 2006). On other hand, over 40% of assessed waters in the United States do not meet water quality standards and thus are impaired. They are mostly polluted by sediments, excess nutrients, and harmful microorganisms (Benham et al., 2005).

Diarrhoea was ranked third in the top communicable diseases worldwide in 2002, causing 1.8 million deaths each year. However, diarrhoea and many other water-related diseases can eventually be controlled in a sustainable way by universal access to safe water and adequate sanitation, improved hygiene, and optimal water management practices (UNESCO-WWAP, 2006).

There are no unanimous opinions about microbial pollution indicators in aquatic systems. However, coliform group bacteria (CGB), especially total coliform bacteria (TCB) and fecal coliform bacteria (FCB), have been selected as water microbial indicators traditionally. Although coliform group bacteria generally do not cause danger to people or animals, they indicate the presence of other disease-causing bacteria in aquatic systems. FCB live only in human and warm-blooded animal bodies and seems to be a good indicator for human and warm-blooded

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animal wastes tracking in aquatic systems. Generally most of the existing standards have limited the concentration level for TCB and FCB concentrations in water resources for different usages (e.g. drinking, recreational water). For example, US EPA (1968) has established FCB concentration limit of 200 CFU/100 mL for recreational and contact usages, and equal to zero for drinking usages (USEPA, 2001).

Much research has been done in recent years to model fate and transport of CGB in watersheds. However, effective estimation of CGB pollutant production as well as its die-off rates is essential for every comprehensive modeling in the watershed scale. In this article, sources and fates of CGB in the Jajrood River watershed will be studied and quantified, and it is a basis for further modeling attempts.

2. Watershed Description

2.1. General description

The Latian Dam watershed, with an area of approximately 700 km^2, is located in the northeast of the metropolitan city of Tehran, Iran. The Latian Dam reservoir is one of the main drinking water resources of Tehran. It supports around 30 percent of Tehran's freshwater consumption demand. The Jajrood River is the primary river in this watershed. In addition to freshwater consumption, it has many recreational usages, especially in the warm months. Fig. 1 shows the location of the Jajrood River watershed in the country of Iran.

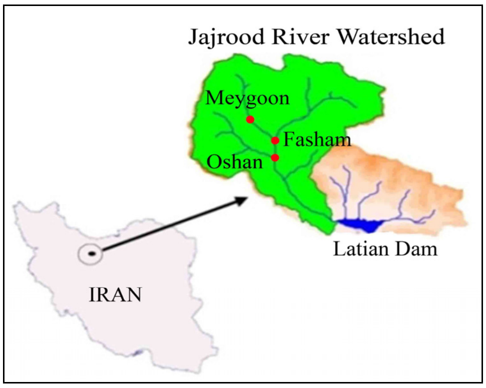

Fig. 1. The Jajrood River watershed location in Iran

The Jajrood River watershed is a small and mountainous watershed. There is about 2000 meters of variation between the altitudes of the lowest and highest points in the study area. The average annual precipitation is 580 mm, among which snowfall is dominant in the cold months. The long term average flow of the Jajrood River (1956-2005) is 7.4 m^3/s. The highest (22.2 m^3/s) and lowest (2.7 m^3/s) monthly average flows have been recorded in May and September, respectively.

The Jajrood River watershed with the area of 460 km^2, is comprised of 61.3% poor grassland, 34.6% well grassland, and 3.8% orchard landuse classes. Fig. 2 illustrates the Jajrood River watershed characteristics and perspectives.

