Birzeit Water Drops

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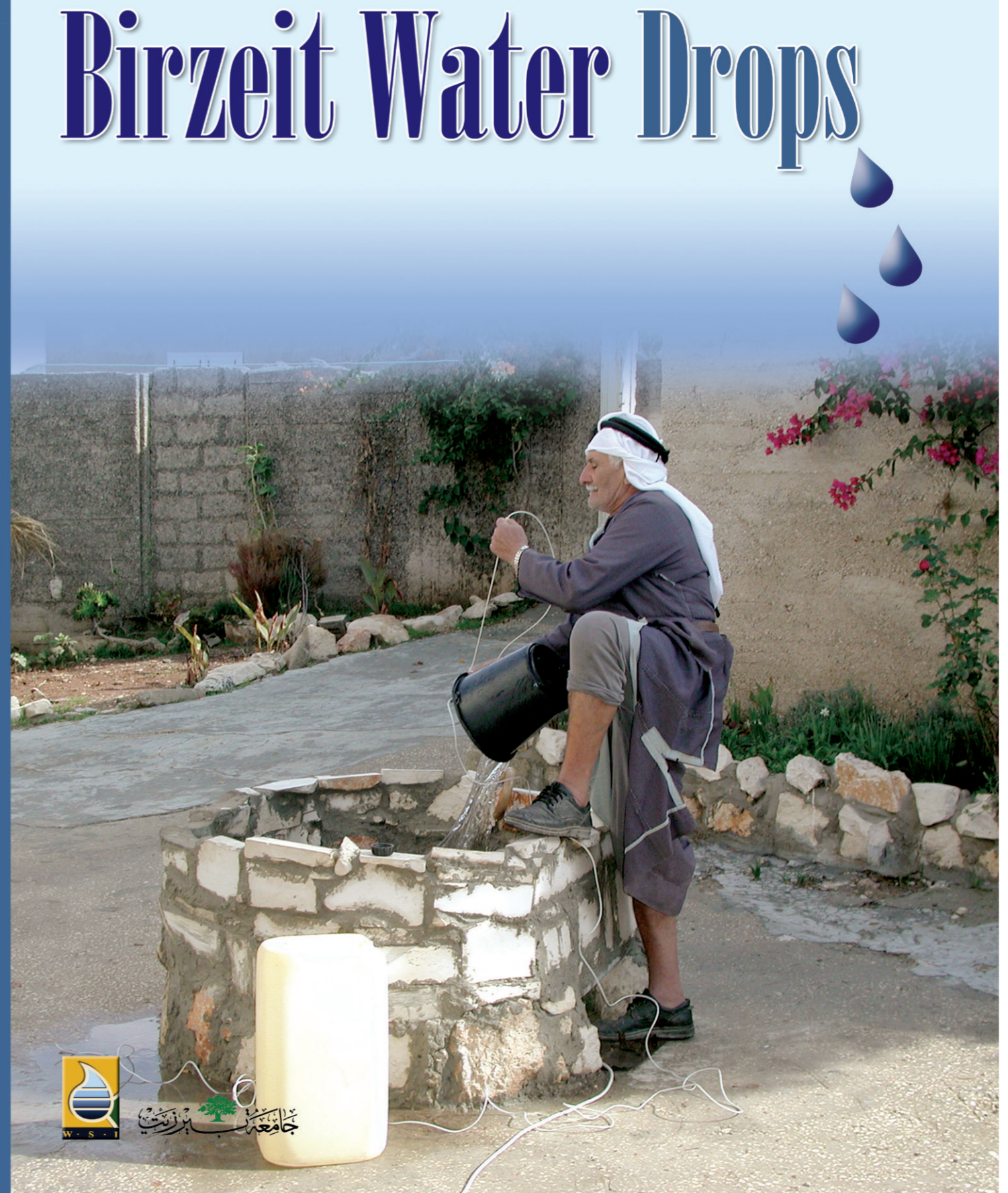
WATER IS THE EARTH`S EYE LOOKING INTO WHICH THE BEHOLDER MEASURES THE DEPTH OF HIS OWN NATURE...

Henry David Thoreau
The 2nd UN World Water Development Report, 2006

Our Mission

Education, training, research and consultancy for the planning, provision and management of water and environmental aspects.

