NATURAL WASTEWATER TREATMENT IN MOUNTAIN AREAS IN LEBANON

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Abstract

One of the most important stages and energy intensive operations at the wastewater treatment plant is the aeration. Several researchers have conducted laboratory works to investigate the aeration efficiency of stepped cascades. The proposed study consists of taking advantage of the hilly topography of Lebanon mountains for natural wastewater treatment by creating stepped cascades, without using any types of costly equipment that may further result in additional air emissions the environment. In this paper, the natural land formation of one of the mountains in Lebanon is shaped as a stepped cascade and the aeration efficiency was measured and compared to mathematical models prepared by Gameson et al., WRL, Nakasone & El-Monayeri. The use of fixed film bacteria has been also investigated. Good agreement between the site measurements and the models that account for the flow rate & cascade geometry was obtained. The results indicate that the stepped cascade and the fixed film bacteria contribute to the improvement of wastewater characteristics.

Keywords: Aeration efficiency, natural wastewater treatment, stepped cascade, fixed film bacteria

Introduction

Wastewater treatment is the process of removing contaminants from sewage, and includes physical, chemical and biological processes. Its objective is to produce an environmentally safe fluid suitable for disposal or reuse. There are many procedures for wastewater treatment, some of which are costly and require specific experience. In Lebanon, wastewater treatment is a national issue, especially in the mountainous areas where the use of septic tanks and other primitive sewage disposal is widely spread. Identifying appropriate treatment options for improving treated effluent has a high priority in Lebanon, since villages without sanitation facilities discharge their effluent to nearby agricultural areas, valleys, or to septic tanks, neither of which are environmentally friendly since they cause major environmental impacts such as ground water pollution.

Oxygen is a necessary element to all forms of life. The concentration of dissolved oxygen is very important in water and wastewater whether before or after treatment. It is a prime indicator in determining how satisfactory a biological wastewater treatment plant is operating.

Adequate level of oxygen is necessary to survive the aerobic bacteria which turn the organic wastes into inorganic byproducts. If the dissolved oxygen level is too low, aerobic bacteria will cease with possibility of shifting to anaerobic conditions with consequent time-consuming biomass replacement process. Dissolved oxygen is thus one of the most critical measurements in wastewater treatment plants and the control of its levels is critical to the operation of the wastewater treatment plants in terms of power consumption and degree of treatment.

In aeration tanks are suspended growth occurs. In order to increase the activity of microorganisms and keep the organic waste thoroughly mixed, air is supplied to the aeration tanks through common methods as:

- Gravity Aeration
- Mechanical aeration
- Diffused air aeration

All these methods except the gravity aeration consume high energy during operation in addition to the required skilled labors for operation and maintenance; therefore, they result in high running cost. In view of these constraints, and due to excessive environmental stress and pollution related to population growth and the wide spectrum of technology that could be addressed to solve such solutions, going green and being sustainable become a must. Therefore, in current study case, it was essential to get benefit of the natural aeration available from natural available gradient at mountains to enhance wastewater self-purification process and achieve a considerable enhancement in wastewater quality as discussed hereafter.

Background

Natural re-aeration structures have been used in various civil and environmental applications (Chanson, 2001). Natural aeration systems lead to a reduction of 90% in consumed energy compared to mechanical aerators (Sabry, 2010). This may earlier have led many municipalities in small communities and rural areas to discharge the wastewater into rivers and lakes without any treatment ignoring all environmental concerns. Gravity aeration is considered the least costly method to raise the dissolved oxygen levels (Tchobanoglous et al. 2003). During the flow of wastewater in gravity aeration, the wastewater and air are in close contact where gas exchange occurs between the air and the wastewater. Oxygen diffuses from the air into the wastewater and helps to increase the dissolved oxygen content of the wastewater (Sanjib et al. 2010). Gravity aeration can be performed using several types of hydraulic structures such as a simple weir, an inclined corrugated sheet or a stepped cascade which has shown to be one of the cost effective promising techniques (Koduri & Barkdoll 2003) in replenishing dissolved oxygen (Metcalf & Eddy 2003) in water and wastewater streams.

