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# DESIGN CRITERIA FOR WASTEWATER OF RESIDENTIAL COMMUNITY: CASE STUDY FROM JORDAN

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**Abstract:** Wastewater characterization is vital for design, operation, collection, treatment, disposal and reuse purposes. It is necessary to assess the strength of wastewater management systems in terms of sustainability. In Jordan, there are no official values of hydraulic and organic loads generated per capita. This study aims to establish design criteria for wastewater of residential community in Jordan. Fuhais wastewater treatment plant was selected as a case study. Annual, monthly, daily and hourly flow variations of wastewater to the plant were studied. Characteristics of the influent and effluent wastewater were determined. The efficiency of the plant was evaluated. Per capita hydraulic load, and the contaminants load were found. One hundred and twenty samples were taken from the inlet and outlet of the plant and analyzed for BOD, COD, TSS, TDS, $NH_4$, TN, pH and P parameters. The results indicated that the average influent concentration of BOD, COD, TSS, TDS, $NH_4$, and P were 598, 1090, 570, 875, and 52.4, 18.7 mg/L respectively. The plant has an excellent efficiency regarding the removal of $BOD_5$, COD, and TSS while it has lower efficiency regarding N and P removal. The average hydraulic load was 97.4 l/c.d. The average contaminants loads were: 58.4, 106.9, 55.8, 7.2, and 1.82 g/c.d for $BOD_5$, COD, TSS, TN and P respectively. There is a significant variation between the values of these parameters compared to those values in other countries.

**Keywords:** Hydraulic load, Nitrogen load, Organic load, Phosphorus load, Treatment plant, Wastewater treatment

## 1. INTRODUCTION

Jordan is a dry to semi-dry country. About 78% of the population is located in urban areas concentrated in four governorates: Amman, Irbid, Zarqa and Balqa (DOS, 2006). The high population growth rate together with the country's rapid economic development has been accompanied by an increase in water demand, while the available water resources are limited and decreasing. Jordan's water resources are, on per capita basis, among the lowest in the world. The available amount of water from existing renewable sources is projected to be less than 91m$^3$/capita/year by the year of 2025, which is very low in comparison with the international water poverty line of 1000 m$^3$/yr (Al-Zboon, et al., 2008). Water shortage has forced Jordan to prospect for new non-traditional water resources to bridge the gap between demand and the available resources. Wastewater reuse is considered as an attractive option for this purpose (Al Smadi, et al, 2010). Wastewater is the major sources of surface water pollution. Untreated wastewater contains significant level of contaminants such as organic mater, bacteria, nitrate, ammonium, and phosphorus (Gurzau, et al., 2010; Gurzau. et al., 2011; Barjenbruch,et al., 2009).

Currently, the reuse of reclaimed wastewater is an international practice which is promoted by the development of wastewater and secondary effluent treatment technologies (Janqa et al., 2005; Simon, 2006). The degree of required treatment is determined by the beneficial uses of the receiving streams, lakes, and reuse for different purposes (Hammer, & Hammer 2008; Ligman, 1984;

Dragićević, 2010). The principal objective of wastewater treatment is to prevent pollution of the receiving watercourse, and to protect human health and environment. Another quest is to achieve the required water quality for reuse. Reclaimed wastewater is applied on soil, on cultivated as well as marginal areas in various facilities such as in irrigation, industry, and for ground water recharges (Kalavrouziotis & Apostopoulos, 2007; Bushnak, 2003; Salgot et al., 2006; Ernst et al., 2007). For these reasons it is necessary stop the consumption of freshwater by pollution and to return wastewater to the water cycle as a beneficial source of water (Gurzau, et al., 2010).

The integrated and safe application of the reuse of reclaimed wastewater dictates the development of a comprehensive environmental plan, which will take into consideration all parameters relative to such reuse, qualitative characterization of wastewater as well as examination of physical-chemical and environmental properties of all applications on soil, plants, building installations, and pipes (Kalavrouziotis & Apostopoulos, 2007; Salgot et al., 2006; Magalhães et al., 2005). Characteristics of wastewater varies from location to location depending upon land uses, variations in living styles, discharges of industrial and commercial wastewater, interference between surface and ground water, and both diurnal and seasonal fluctuation. Wastewater composition depends on the specific water consumption and the amount of human waste discharged UNEP, (2006).