Special thanks to Omar Zayed who took the photo of the cover

FOREWORD

'Coping with Water Scarcity' is the theme for World Water Day 2007, which is celebrated each year on 22 March. This year's theme highlights the increasing significance of water scarcity worldwide and the need for increased integration and cooperation to ensure sustainable, efficient and equitable management of scarce water resources, both at international and local levels.

The rise in water use is more than twice the rise in the population over the last century, and an increasing number of regions are constantly water short. Climatic variability, population growth and economic development among other global changes put pressure on water resources. Water scarcity is forced by inappropriate water management and inadequate governance.

Water Studies Institute (WSI) is going on with its mission towards sustainable development and playing a significant role in facing water scarcity despite the challenges that it faces due to Israeli occupation that is gaining control over 80% of water resources in Palestine. Moreover, throughout its progress, WSI has been always concerned with environment as well as water; therefore, Birzeit University's board of trustees has decided starting from September 2007, to change the name of the Water Studies Institute to Water and Environmental Studies Institute.

However, during the last months the Palestinians faced a severe water crisis in Um-Al Nasser town in Gaza. Disaster struck on Tuesday 27 March 2007 when a 6.5 acre septic cesspool containing 20, 0000 cubic meters of sewage water collapsed completely. It had weakened over time and had sustained several hits during the Israeli-Palestinian conflict. The spokesman of the emergency department at the Palestinian health ministry said that what happened in Um Al Nasser required the health ministry to declare a state of emergency. The sewage flood could result in health complications and diseases in the area. Sixty cottages have been completely destroyed and 226 others have been partially damaged due to this humanitarian crisis. Hundreds of Bedouin families are now living in tents that have been supplied by the International Committee of the Red Cross. Why has this crisis happened, who is responsible and how can we prevent such crises to happen in future? These are questions that every Palestinian is asking and on which responsible authorities are working.

This issue of the BWD includes five articles that were published in refereed journals in different areas in water and environmental subjects. In addition, updates on the WSI`s activities and staff news are included.

Ziad Mimi,
Director, Water Studies Institute

Domestic Septage Characteristics and Cotreatment Impacts on Albireh Wastewater Treatment Plant Efficiency

Rashed Al Saed and Taghreed Hithnawi

Septage co-treatment at AWWTP

The article can be quoted as:

Domestic Septage Characteristics and Cotreatment Impacts on Albireh Wastewater Treatment Plant Efficiency

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ABSTRACT

This paper presents and discusses the potential impacts of domestic septage on Albireh Wastewater Treatment Plant (AWWTP). Using ANAwin, a German software package for sewage works design, the results obtained from septage lab analysis were utilized to simulate the impacts of daily loads on the oxidation ditch design parameters (sludge age, biosolids production rate, specific oxygen uptake rate), treatment efficiency and annual running costs. The septage received at AWWTP revealed a heterogeneous origin, with a variable volume (115-176 m³/d) and reached an average daily volume of 153 m³. The results of the investigation lead to a specific septage generation rate in Albireh city of about 1.2 m³ per capita per annum. The ANAwin software package confirmed the negative impacts of septage cotreatment on AWWTP unit operations design and deterioration of its effluent quality. However, further investigations are needed to find other septage disposal options and simulation tools to sustain domestic septage management and to protect both public health and environmental resources.

KEYWORDS: Albireh wastewater treatment plant, impact assessment, operational design parameters, oxidation ditch, septage quality, septage cotreatment, treatment efficiency.

1. INTRODUCTION

Wastewater management in Palestine has been a neglected issue over the past years. However, little technical data are recently made on urban wastewater characteristics discharged from certain urban cities in the West Bank (Tahboub, 1999; Mahmoud *et al.*, 2003). The effectiveness of the existing urban sewage collection and treatment facilities is usually constrained by limited treatment capacity, failure in system design, aging unit operations, insufficient operation and maintenance, and by the lack of experienced operational staff (Al-Sa`ed and Mubarak, 2006).

Moreover, raw or partially treated municipal wastewater is discharged into seasonal wadis, where in some cases agricultural irrigation is practiced and thus posing serious environmental and public health risks (Al Sa'ed, 2005).