Stepped cascade is a type of aeration structure characterized by large amount of self-entrained air (Baylar et al. 2010). Gameson (1957) was the first to report on aeration performance of weirs in rivers. After that, several experimental investigations were conducted to study the effect of varying the shape of the weir on the aeration performance. It was found that oxygen transfer efficiency was the highest with the triangular notch weir and lowest with the rectangular weir (Baylar et al. 2006). The flow in stepped cascades bounces from one step to another as a succession of drop structures. Stepped or cascade spillways are used since more than 3000 years in the construction of large dams, reservoirs and channels. Since the 19^{th} century, several researchers Essery and Horner (1978), Chamani and Rajaratnam (1994,1999a) and Chanson (1995, 2002) focused on the hydraulic design of the cascade spillways. They mainly focused on using stepped cascade to assist energy dissipation of the flow. Chanson (1995), Baylar et al. (2007) and Sanjib et al. (2010) carried out some experimental studies for predicting aeration efficiency of spillway and cascades structures. Therefore, stepped cascades play the role of improving water & wastewater characteristics by increasing dissolved oxygen level in addition to its hydraulic role for energy dissipation.

The flow on stepped cascades can be nappe, transition or skimming flow. In nappe flow regimes, water bounces from one step to the next at low flow rates. In skimming flow regimes, the water flows down the stepped face as a coherent stream, skimming over the steps and cushioned by the recirculating fluid trapped between them at high flow rates.

Emiroglu et al. (2003) found that skimming flow is observed in high discharges and that nappe flow occurs more than skimming flow as chute inclination angle decreases. Several researchers have investigated experimentally the aeration performance of weirs & stepped cascades. Chanson et Toombes (2002a) conducted studies on stepped cascades and confirmed that aeration efficiency occurs in nappe flow regime only. Baylar et al. (2006) conducted some experimental investigations about aeration efficiency in stepped cascades and found that nappe flow regime occurs with increasing the height of the step and that nappe flow regime has higher aeration efficiency than skimming flow. Sanjib et al. (2010) carried some aeration experiments and found that the overall aeration efficiency for a particular height of stepped cascades increases with the number of steps. Various empirical equations and models have been developed for oxygen transfer over cascade stepped aerators. Many empirical models have been predicted for different hydraulic structures using the physical properties of the structure or the running flow conditions to estimate the oxygen transfer efficiencies; therefore such models should be used with caution (Koduri & Barkdoll 2003). All these measurements were taken during experimental works for water falling over stepped cascades. El-Monayeri et al. (2006) conducted some experimental works to investigate the aeration efficiency for wastewater. It was found that the increase in dissolved oxygen level in wastewater appears to be less than in clean water upon falling from the same fall height. Khalifa et al. (2011) conducted some studies and prepared a model focusing on the effect of the pollutant load on aeration efficiency. Sabry et al. (2010) examined the performance and feasibility of using different natural aeration methods for raw sewage and found that cascade aerator has the best removal efficiency in BOD, COD and TSS.

As the wastewater is bouncing from one step to another, the aeration of the flow and the strong turbulent mixing improve the air-water transfer of chemicals which may characterize the stepped cascades by a large amount of self-entrained air and hence increases the levels of dissolved oxygen and improving the aeration efficiency.

O'Connor-Dobbins (1958), (Churchill et al. (1962), Owens et al. (1964) proposed several equations in terms of velocity and water depth to compute the re-aeration rate in streams. Several investigators carried out several experimental works concerning the oxygen transfer and aeration efficiency of several types of hydraulic structures. Gameson (1957) was the first who examined the oxygen deficit ratio over weirs. Holler (1971) developed an equation to estimate the oxygen deficit ratio based on the drop height. The U.K. Water Research Laboratory (WRL) (1973) modified Gameson's equation (1958). Foree (1976) developed an empirical correlation to relate the oxygen deficit ratio to the drop height for low-level in-stream dams behaving as waterfalls. Avery & Novak (1978) carried out a number of laboratory investigations into weir and hydraulic jumps. In 1986, Nakasone proposed a new approach to compute the aeration efficiency by developing an equation taking into consideration new parameters such as the flow per unit width of the weir and the pool depth. Rindels & Gulliver (1990) prepared prototype weirs and spillways and developed an equation to correlate the oxygen deficit ratio to the drop height, tailwater depth and unit discharge. Wilhems et al. (1992) reviewed the aeration performance of existing hydraulic structures. In 1998, Wormleaton & Soufiani (1998) adjusted the temperature correction factor presented in Gameson et al. (1958) equation. Aboul Fotoh (2007) and El Gohary (2007) tested the effect of using submerged plastic media on the biological process, hydraulics of the stream. El-Monayeri (2009) adjusted Nakasone model by considering the effect of COD value in order to account for the effect of pollutant load.