In Jordan there are twenty three municipal treatment plants, which cover most of the major cities and towns. These plants serve about 56% of the population (Al-Zboon, et al., 2008). Jordanian standards for reclaimed wastewater (JS893/2002) try to regulate both water reuse and environmental discharges. In the present time, the reclaimed wastewater is used for restricted agriculture either near the plants or downstream after mixing with natural surface water (Al-Mulqui et al., 2002). More than 70 million $m^3$ of reclaimed water, around 10% of the total national water supply, is used either directly or indirectly in Jordan each year and will increase to a share of more than 15% within the next 30 years (Bdour & Hdadin, 2005; McCornick, 2007).

In Jordan, there are no official data of hydraulic and organic loads generated per capita. Due to the absence of national data, the designer usually used international figures which could be far away from the national ones. For example the largest treatment plant in Jordan (As-Samra) was designed to treat a flow of 68.000$m^3$/d. Today it receives more than 250.000$m^3$/d. Also, it was designed for an influent $BOD_5$ of 526 mg/L while the actual average and maximum values exceeded 740 and 1300 mg/L, respectively (WAJ, 2006). Inaccurate selection of design parameters caused many operational problems such as over hydraulic and organic load and reduction in its efficiency (Al-Zboon et al., 2008). Therefore it is very important to determine these parameters and to set national values. Most of the time, it is difficult to carry such in WWTP due to the lack of data such as: numbers of persons involved in WWTP service, illegal connection to WWTP, and number of industries which are connecting to WWTP. For all the previous reasons, Fuhais WWTP was selected as a case study for residential community to conduct this study on.

In this study the annual, monthly, daily and hourly flow variations of wastewater to Fuhais WWTP were studied. Influent and effluent wastewater characteristics of the plant were determined. The plant removal efficiency was evaluated. Capita hydraulic load (Q), and the contaminants load biological oxygen demand ($BOD_5$), total suspended solids (TSS), total nitrogen (TN), and phosphorous (P) were found and compared to international figures.

## 2. MATERIALS AND METHODS

### 2.1. Plant description

Fuhais is a small community located at about 15 Km in western of Amman with total population of 24,150 persons (DOS, 2006). Fuhais WWTP was selected for this study to be a representative plant that treats residential wastewater for the following reasons: Firstly, it is a small limited area with no source of industrial waste which could affect the amount of water consumption and wastewater generation discharge. Secondly, the plant receives only domestic wastewater, so pumped water to the area is only consumed by domestic use; hence the calculation of per capita water consumption will be easier and more accurate. Thirdly, the sewer system carries wastewater only and there is no mixing with rainfall (separate system). Fourthly, it is a new sanitary system, built in 1997 with a well-maintained piping system which will reduce the possibility of leakage from pipes. Finally, water table is low which is excluding the possibility of infiltration process.

An extended Aeration mode of operation is applied for treatment of wastewater in Fuhais plant. It has been treating wastewater since it was put in operation in 1997, with design capacity of 2400$m^3$/day and with $BOD_5$ concentration of

600mg/L. The plant consists of a primary treatment unit which includes screening, grit chamber, and equalization tank, a secondary treatment unit (biological treatment processes), an extended aeration activated-sludge process, and secondary settling tank, a chlorination unit, polishing lagoons, sludge thickeners, and sludge drying beds (WAJ, 2006; Al-Zboon et al., 2008). The effluent from the plant is discharged to the valley and eventually to Shuieb Dam. Less than 10% of the effluent is directly reused for agriculture within the plant site. The generated wet sludge is pumped to drying beds in summer, while in winter; it is carried by vehicles to Ain-Ghazal pretreatment plant and then, it is conveyed to As-Samra WWTP (WAJ, 2006).

### 2.2. Sampling

In characterizing wastewater, quantitative and qualitative characteristics are often expressed in terms of $BOD_5$, TSS, TN, P, hydraulic load, and organic load These parameters vary considerably depending on many parameters such as water consumption, strength of waste and seasonal variation.. For residential areas, daily flow values and pollutant contributions are expressed on a per person (capita) basis. Applying per capita data to predict total residential wastewater characteristics requires that a second parameter be considered, namely, the number of persons residing in the area (Bennett & Linstedt, 1975).