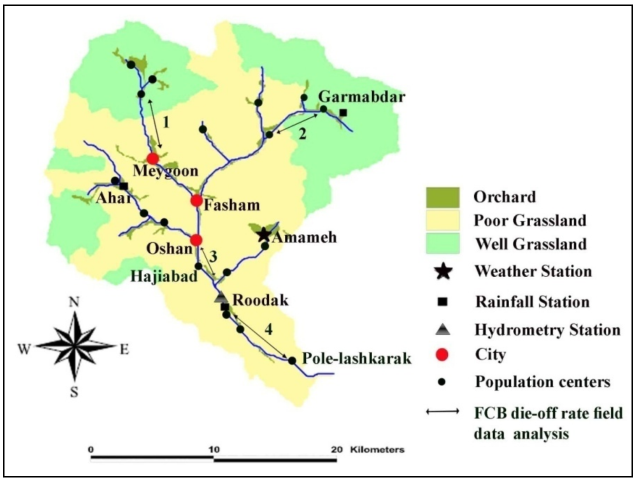

Fig. 2. The Jajrood River watershed characteristics

The Jajrood River watershed has three main cities (Oshan, Fasham, and Meygoon with total stationary populations of 9300) as well as 20 rural population centers. Table 1 shows human and livestock populations in the Jajrood River watershed in the year 2001.

Table 1. Human and livestock populations in the Jajrood River watershed

Population Type	*Human*			*Animal*	
	Stationary	*Seasonal*	*Tourist*	*Cow*	*Sheep*
Numbers	15479	19940	62300*	380	21400

* On Fridays

Therefore, the Jajrood River watershed is considered a highly populated watershed. As a result of being located near the capital city of Tehran, the population of the watershed is characterized by high mobility. Three categories have been distinguished among the population: stationary, seasonal, and tourist populations. Stationary population stays in the region for the whole year. Seasonal population comes to the region and stays there during the warm months. The tourist population comes to the region in the warm months and stays there just on a daily basis. The daily variations in the tourist population are very high throughout the week, with a peak on Fridays (weekend) and holidays during the warm months of year (see Table 1). It is estimated that the tourist population on Thursdays and other week days is 15% and 10%, respectively, of the Friday tourist population.

Sheep and dairy cows are the main livestock in this area. One of the characteristics of the Jajrood watershed pertains to sheep migration. Sheep are brought to the watershed in the warm months from April to October, and leave the region in the cold months of year. The number for other types of animals is negligible.

Table 2. Physico-chemical characteristics of the Jajrood River in the inlet of Pole-Lashkarak Station

Parameter	***Temperature***	***pH***	***TDS***	***Turbidity***	***Ammonium***	***Nitrate***	***Phosphate***
Value	9.1°C	8.3	219.3 mg/L	137.7 NTU	0.14 mg NH_4^+/L	4.5 mg NO_3^-/L	0.04 mg PO_4^{3-}/L

Table 3. CGB statistics of the Pole-Lashkarak station

Bacteria	***Parameter***	***Jan***	***Feb***	***Mar***	***April***	***May***	***June***	***July***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
Total Coliform (MPN)	Max	9400	5000	16000	7000	30000	90000	160000	50000	50000	28000	50000	11000
	Average	3615	2325	10500	6000	9500	23113	43714	18100	17920	10450	14940	5067
	Min	170	400	5000	5000	800	4900	13000	1300	1300	200	1700	2200
Fecal Coliform (MPN)	Max	1300	1600	1100	900	2200	28000	54000	11000	2200	5000	50000	2300
	Average	467	446	677	800	1075	7641	18214	3186	1480	1863	10562	986
	Min	20	60	130	700	400	230	1300	130	800	200	200	170

The existing TCB and FCB concentration data as well as other physico-chemical characteristics of the Jajrood River have been sampled in 17 stations along the river by the Water and Wastewater Authority (WWA) of Tehran. The sampling data time period is 1998-2005, and data were generally sampled once per month. Table 2 presents the average values of some main physico-chemical characteristics of the Jajrood River in the inlet of Pole-Lashkarak Station.

2.2. Microbial pollution perspective

In spite of the importance of the Jajrood River as a major water resource, it suffers from microbial pollution. CGB concentration often reaches magnitudes that are assumed to cause health risks in human contact and recreational usages. It should be noted that there is a direct correlation between the human diseases (mostly gastroenteritis and skin symptoms) and water microbial indicators even for the recreational usages (Cheung et al., 1989). Fig. 3 represents the monthly average of TCB and FCB concentration in the Jajrood River in the Pole-Lashkarak station.