Aeration Efficiency Models

The aeration efficiency of any hydraulic structure, E, may be defined as (Gameson 1957):

$$E = \frac{C_d - C_u}{C_s - C_u} = \frac{r-1}{r}$$

Where;

C_d & C_u are the downstream and upstream dissolved oxygen concentration respectively;

C_s is the oxygen saturation concentration;

r is the oxygen deficit ratio.

For E equals to zero corresponds for no aeration and 1 for total downstream saturation. For E greater than one corresponds to supersaturated downstream water, a value of one means that the full transfer up to saturation value has occurred.

Avery and Novak (1978) developed the following equation to calculate the overall deficit ratio (r_{tot}) and efficiency (E_{tot}) for a number of cascade steps (n):

$$r_{tot} = r^n$$

$$E_{tot} = 1 - (1-E)^n$$

According to Henry's Law, liquid temperature has a direct proportional effect on the solubility of gas in liquid. Liquid temperature is one of the most important parameters to which the oxygen transfer efficiency is sensitive. Dissolved oxygen levels fluctuate hourly, daily, weekly and seasonally. They vary with temperature and altitude. Cold water holds more oxygen than warm water and water holds less oxygen at higher altitudes. Several researchers examined the temperature effect on the aeration efficiency. The most often used temperature correction factor is the one developed by Gulliver et al. (1990).

$$E_{20} = 1 - (1-E)^{\frac{1}{f}}$$

Where E is the aeration efficiency at the water temperature of measurement (T) in Celsius, E_{20} the aeration efficiency at the 20°C and f is described by:

$$f = 1.0 + 0.021(T-20) + 8.26 \times 10^{-5}(T-20)^2$$

Several models and equations have been developed for the oxygen transfer and aeration efficiency as mentioned below:

Gameson et al. (1958)

$$r = 1 + 0.34\, a_w b_w H_d (1 + 0.046T)$$

where a_w = 0.85 for sewage water and b_w = 1.3 for stepped weirs

Water Research Laboratory (1973)

$$E = 1 - [1 + 0.38 a_w b_w H_d (1 + 0.046T)(1 - 0.11 H_d)]^{-1}$$

Nakasone (1986)

$$E_{20} = 1 - e^{-aH_d^b q_w^c d_s^d}$$

where:

q_w is the flow rate per unit width

d_s is the pool depth

$H_d = D + 1.5\, H_c$

D = Weir drop height above the downstream water level

H_c = Critical water depth on the weir

a, b, c & d are constants that vary with the flow rate and cascade geometry

El-Monayeri (2011)

$$E_{20} = 1 - e^{-aH_d^b (COD \times q_w)^c d_s^d}$$

COD is the chemical oxygen demand in kg/liter

Materials & Methods

The current conventional treatment technologies relying on extensive use of mechanical aeration system for aerobic processes are often expensive to construct and operate. Meanwhile, and in many cases, like mountainous rural areas and small communities wastewater is left untreated due to unaffordable expenses. This study focuses on the importance of natural aeration using stepped cascade and the benefits of using submerged plastic media downstream the stepped cascade in order to enhance the quality of the discharged sewage flows from above mentioned areas. The efficiency of the natural cascade aeration will be evaluated in the presence of a biological media downstream the cascade in a real model as described below.

Raw wastewater was obtained from one of the manholes located on the main sewer line of the campus of Beirut Arab University in Debbieh, one of the mountainous areas in Lebanon. The sewer line collects wastewater from toilets and kitchens of the Engineering, Architecture and Science faculties, student's dorms and administration buildings. Figure 1 shows the location of the project and Figure 2 shows the topographic profile of the mountain which is typical to mountains in Lebanon.

The natural land formation was thus shaped as a stepped cascade, and allowed the use of steep slopes while covering the ground with blinding concrete to prevent infiltration of wastewater to the underground to prevent pollution. The samples were analyzed in the field and in laboratory according to APHA standards in order to determine the characteristics of the wastewater which includes dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, suspended solids and pH. The physical and chemical characteristics of raw wastewater are shown in Table 1.