$BOD_5$, COD, and TSS are the most important parameters used to define the characteristics of municipal wastewater. Nitrogen (N) and phosphorous (P) are sources of nutrients for plants that cause eutrophication phenomenon and dissolved oxygen depletion in surface waters. Total dissolved solids (TDS) and pH are limited in the standards for water reuse and measured during the study period.

In order to determine the characteristics of wastewater, representative samples were taken from the inlet and outlet of the plant during January to December 2006. One hundred and twenty samples were collected and analyzed for quality parameters. A flow meter was used to monitor the influent flow where hourly and accumulated daily flows were recorded. Representative samples were collected very carefully to avoid agitation or any contact with air. Samples were collected, transported and analyzed in the environmental laboratory at AL-Huson College according to the Standard Methods (Table 1) (APHA, 1998). If delay before analysis was expected, the samples were preserved and stored in a refrigerator according to the recommended procedure in the standard methods.

Table 1. Parameters tested through out the experimentation runs

| Parameter | Analysis Method |
|---|---|
| Acidity (pH) | pH meter |
| Biochemical Oxygen Demand ($BOD_5$) | Titration method |
| Chemical Oxygen Demand (COD) | Titration method |
| Total Suspended Solids TSS | Filtration method |
| Total Dissolved Solids TDS | Filtration method |
| Ammonium NH4 | Spectrophotometer |
| Ortho phosphate ($PO_4$) | Spectrophotometer |
| TN | Kjeldal nitrogen |

### 2.3. Computation of per capita load

The actual amounts of pumped water to the area were determined over a year and average water flow rate was taken monthly. The actual water consumption was estimated to be 70% of the supplied quantity, while the amount of losses and unaccounted water was 30% (WAJ, 2006). This ratio (30%) represents the amount of water that is lost through leakage from pipes and illegal connections. Also the influent and effluent wastewater flow rates were taken daily and accumulated monthly. The number of wastewater connections for served homes was taken from the records of WAJ. The number of the connections to the sanitary system is 2068, which equal to 72% of the total number of licensed houses (2872). In order to find the number of served persons per connection, 120 random samples of homes were taken and the total number of served people was found.

Equations 1, 2, and 3 are used to calculate the average per capita loads:

$$\text{Water consumption (l/c.d)} = \frac{Q_w}{D \times P} \quad (1)$$

$$\text{Wastewater generation rate (l/c.d)} = \frac{Q_{ww}}{D \times Ns} \quad (2)$$

Per capita loads in terms of BOD, COD, TSS, TN and TP were determined by dividing the total load by the total number of served persons as shown in equation 3.

$$\text{Load (g/c.d)} = \frac{C \times D_{ww}}{D \times N_s * 1000} \quad (3)$$

Where:

$Q_w$: actual monthly water consumption for the community (l).

D: number of days/month.

P: population (person)

$Q_{WW}$: Monthly wastewater generated in the community (l).

$N_S$: Number of served people = $N_C \times R$

$N_C$: Number of connections.

R: average number of served persons/ connection = (6 persons/connection)

C: concentration of the considered parameter (mg/).

## 3. RESULTS AND DISCUSSIONS

### 3.1. Variation in the influent flow

Figure 1 represents yearly wastewater flow to Fuhais plant since it was put in operation in 1997 till the end of 2006. It can be observed that the quantity of waste water flowing to the plant has increased gradually with years. The influent flow increased by 350% during such period. This is due to new connections, and continuous expansion of the served areas.