The existing situation of the sewerage system is extremely critical. Approximately, 65% of houses in the main cities are connected to the sewerage system (MOPIC, 1998). According to Al-Sa`ed (2005), about 17% of collected urban wastewater by central networks is being either fully or partially treated in central sewage works. Almost 64.2% of the households in the West Bank have cesspool sanitation and almost 0.7% without any sanitation system. While the rest households (20%) with no central sewerage networks disposed of wastewater into percolating pits (PCBS, 2002). The septic tanks are emptied by the private sector; mainly through individual vacuum trucks and disposed of, either in nearby located sewage treatment plants, if any; and most likely they are overloaded, or discharged directly into small wadi beds (seasonal water courses).

There are no regulations in Palestine that govern septage management and the newly issued Palestinian Environmental Law lacks regulations for effluent quality standards for treated effluent reuse or biosolids utilization. Existing municipal by-laws on safe septage disposal are weak and lack enforcement power due to prevailing political situation and informal socio-cultural issues.

However, for the purpose of this research, the code of the Federal Regulations, "Part 503" issued by U.S Environmental Protection Agency (USEPA, 1993), was adopted. Domestic septage is defined by the code of Federal Regulations in 40 CFR Part 503, section F as follows: "Domestic septage: either liquid or solid material removed from a septic tank, cesspool, portable toilet, marine sanitation device or similar treatment works that receive only domestic sewage, the latter is defined as waste and wastewater from humans and household operations".

According to US Environmental Protection Agency (USEPA, 1999), well-designed septic tanks will usually retain 60 to 70% of the solids, oil, and grease that enter it. The scum accumulates on top and the sludge settles at the bottom, comprising 20% to 50% of the total septic tank volume when pumped. Published literature (ATV-A 123, 1985, USEPA, 1994) indicated that septage quality could strongly differ from place to place as many factors influence the physical-chemical characteristics of septage. In the German working sheet ATV-A 123 (ATV-A 123, 1985), safety factors assumed for a safe co-treatment of septage in urban sewage works are difficult to interpret and form no guarantee for a stable nitrogen removal process. To date, few attempts were made on proper septage treatment, either in combination with wastewater or separately. Treatment options used include waste stabilization ponds, composting with municipal organic refuse, activated sludge systems, anaerobic pre-treatment and constructed wetlands (ATV-A 123, 1985; USEPA, 1994; Strauss et al., 1997; Ingallinella et al., 2002; Nassar et al., 2006). Investigating the efficiency of constructed wetlands followed by waste stabilization ponds, Koné and Strauss (2004) found high ammonia content in septage inhibited both algal and plant growth in pond systems and constructed wetlands. Recently, Nassar et al. (2006) reported that constructed reed beds, which were operated and monitored for three years, were economically more attractive for municipal sludge drying in Gaza Strip than traditional sludge drying beds.

Despite the fact that most Palestinian conventional wastewater treatment plants generally accept septage delivered by vacuum trucks, little is known about the main reasons behind malfunctioning of the treatment processes. Since the establishment of Albireh WWTP in 2000, sludge bulking-foaming associated with deterioration in the effluent quality has been annually reported (Albireh Municipality, 2003). Caused by sludge bulking-foaming, high nitrogen and suspended solids in the treated effluent render its suitability for the planned agricultural irrigation. Several attempts were made to understand the reasons behind this annual phenomenon, however, with limited success.

This study was conducted to investigate the impacts of domestic septage co-treatment at Albireh WWTP and introduce protective measures to improve operation. The potential implications of septage co-treatment on structural and unit operation design parameters based on septage volume and characteristics, energy demand and the estimated annual costs associated with receiving septage at Albireh sewage works will be presented and discussed. It provides also reliable information for decisions to proceed with the next step, which would include a detailed technical study including unit process simulation at pilot scale to evaluate the impact of septage on other biological processes including poor sludge settling properties in the current oxidation ditches.

2. MATERIALS AND METHODS

Study Area and System Description

Ramallah and Albireh governorate, located in the central region of the West Bank, is considered as one of the most important administrative and economic centers in Palestine. Albireh Wastewater Treatment Plant (AWWTP) is located approximately at a distance of 1.5 km down stream the Wadi Al-Ein to the east of Albireh city. Fig. (1) illustrates an overview of the AWWTP showing the first treatment train, which consists of two oxidation ditches; each of which has the design capacity to serve about 25,000 inhabitants (Albireh Municipality, 1998). Albireh city has a central public sewer network of a modified combined system, where part of the collected stormwater is mechanically treated at AWWTP site in the stormwater tank, which discharges the Combined Sewer Overflow (CSO) into Wadi Al-Ain. Though temporal storage of septage in the stormwater tank is not a common pre-treatment practice (Fig. 1), however, it can facilitate septage batch mode co-treatment especially during night period under controlled pumping intervals.