Table 1: Physical & chemical characteristics of raw wastewater

Parameters	**Average ± Standard Deviation**
BOD (mg/l)	252 ± 15
COD (mg/l)	326 ± 18
TSS (mg/l)	156 ± 49
pH	7.24 ± 0.22

Figure 1: Project Location

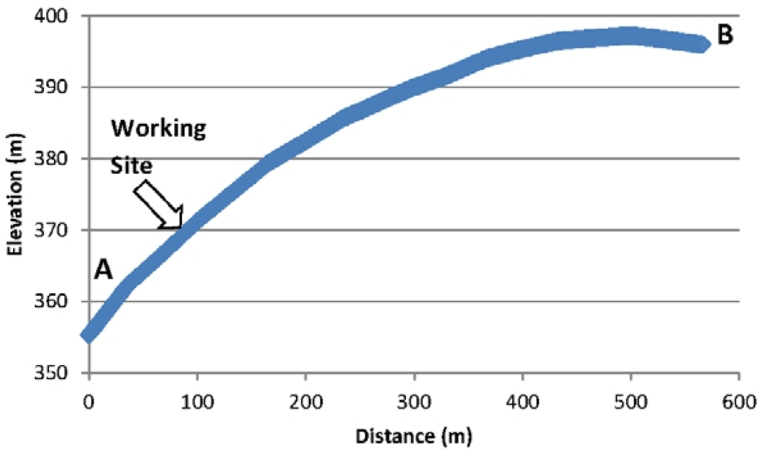

Figure 2: Topographic Profile

Figure 3 shows the schematic representation of the stepped cascade. The wastewater was pumped from the sewer manhole through a plastic pipe to an upstream basin 1.5m long, 0.6m wide and 0.4m deep. The discharge was measured by means of a flowmeter followed by a flow control valve installed on the discharge pipe. The cascade plan area is 1.5m x 0.6m with a drop of 0.4m and a total number of 5 steps. At the downstream of the cascade, the wastewater is directed through a fixed media assembly to promote intimate surface contact and cause microbial growth. The downstream basin is 1.5m long, 0.6m wide and 0.4m deep. The media consists of a set of polyethylene rings having a cylindrical shape of 2cm diameter and 2cm height. In order to improve the growing up of a quality biomass, the downstream basin was filled with 50 liters of activated sludge which was brought from the sewage treatment plant of the university.

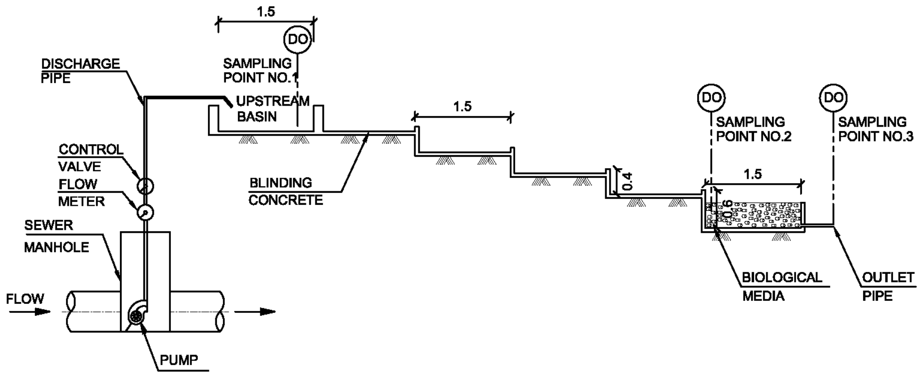

Figure 3: Schematic representation of the field work

Wastewater samples were collected upstream & downstream the stepped cascade and at the outlet of the biological media basin. The following parameters were tested for each wastewater sample:

- Dissolved oxygen concentration (DO)
- Biochemical oxygen demand after 5 days (BOD_5)
- Chemical oxygen demand (COD)
- Total suspended solids (TSS)
- Temperature
- pH

The dissolved oxygen was measured by the portable meter CyberScan DO100 Model for three sampling points; upstream, downstream the cascade and at the discharge pipe of the biological media basin as shown in Figure 3. The DO meters were daily calibrated as recommended by the manufacturer.

pH is an important indicator and temperature is an important parameter since it is in a direct relation with the dissolved oxygen concentration.

Biochemical Oxygen Demand, is one of the most important and useful parameters indicating the strength of wastewater (amount of organic load/pollution). It is an estimate of the waste strength in terms of the amount of dissolved oxygen required by the microorganisms to break down the wastewater. It is the most commonly used parameter to define the strength of the wastewater (Hammer, 1996).