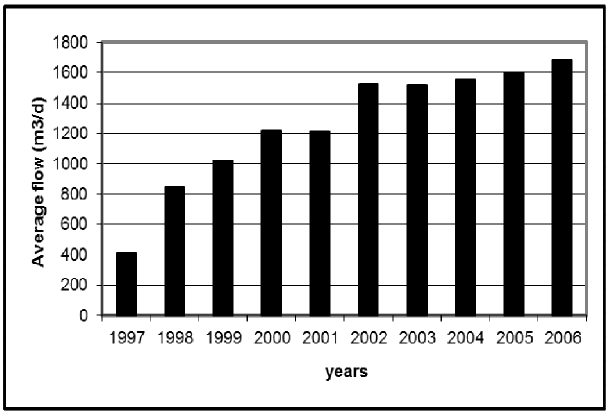


Figure 1. Yearly influent flow rate to the plant

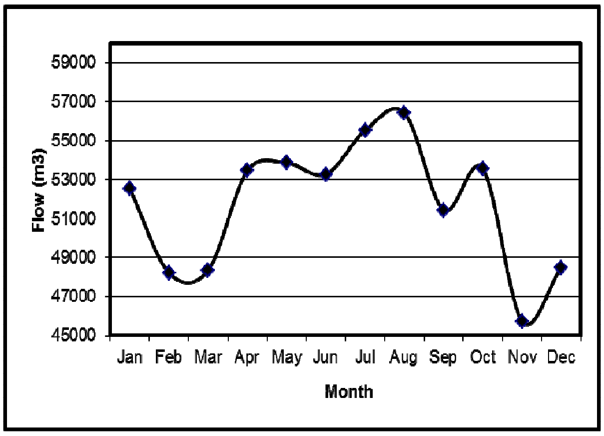


Figure 2. Monthly influent flow rate to the plant.

Monthly variations in wastewater flow to the plant are shown inf figure 2. The winter season has lower flow rates than the summer season. The highest influent flow rate of wastewater is in August while the lowest flow occurred in November. This is related to the increment in water consumption during summer season compared to winter season combined with the fact that this is a separate treatment system. Also, summer is the holiday season and most of people stay in their homes. This figure is reversed in European countries where the influent flow rate is generally lower in summer due to reduced rainfalls where rain water is combined with wastewater (Pons, et. al., 2004).

Average hourly, daily, and monthly influent to the plant was investigated for one year (2006). As shown in figure 3, it can be seen that the maximum flow entering to the plant is on Friday and Saturday. This is expected since these days are the weekend days and hence water usage will increase in this period. In small communities like Fuhais case where most people are working in other cites and comeback to their homes at weekend, the peak flow occurs during these days due to increase in water consumption.

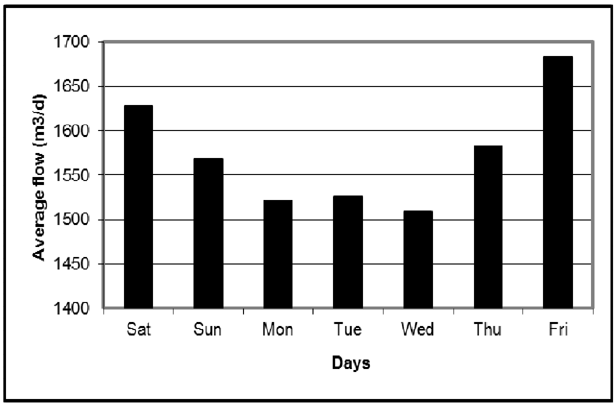


Figure 3. Average daily influent flow rate to the plant

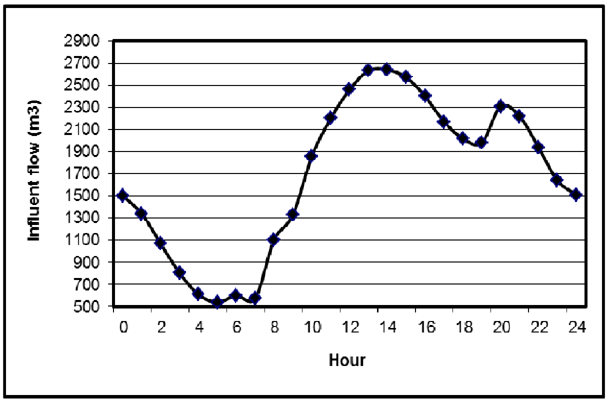


Figure 4. Average hourly influent flow rate to the plant

Regarding average hourly influent flow variations, there are generally two peaks in wastewater flow each day corresponding to sewage generated in the morning as people get ready for the day, and early evening when they return home (Steel & McGhee, 1979). Figure 4 reflects variations in wastewater hourly flow rates. Flow increases gradually after 7 am once daily activities began and reaches a maximum value at 1PM. The second peak occurs at 8 PM when the residents return home and during evening dinnertime.