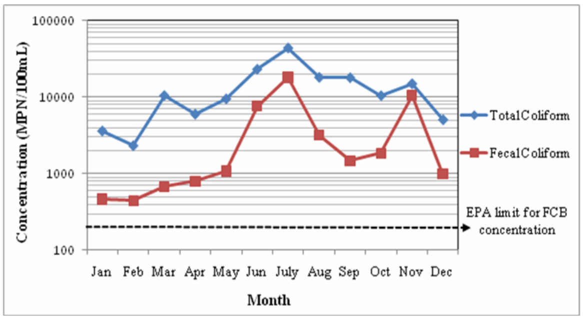

Fig. 3. Monthly average of CGB concentration in the Pole-Lashkarak station

Table 3 shows the used CGB raw data statistics in the current study. According to Fig. 3, the FCB concentration in the Jajrood River is much higher than the EPA (1968) limit for recreational usages. In some cases, it is as high as 100 times the EPA limit. In addition, the higher concentration of CGB in the Jajrood River, the higher the health potential risk to the drinking water of Tehran. So, it is necessary to appropriately detect and evaluate the Jajrood River microbial pollution sources.

3. Microbial pollution sources

3.1. Differentiation between fecal sources

TCB can have soil as well as wastewater origin. So it is not a good indicator in the investigation of potential pollutants. FCB, on other hand, can only be found in human or warm-blooded animal feces. So it can be used as a basis for tracking of the wastewater as the primary pollutant in the river body. Some officials present FCB and fecal streptococci bacteria (FSB) data as a ratio in an attempt to indicate the origin of bacterial pollution. A FCB/FSB ratio of 4 or greater has been said to indicate a human source. The corresponding ratio for domestic animals is on average 0.1-0.6, and for wild animals less than 0.1. As this ratio has been applied to surface and ground water samples, these numbers hold true only for recent fecal contamination (US EPA, 2001).

The Jajrood River is considered a small and mountainous river and sedimentation rarely happens in the river water column. Therefore, it is assumed acceptable to apply the FCB/FSB ratio as a basis for differentiation between different fecal pollution sources in the Jajrood River. FSB has been measured as a part of the sampling procedure of Water and Wastewater Authority (WWA) of Tehran. The available FSB can present a good view of the microbial pollution status.

Fig. 4 shows the classification of microbial pollution sources according to the above ratio in the Pole-Lashkarak Station (near the watershed outlet), which represents the pollution in the Jajrood River watershed as a whole. From the available 60 data series, human wastewater, livestock and wild animal wastes are the origin of 45%, 21.6%, and 1.6%, respectively, of fecal contamination of the Jajrood River. As it was predictable, wild animals have a negligible role in the microbial pollution. The only wild animal source of microbial pollution in the Jajrood River has been recorded in the month of May, and it may be due to direct access of wild animals to springs which flow into the Jajrood River or its tributaries. Many of the calculated ratios are between 0.6 and 4, which does not indicate any source of pollution. Human sources of pollution are perceived in most months, with a peak in the months of June and July. This is the main contributor to the microbial pollution of the Jajrood River, and its contribution being as much as two times that of the animal sources. Domestic animals often have a contribution in microbial pollution and its peak is in the months of September and October.

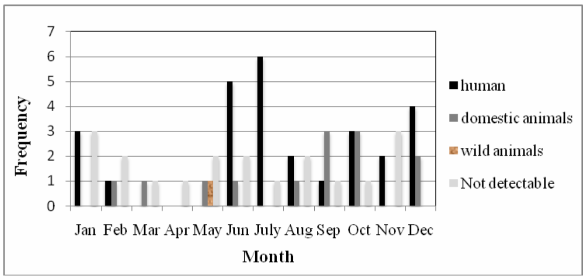

Fig. 4. Classification of fecal sources according to the Pole-Lashkarak station dataset

3.2. Runoff contribution

Runoff flow can wash the bacteria from surface lands and transport them to the river. Two main wash-off-related mechanisms of microbial pollution in the study area are fertilizing operations in orchards, and livestock grazing operations in well grassland landuses. Orchard landuse covers a small area in comparison with other landuses, but it is located close to the Jajrood River and could therefore have an important role in its microbial pollution during runoff events. It is estimated that all cow manures are applied in orchard landuse as fertilizer. Sheep grazing in well grassland landuse might also contribute in the Jajrood River's microbial pollution in wash-off events.