Dissolved oxygen refers to the amount of oxygen that is contained in water. While dissolved oxygen concentrations are necessary to carry out the BOD determination, dissolved oxygen levels are also quite important in determining how satisfactory a biological wastewater treatment is operating. Chemical oxygen demand (COD) identifies the amount of oxygen equivalent of the organic matter that is vulnerable to oxidation by a strong chemical oxidant. Total Suspended Solids (TSS) gives a measure of the turbidity of water.

The use of submerged fixed film in the biological treatment of wastewater has been used for over 60 years. It utilizes films of attached bacteria to the wastewater. As organic matter and nutrients are absorbed from the wastewater, the film of microorganisms grows and thickens.

Results

The measured dissolved oxygen upstream and downstream the stepped cascade was recorded for six flow rates (10, 20, 30, 40, 50 & 60 m^3/hr) for duration of 30 days. It is noticed that the values of the dissolved oxygen downstream are higher than the upstream values for all flow rates, which means that the stepped cascade has its effect on increasing dissolved oxygen and hence enhancing wastewater characteristics. As stated above, the number and dimensions of the stepped cascade are fixed. Figure 4 shows the measured DO values at the three sampling points of the stepped cascade for the 30 days.

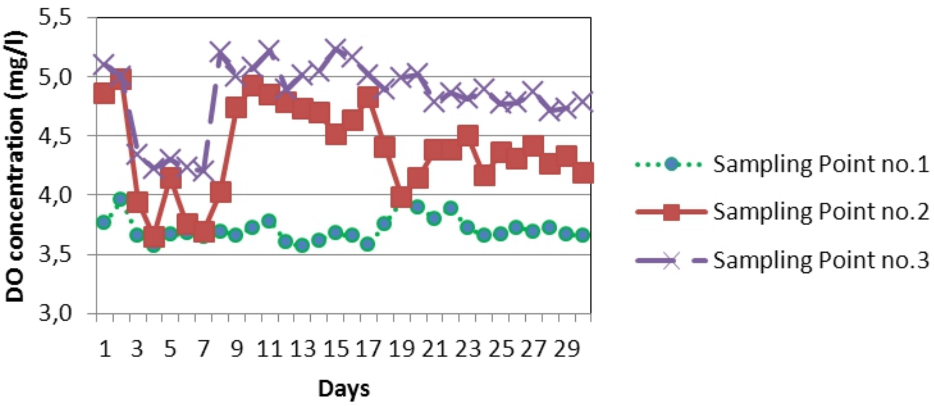

Figure 4: Measured Dissolved Oxygen

It is noticed that in some days, the aeration efficiency is better than others for the same flow rate and water characteristics. This is due to the presence of high wind speed during these days. Figure 5 shows the average values of the upstream and downstream dissolved oxygen at sampling points 1 & 2 for all the measurements taken during the field work and the percentage of the increase in dissolved oxygen concentration. Also, it was noticed that the concentration of DO in the water samples having low temperature is higher than the samples having higher water temperature. The turbulence of water also caused foam on the water surface. It was noticed that the amount of the foam increases and decreases in relation with the water depth and type of flow. For small flows, nappe flows with small water depth were found causing a higher water fall and resulting in a larger amount of foam. The measurements show that the percentage of increase in DO between sampling points 1 & 2 is 27.7% for flow rate 10 m^3/hr then it increases to 28.2% for flow rate 20 m^3/hr, and further to 33.5% for flow rate 30 m^3/hr. For higher flow rates 40, 50 and 60 m^3/hr, the net percent increase decreased gradually to 31.5, 27.6 and 27.1% respectively as shown in Figure 5. This could be due to the decrease of the water falling drop since the depth of water in the step increases with increase of the flow rate similar to the findings of Toombes (2002). Also, this may be due to the short residence time of water for high flow rates where the flow tends to be skim flow instead of nappe flow. The average increase in DO between sampling points 1 & 2 for all the readings of all flow rates is 29.3% which will have a great positive impact on overall mechanism of enhancing / treating studied raw through low cost (construction / operation) installations, while being sustainable and environmentally friendly. Concerning, the dissolved oxygen increase between sampling points 2 & 3, this was low and estimated at a percent increase of 10.1%. Such low effect could be due to the short residence time of the wastewater in the downstream basin and due to the need of the improvement of the biological media.