AWWTP received an average daily flow of 3038 m³/d (monthly average during the time of this study, 2002). The municipal sewage in Albireh city is mainly of domestic origin with small industrial enterprises discharging about 7% of the total daily dry weather flow into the public sewer networks after proper pre-treatment

stages. No industrial septage is being treated at AWWTP, Albireh city as recommended by an Industrial Cadastre, and incorporated in the draft "Sewerage By-Law" where the municipality regularly monitors all industrial discharges and comprises no harmful impacts on the treatment process (Meierjohan, 1999). The biological process includes a low loaded activated sludge system (oxidation ditch), which besides the removal of carbonaceous compounds also achieves a reduction in the nitrogen load through biological nitrification and denitrification processes.

Sampling Program and Analytical Methods

Samples were collected from different septage haulers delivering septage from different places in Albireh at different times. Composite samples were taken during the discharge of the truck content after which the material has been mixed; three individual samples were collected at the beginning, middle and at the end of the truck discharge to guarantee representative composite samples. Because of the wide variations in septage characteristics, a large number of samples were taken from truckloads (Table 1) over a period of four months (March-June, 2003). All samples were preserved during the sampling time by storing them in special cool boxes at 4°C.

Initially, the actual records of septage quantities were taken from AWWTP daily monitoring records, and later the data were verified by a field questionnaire distributed at local septage haulers during the study period. Data on AWWTP performance were utilized from the monthly reports for the calculation of dry weather flow, pollution loads and septage quantity (Albireh Municipality, 2003).

Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5), Total Solids (TS), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Total Kjeldahl Nitrogen (TKN), ammonium (NH_4-N), sulfate (SO_4), hydrogen sulfide (H_2S), ortho-P, temperature, fat and grease were all determined according to *Standard Methods* (APHA, 1995). Finally, the temperature and pH were measured onsite (HACH) while the rest of analysis was conducted later at the Water Engineering Lab of Birzeit University.

Use of ANAwin Software Package for Septage Impact

This German Software package enables the layout of biological wastewater treatment plants according to ATV-guidelines, ANAwin, Version 2, 1996 (ANAwin, 1996). The ATV-A 131 (ATV-A 131, 1991), a German working sheet forms the basis of this software package to design and re-check the layout of activated sludge systems. It is worth mentioning, that AWWTP was designed according to the ATV-A131, which is considered as a German Standard. Details about the usage of this software package can be found in the users' Manual (ANAwin, 1996). ANAwin was used to simulate the impact of septage increment (%) on the unit operation design of the aeration tank including structural and biological design parameters at variable temperatures (13°C and 20°C; winter and summer periods). Ongoing research will utilize other software packages and apply advanced molecular techniques to assess the septage impacts on nitrification-denitrification processes and sludge foaming/bulking in AWWTP.
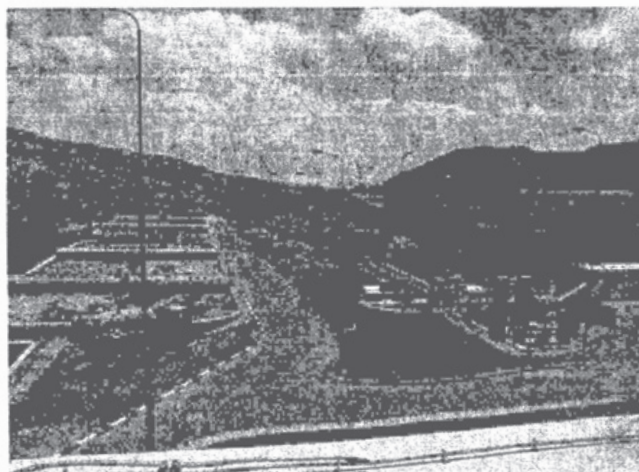

Fig. 1. Overview or Albireh Wastewater Treatment Plant (AWWTP).

Table 1. Comparison of Albireh domestic septage wastewater with published literature.