In residential districts the greatest use of water is in the morning, hence the peak flow will be quite pronounced and occur in the late morning to noon depending on the length of carrier sewer pipe. Lowest wastewater flows typically occur in the very late night to very early morning hours (5 AM). Karagozoglu and Altin (Karagozoglu & Altin, 2003) found that the peak values of the flow-rate for a medium size city in Turkey were observed between the hours 09:00 and 14:00.

### 3.2. Wastewater characterization

#### *3.2.1. Influent Characterization*

Figure 5 shows influent $BOD_5$ from January to December at Fuhais WWTP. The values of $BOD_5$ fluctuate from 520 mg/L in January to 704 mg/L in December with an average value of 598 mg/L. This value is higher than that in other countries. For example the average $BOD_5$ concentrations in Austria, Belgium, Denmark, France, and Netherlands are: 285, 187, 163, 268, and 171 mg/L, respectively (Pons, et al, 2004). Due to the scarcity of water, insufficient quantity of water is pumped to the community which affects the daily water consumption and subsequently increases the strength of waste. Metcalf et al., (1991) mentioned that the wastewater is classified as a strong waste if $BOD_5$ exceeds 400 mg/L. Therefore, wastewater entering Fuhais plant is considered as a very strong waste. The highest concentration of $BOD_5$ is in July and the lowest concentration is in January. Higher values of $BOD_5$ in summer are expected due to the high evaporation rate which increases the concentration. Also, huge amount of waste is discharged to the sewer during fruit growing season in summer. Another reason is the population migration to the tourist areas in Fuhais during summer.

The influent COD values ranged from 962 mg/L in December to 1318 mg/L in September with an average value of 1090 mg/L as shown in figure 6. Similar to BOD, the concentrations of COD during the summer are higher than that during the winter. The higher value in September could be related, in addition to the same reasons for BOD increment, to the streets contaminants that are washed out with the first rainfall event from uncontrolled openings of manholes.

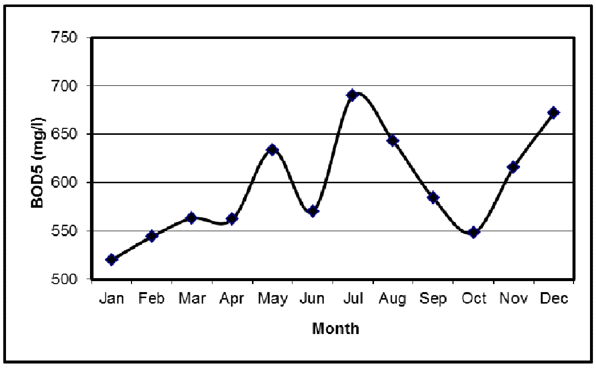


Figure 5. Influent $BOD_5$ concentration to the plant.

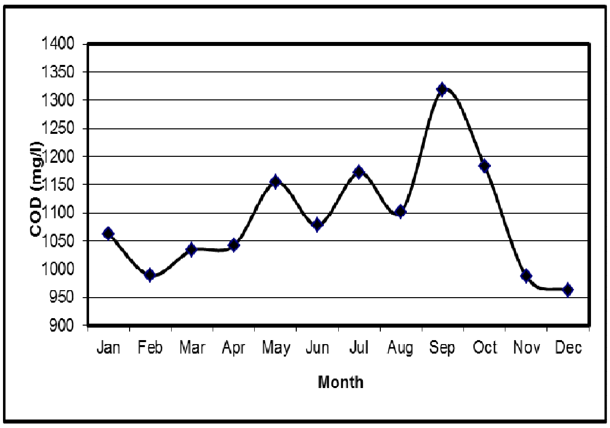


Figure 6. Influent COD concentration to the plant

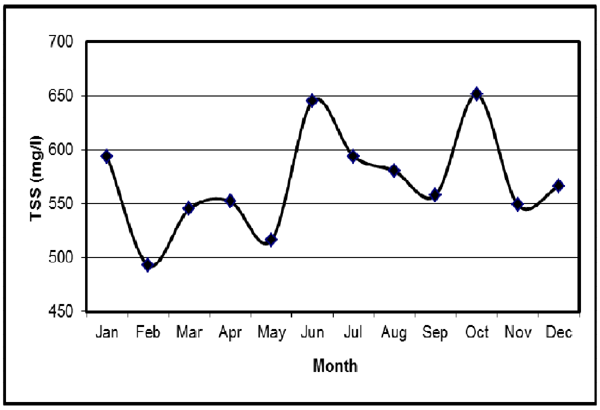


Figure 7. Influent TSS concentration to the plant.