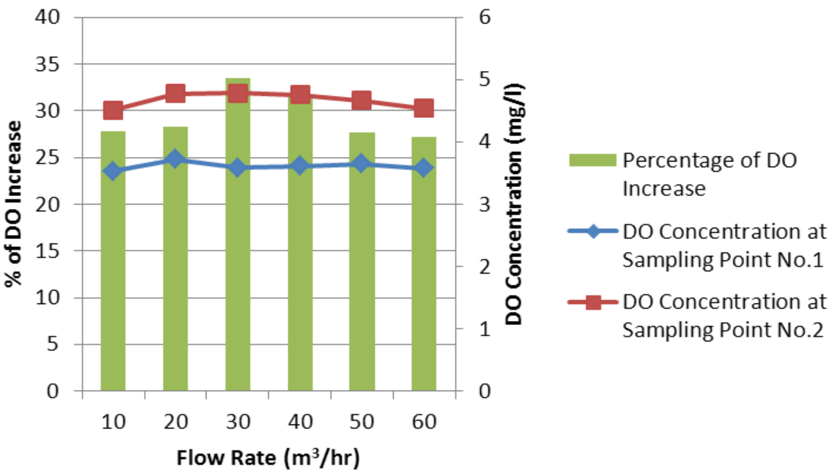

Figure 5: Increase of DO concentration (Sampling Points 1 & 2)

Figure 6 shows a comparison between the measured upstream and downstream dissolved oxygen concentrations and the computed values of the downstream dissolved concentration using the four mathematical models mentioned above for the six flow rates. It is noticed that the measured downstream dissolved oxygen values are more close to the values computed by Nakasone and El Monayeri equations than the ones computed by Gameson et al. and WRL equations. This could be due to neglecting the flow rate in both Gameson et al. and WRL equations. In all cases, the values computed using Gameson et al. equation are always close to those computed using WRL equation, and the ones computed using Nakasone equation are always close to those calculated using El Monayeri equation. The measured downstream dissolved oxygen average values are 7.3% & 8.4% greater than the values calculated using Nakasone and El Monayeri equations, while they are 30% and 31.1% less than the calculated values using Gameson et al. and WRL equations for flow rate of 10 m^3/hr.

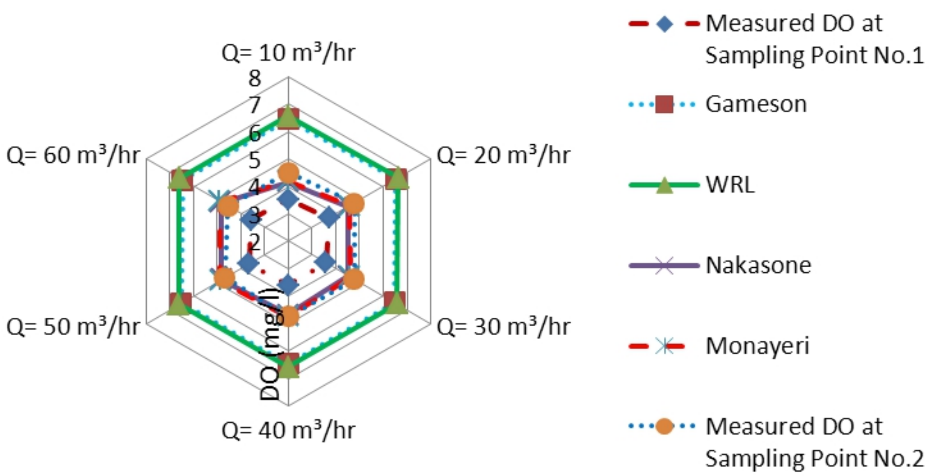

Figure 6: Comparison between measured and computed DO concentrations

Conclusion

In the present study, aeration performance of stepped cascade in the presence of a fixed film bacteria downstream the cascade was investigated for wastewater. The study confirms that the stepped cascade can be used as a natural wastewater treatment especially in mountain areas where it can benefit from the steep slopes to save and reduce the use of mechanical equipment. The results obtained from field work were close to the calculated (estimated) values using Nakasone equation and El Monayeri equations. Also, it is noticed that the field measurements upstream and downstream the cascade are far from the values computed using Gameson et al and WRL equations; this could be due to the absence of the flow rate effect in these equations and their dependency on the temperature and drop height only. Meanwhile, it was found that the dissolved concentration can increase significantly with the increase of wind speed which can be considered in future works. Furthermore, it was found that the biological media in the downstream basin didn't improve the wastewater characteristics significantly; this could be due to the short residence time of the water in the downstream basin and due to the need for improving of the biological media which can be considered in future researches.

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