Currently, there is no experimental data to evaluate the wash-off effects in the Jajrood River's microbial pollution. The available microbial data have been gathered under non-rainy conditions. However, the effect of wash-off processes would be limited to the rainy events which cause effective runoffs. Fig. 5 shows the number of days between two consecutive rainfall events in the study area recorded at Ahar rainfall station (see Fig. 2) during the warm months of year. As already mentioned, the animal living time in the study area is limited to the warm months of year. The average frequency of the dataset is 7.3 days. This value corresponds to the average consecutive days in study area without any rainfall event.

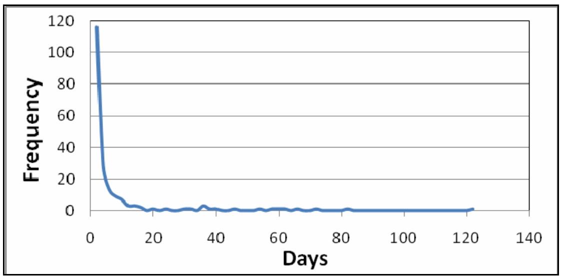

Fig. 5. Number of the consecutive days without any rainfall event in the Ahar rainfall station

3.3. Human wastewater

As described before, several population centers are located near the Jajrood River. Domestic wastewater is considered the primary source of microbial pollution in the Jajrood River watershed. Currently, the produced domestic wastewater is disposed in local cesspits. Since the available population centers are located alongside the river, seepage of bacteria from the local cesspits is the primary source of the microbial pollution that impairs the river in all sections. It is also impossible to determine the exact point of seepage to the river. However, the microbial load of the domestic wastewater is considered to be proportional to the inhabitants of population centers.

In some cases, the FCB concentration value in the Jajrood River is so high that it can indicate the arrival of raw wastewater in river. Therefore, direct spill of raw wastewater is one of the main sources of microbial pollution in the Jajrood River.

Conjugate analysis of Figs. 3 and 4 indicates that the peak of domestic wastewater pollution is in the months of June and July, which is in agreement with the maximum traffic of people in the watershed. It thus seems to be result of seasonal and tourist population traffic to the region.

3.4. Domestic livestock

The dominant domestic livestock in the study area is cows and sheep. Cow manure is gathered and applied in orchard landuse as fertilizer. Sheep manure is also left in the well grassland landuses during a grazing operation. As stated before, there is no data available for the rainfall times to clearly indicate the role of manure wash-off mechanisms. Therefore, according to the available data, the most important livestock-related mechanism that contributes to the microbial pollution of the Jajrood River is the direct access of livestock to the river and its release of feces in it.

According to Fig. 4, domestic animals frequently influence the Jajrood River especially in months September and October. It is possible that livestock migration is the reason of livestock microbial pollution in these months.

4. CGB die-off

Bacterial die-off is the primary parameter that governs bacteria fate in the watershed. Bacterial die-off is the opposite aspect of bacteria production and assumed to be a process of bacteria reduction. Conjugate investigation of bacteria production and die-off would result in good knowledge about bacteria dynamics in the water body.

The bacterial die-off rate determines the time rate of bacteria net mortality under the influence of different environmental variables. There are many variables that have impacts on the bacterial die-off rate, such as temperature, sunlight, pH, humidity, dissolved oxygen, nutrients, etc. (Crane and Moore, 1986; Wilkinson, 1995). Although there have been many efforts to quantify the role of each variable in the lumped die-off rate value, these roles have not been clearly determined yet.

Two primary forms of CGB die-off rates in this study pertain to CGB in the river body and in manure. Each of these die-off rates will result in bacteria population reduction. Therefore, it is essential to extract a good estimation of the above die-off rates in the study area. In this research, laboratory and field data have been employed for this purpose.