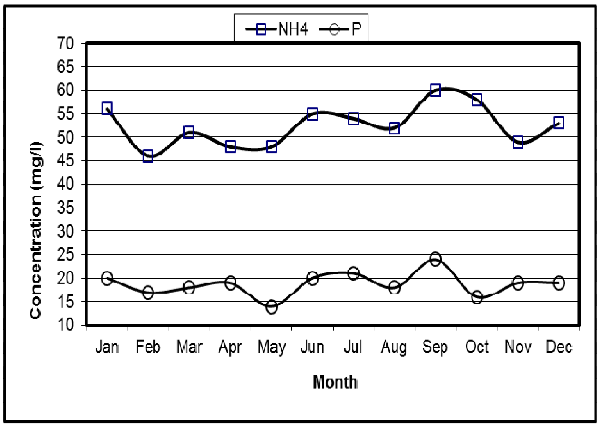


Figure 8. Influent $NH_4$ and P concentrations to the plant

Variations in TSS values entering to Fuhais plant during the year 2006 are shown in figure 7. The TSS values were almost stable during the year with an average value of 570 mg/L which is below the design criteria. The average concentrations of $NH_4$, and P were 52.4, and 18.7 mg/L, respectively as shown in figure 8. The higher concentrations of $NH_4$ and P during the summer could be attributed to the agricultural waste that enters the sewer during this period. The pH values are approximately constant with an average value of 7.9. Total dissolved solids have an average concentration of 875 mg/L. Regarding the concentration of COD, TSS, TDS, $NH_4$, and P the influent to the plant is classified as a strong wastewater (Metcalf et al., 1991).

Investigating figures 5 to 8 showed that the variations during the year with respect to BOD, COD, and TSS are higher than those for P and $NH_4$. Concerning P and $NH_4$ there is no systematic trend (increase or decrease) could be observed. The quantity and characteristics of wastewater fluctuate over the seasons of the year and between weekdays and holidays.

### *3.2.2. Effluent Characterization and Removal Efficiency*

Performance monitoring of onsite treatment systems serves several purposes. Its primary purpose is to ensure that treatment systems are operated and maintained in compliance with the regulation requirements. It provides performance data useful in making corrective action, decisions and evaluating area wide environmental impacts for land use and wastewater planning (EPA, 2002).

The effluent $BOD_5$ values during the study period ranged from 11 mg/L in January to 33 mg/L in December with an average value of 22 mg/L. The average values for all months are less than the Jordanian standard for discharged water to the streams and wadis (50 mg/L). The effluent COD from the plant ranged from 54 to 108 mg/L and all values within the standards (150 mg/L). The effluent TSS values from the plant varied from 25 mg/L in December to 52 mg/L in May. The effluent $NH_4$ concentrations ranged from 11.9 to 13.6 mg/L. Concerning BOD, COD, TSS, pH, P and TDS parameters, the effluent from the plant complies with Jordanian standards for discharged water to the streams and wadis (Table 2).

Figure 9 shows the removal efficiency of the plant in terms of $BOD_5$, COD, TSS and $NH_4$.. It can be seen that the plant has an excellent efficiency regarding the removal of $BOD_5$, COD, and TSS. The removal efficiency of $BOD_5$, COD, and TSS is almost more than 90 %( not clear, please reformulate). Nitrification and denitrification are the predominant processes in removing nitrogen components from wastewater. It is difficult to control this process which causes incomplete removal of $NH_4$. This explains the lower removal efficiency of $NH_4$ (69-85%) in figure 9. There was incomplete data regarding phosphorus removal for all months, but the available data for 8 months indicated that the average removal efficiency was 55%.