4.1. Laboratory tests

The manure bacterial die-off rate plays a key role in the reduction of the bacteria population before transportation into the river by any runoff events. So, the CGB die-off rate in combination with the number of days from manure excretion till the first effective runoff event could be used to show the amount of reduction in CGB population. However, there are several environmental factors which simultaneously affect the bacterial die-off rates. The question is how can we arrive at a good estimation of CGB die-off rate in manure? Indeed, we need some simplifications for this purpose.

Fecal bacteria in manure/fertilizer are classified into two categories: sorbed onto soil particles and in solution. It is estimated that around 90% of fecal bacteria are in the solution phase. It is also assumed that the bacterial die-off rate in the sorbed phase is one-tenth of the solution phase (Parajuli, 2007).

Temperature is the primary environmental factor that influences the die-off rate in manure; the effects of other environmental variables such as humidity and light radiation ultimately can be measured in the temperature change. Therefore, in this research the temperature impact on the bacterial die-off rate is the only factor that is considered in the estimation of the bacterial die-off rate in the manure.

In the laboratory tests, grab samples from the Jajrood River at the Roodak station were taken on 21 November 2007. These samples were fully covered and placed in an ice chest. Next, the samples were transported to the laboratory immediately and held in an incubator (Tebazma, Iran) at 20°C for 10 days. Frequent MPN tests were carried out on the samples during this period. The MPN tests were done using standard cultures: lactose, BGLB, and EC broths (Merck, Germany). Fig. 6 shows the variation of TCB and FCB concentration in the samples. Interpolating lines were drawn representing the supposed first-order die-off rate.

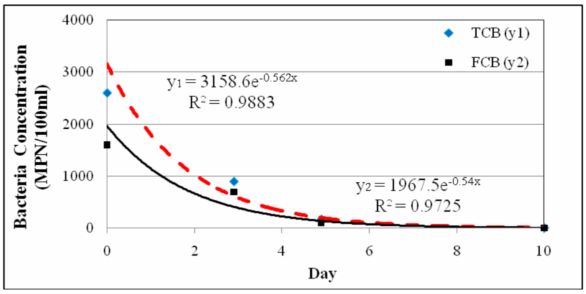

Fig. 6. CGB concentration variation in laboratory samples

The laboratory tests yield similar values for the TCB and FCB die-off rates, which are 0.56 and 0.54 day^{-1} respectively. This quantity is interpreted as a result of the temperature effect on bacterial die-off rate and is assumed as bacterial die-off rate in manure solution. TCB and FCB that have sorbed in manure soil particles are estimated to have die-off rates of 0.056 and 0.054 day^{-1} respectively. It should be noted that the above values stand for the net die-off rates which are the summation of the actual die-off rates and the reproducibility of the microbial population during the test.

4.2. Field data investigation

On the other hand, historical field data measurements were used for appropriate estimation of CGB in the Jajrood River. Bacterial die-off rate in river bodies is a variable parameter, especially in small streams (with a flow of less than 20 m^3/s), that knowledge on it is scarce (Beaudeau et al., 2001). There are very high variations between TCB and FCB die-off rate values in different river bodies. Although typically FCB die-off rates in rivers are in the 0.5-3 day^{-1} interval (Gibson, 2006), there are reports that have determined this rate as high as 26.4 day^{-1} (Bowie et al., 1985).

Eight years of monthly CGB concentration data in several stations on the Jajrood River were employed for the field data analysis. Four reaches of the Jajrood River were selected (they are specified in the Fig. 2) and TCB and FCB concentration data in upstream and downstream stations from the same day were analyzed. Bacterial die-off rates in each section were calculated using the first-order die-off equation (1):

$$B_3 = B_1 e^{-kt} + B_2 e^{-kt'} \qquad (1)$$

where B_1, B_3 are the bacterial loads at the upstream and downstream stations, respectively. B_2 is the bacterial load from the population centers within the selected reaches and is estimated according to the area situations and academic references (Metcalf & Eddy, 2004). Also, t is the travel time from upstream to downstream station and t' is the mean travel time from the population centers to the downstream station. K is the bacterial die-off rate.

Table 4 shows the results of the field data calculations of TCB and FCB die-off rates in the river body. On this basis, average die-off rates of TCB and FCB in the Jajrood River are determined as 4.52 and 6.38 day^{-1}, respectively. It seems that high levels of oxygen content in the river and direct sunlight on the complete river depth are responsible for high values of die-off rates in the Jajrood River.

5. Conclusions

This article discussed CGB, especially FCB dynamics in the Jajrood River watershed. The main sources of FCB in the Jajrood River were determined as direct discharge and seepage of domestic wastewater from local cesspits, and livestock direct excretion. Currently, there is not enough data available to assess the contribution of runoff events to the microbial pollution of the Jajrood River.

On the other hand, bacterial die-off rates in two parts of manure and the river body have a considerable impact on bacterial population reduction. FCB die-off rates in manure solution and sorbed onto soil particles were estimated equal to 0.54 and 0.054 day^{-1} at 20^{o}C, respectively. It is clear that this value would be increased in temperatures higher than 20^{o}C. Since most of the manure FCB existed in the solution phase (around 90%) and the FCB die-off rate in manure solution is sufficiently high, it is obvious that most of the manure FCB will be reduced to safe limits in the first several days after excretion. By employing the first order decay formula and using both the above FCB die-off rate in the solution phase and the average number of days without any rainfall event in the study area (Figure 5), the ratio of FCB concentration in the animal manure at the time of the wash-off event to its initial concentration at the time of excretion is 0.019. Based on this ratio, around 98.1% of the animal manure which is excreted in the earth surface would be decayed before the first rainfall event.

In addition, the FCB die-off rate in the Jajrood River was determined as 6.38 day^{-1}, which is a high value in comparison to the usual values. Although the length of the selected reaches along the Jajrood River is small, the high value of the FCB die-off rate causes considerable decrease in FCB concentration. In spite of the high microbial impairment of the Jajrood River, it has a great natural ability for purification and causes significant decrease in microbial population. By employing the first order decay formula and using FCB die-off rate value for the Jajrood River and doing a simple calculation, the magnitude of FCB removal from the potential domestic wastewater of the main cities of the region can be easily estimated. The ratio of FCB concentration in the Pole-Lashkarak Station (near the watershed outlet) to the FCB concentration in discharge point for three main cities of Oshan, Fasham, and Meygoon with distances of 13.79, 18.00, and 24.29 Km from the Pole-Lashkarak Station, are 0.36, 0.26, and 0.16 respectively. It means that respectively, 64%, 74%, and 84% of the initial FCB discharge to the Jajrood River from the cities will be removed naturally.

According to the author's experiences, some current models like AVSWATX consider the bacteria die-off rates in the water bodies in limited interval (e.g. 0-3 for the AVSWATX). So, base on this article's findings, those models are not comprehensive and can not be implemented to model special cases like the Jajrood River.

In spite of severe microbial pollution, it seems feasible to manage FCB pollution of the Jajrood River by implementing some management practices. First of all, domestic wastewater direct discharge and direct access of livestock must be prohibited throughout the watershed. Indeed, eliminating any direct input of wastewater into the Jajrood River will considerably reduce the current bacterial indices. Authors believe that completion of wastewater collection and treatment project in the area would considerably change the microbial status of the Jajrood River. The next practice should pertain to the FCB modeling on the watershed scale.

By using FCB die-off rates, the maximum capacity of microbial loads to the Jajrood River can be determined so as to reduce the bacterial loads to the standard specified limits. On this basis, maximum legal loads of every population center will be specified. In addition, retention of new excreted manure for some weeks will significantly reduce its fecal bacteria content. So, it is recommended that produced cow manures in the watershed be gathered in the specified places for some weeks before any application as fertilizer to the orchards

Table 4. Calculations of CGB die-off rates in the Jajrood River

Section	*Length (m)*	*Number of data*	*TCB die-off rate (day^{-1})*		*FCB die-off rate (day^{-1})*	
			Average	*Standard deviation*	*Average*	*Standard deviation*
1	4977	16	6.05	4.4	10.32	1.74
2	7055	13	2.77	4.41	2.07	4.14
3	5427	41	7.24	4.6	5.72	5.32
4	6580	15	2.01	2.42	5.93	4.86

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