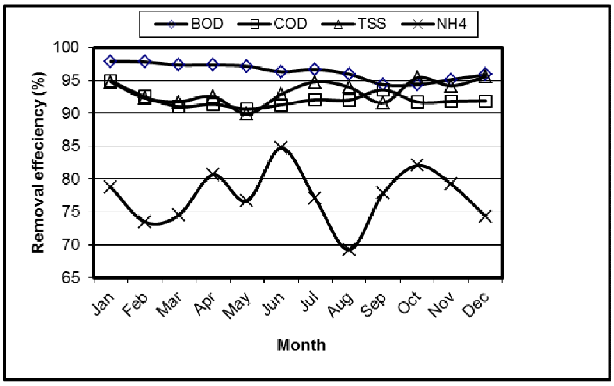


Figure 9. Removal efficiency of the plant in terms of BOD5 COD, TSS and $NH_4$

### 3.3. Water-Wastewater Flow Rate Relationship

Municipal wastewater is derived from the water supply; therefore there is a strong relationship between water supply and sewage flow rate. In order to estimate the amount of sewage to be expected, a study of water consumption must be carried out (Steel & McGhee, 1979).

Table 2. Characteristics of the effluent treated wastewater from the plant

| Parameter | Average | Max | Min | SD | JS |
|---|---|---|---|---|---|
| BOD | 22.0 | 33.0 | 11.0 | 4.8 | 60 |
| COD | 86.3 | 108.0 | 54.0 | 13.7 | 150 |
| TSS | 37.8 | 52.0 | 25.0 | 8.4 | 60 |
| NH4 | 11.9 | 13.6 | 8.4 | 2.1 | Not limited |
| P | 14.0 | 18.0 | 9.0 | 2.9 | 15 |
| pH | 8.2 | 8.7 | 7.6 | 0.26 | 6-9 |
| TDS | 835 | 910 | 785 | 39 | 1500 |

JS: Jordanian standards for wastewater discharged to the streams

The actual amount of drinking water that was pumped to Fuhais community was obtained from the water Authority. The percentage of wastewater (WW) to drinking water (DW) ranged from 77.4% in January to 71.5% in July with an average value of 74.3% as shown in figure 10. This value approximately matches the average values for selected cites and districts in the USA (76%) (Steel & McGhee, 1979). The DW is higher than WW because part of the pumped DW doesn't enter the sewer system where it is used for gardens irrigation, car washing, outdoor house cleaning, and lost due to evaporation. These percentages show an almost stable trend with the lowest values during the hot summer season and the highest values during the winter season due to lower evaporation rate and the effect of rainfall that enter to the manholes.

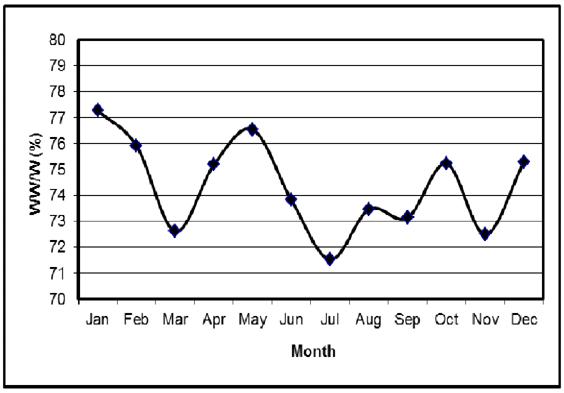


Figure 10. Percentage of wastewater (WW) to drinking waster (W).

### 3.4. Hydraulic load

According to the department of Statistics in Jordan, the number of population in Fuhais community was 24,150 inhabitants. Therefore; the amount of drinking water consumed per capita per day is obtained by dividing the actual amount of daily pumped drinking water by the number of the served population. Only 72% of the houses are connected to the wastewater network. Accordingly, the number of participants is obtained by multiplying the number of population by the ratio of connection. The total number of participant is 17,388 persons. The per capita hydraulic load has the lowest values in November and December (87.6, 90 L/c.d) while the highest values are in July and August (103,104 L/c.d) with an average value of 97.4 L/c.d as shown in figure 11. This is expected due to the increase in water usage during the summer. Common international values of wastewater generation ranged from 227 to 300 L/c.d (Hammer & Hammer, 2008; Metcalf et al., 1991). The average wastewater generation rate in some USA cities are: 451, 302, 231, and 227 L/c.d for Bingham, Detroit, Chesterfield and Berkeley city (DWSD, 2003).

The per capita domestic water consumption in Jordan averages around 85 (L/c.d), which is very low in comparison with other countries (Table 3). Jordanians are using the least of all, not only because they are extremely concerned about water use, but also because water is much less available. Concerning domestic water use, especially during summer, 85% of Jordanians live at the hygienic brink. This reason explains the lower wastewater generation rate in comparison with other international values.

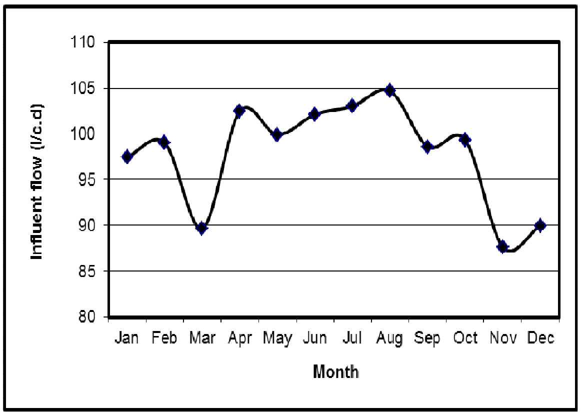


Figure 11. Per capita hydraulic load influent to the plant.

### 3.5. Per Capita Organic Load

In a similar manner, the estimation of contaminants load (g/c.d) in terms of $BOD_5$, COD, TSS, TN and P was based on the influent wastewater flow, concentration, and number of connected persons. The average values for these parameters were 58.4, 106.9, 55.8, 7.2, and 1.82 g/c.d respectively. The generation rates during the summer were higher than that during the winter for all parameters. Again, this is due to the type of eaten foods and fruit during growing season.

Table 3. Per capita water usage in Jordan and different countries

| Country | Greece | London | Netherlands | Jordan | Europe | Israel | Gulf States | Syria, Egypt |
|---|---|---|---|---|---|---|---|---|
| (l/c.d) | 250 | 220 | 260 | 85 | 150-250 | 280-300 | 280-450 | 130 |

Source:1: EEA, 2009, 2: Hubb, 2001, 3: EMWATER, 2005

Table 4. Per capita contaminants load (g/c.d)

| Parameter | Average | Max | Min | SD | Karagozoglu & Altin (2003) | Miranzadeh (2005) | Veenstra, et.al.,(1997) |
|---|---|---|---|---|---|---|---|
| BOD | 58.5 | 71.07 | 50.48 | 6.51 | 47.3 | 38.7 | 60 |
| COD | 106.9 | 129.94 | 86.50 | 13.83 | 85.3 | 59.5 | 120 |
| TSS | 55.8 | 65.86 | 48.11 | 6.29 | 34.9 | 34.4 | 40-80 |
| TN | 7.2 | 8.4 | 6.1 | 0.77 | 7.9 | 11 | 12 |
| TP | 1.82 | 2.40 | 1.45 | 0.22 | 1.32 | 0.87 | 2.5 |

Table 4 indicates that there is a significant variation in the generation load between different countries. This variation could be related to many parameters such as: life style, culture, size of the city, illegal connections, nature of investment, using in-home grinder and climate. Domestic wastewater composition depends on the water consumption, which explains the wide concentration range of the main wastewater constituents (Veenstra, 1979). The socio-economical status of communities affects the quality of wastewater. Based on this it can be concluded that it is incorrect to use design parameters for a certain country to design or to manage wastewater of the other ones.

## 4. CONCLUSIONS

According to the obtained results the following points could be concluded:

1. Variations in wastewater flow rates, generated from residential community, occur hourly, daily, weekly, and monthly, and this variation is affected strongly by the local environment, culture, and characteristics of the community.

2. The generated wastewater from Fuhais community is classified as a strong waste concerning BOD, COD, TSS, TDS, $NH_4$, and P concentration.

3. The plant has an excellent efficiency regarding the removal of $BOD_5$, COD,

4. and TSS while it has lower efficiency regarding $NH_4$ and P removal.

5. Due to the special characteristics of each country, there is a significant variation between the local contaminants load values and the international ones. This result promotes the necessity of the local data.

Additional studies are needed to establish a database for wastewater management in Jordan as a case study of the developing countries.

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