Parameters	Albireh Septage (This study, 2003)				Wastewater[*]	Septage[1]	Septage[2]	Septage[3]
	No.	Range	Average	STD	Average	Average	Average	Range
pH	32	6.9-7.5	7.2	± 0.2	7.3	8	8.1	1.5-12.6
BOD	20	165-1107	434	± 258	495	303	10,000	440-78,600
COD	25	181-9315	1243	± 2259	1400	668	28,200	1,500-703,000
TKN	20	9-525	150	± 168	104	215		66-1,060
NH_4-N	32	5-155	91	± 48	80	152	1500	3-116
PO_4-P	24	5.4-24.2	13	± 6	13	39		
SO_4	32	33-738	128	± 146	138	132		
H_2S	28	52-79	67	± 7		95		
TS	32	328-23,028	3095	± 5663			30,450	1132-130,475
TSS	20	76-13,444	3068	± 4377	736	10,664	14,600	310-93,378
VSS	10	212-11,556	2706	± 3687	617	5105	10,366	353-71,402
Oil & grease	14	264-82,320	22,442	± 29,075				208-23,368
COD/BOD			2.86		2.83	2.20	2.82	
TSS/VSS			0.88		0.84	0.48	0.71	

[*] According to Mahmoud et al. (2003); [1] Ingallinella et al. (2002); [2] Cofie et al. (2006); [3] USEPA (1994).

3. RESULTS AND DISCUSSION

Septage Characteristics

The results presented in Table (1) illustrate the septage characteristics of the study area. Comparing the obtained results with published literature, Table (1) revealed that the US Environmental Protection Agency (USEPA, 1994; 1999) values of septage parameters are higher than the values of Albireh septage parameters. This might be due to different reasons such as septic tank design, the pump out interval, life style and hygiene approaches. In addition, separate discharge of toilet papers in plastic containers and the partial anaerobic processes as of short hydraulic retention time in the cesspools may lead to a low strength septage in developing countries.

By comparing the characteristics of domestic septage with domestic wastewater (Table 1), in many respects, the constituents of Albireh septage are similar to those of municipal wastewater. Table (1) gives also almost similar ratios of COD/BOD and VSS/TSS for septage and wastewater of Albireh city. The reason behind this is the short hydraulic retention time in the septic tanks of most urban dwellings and no industrial septage is received. However, the great difference in total solids between septage and sewage calls for adequate pre-treat of the septage before its discharge into conventional treatment. Due to different sampling points and methods of analysis between septage (truck loads; unfiltered samples) and wastewater (after aerated grit chamber and filtered samples) lead to higher values for grease and oil contents but lower COD concentrations compared to municipal sewage. The VSS/TSS ratio of 0.88 for septage is almost similar to that for sewage as reported by Mahmoud et al. (2003).

Ingallinella et al. (2002) reported a small ratio VSS/TSS of a week domestic septage (0.48) treated in waste stabilization ponds indicated that solids contained low organic portion compared to high percentage (80%) of organic solids in the sewage. However, the average COD/BOD ratio of Albireh septage is within the range (2.2-4) for the faecal sludge-septage mixture (Cofie et al., 2006). This indicates the high portion of biodegradable organic matter in the septage delivered at Albireh wastewater treatment plant.

As a design rule, all septic tanks must be lined not only at sidewalls but also at the bottom to prevent leakage, however, in some cases this is not applied, where septage infiltrates in groundwater and biosolids accumulation prevailed by time. Finally, the wide range in septage characteristics (Table 1) gives clear evidence that annually emptied septic tanks lead to a high strength septage especially in households of rural and refugee camps areas.

Quantity of Domestic Septage

The results of the investigation lead to an annual septage generation rate in Albireh city of about 1.2 m³ per capita (44.5 million cubic meter), which is in conformity with those published data in Germany (ATV, 1985). The annual volume of septage in Palestine was calculated by the multiplication of the annual specific generation rate of un-served population. These results were built on the assumption that 5.4 persons per household and each cesspool served one household. In reality, one cesspool served one building in most cases, and each building consists of 10 to 12 households on average. Furthermore, the cesspool size and pumpage pattern are variable. Lower specific annual production rates were published by EPA (USEPA, 1994; 1999), where estimates of annual septage produced by US onsite systems ranged between 0.4-0.6 m³ per capita.

Population Equivalent of Septage Received at AWWTP

Based on the daily pollution load (COD) of Albireh wastewater, the Population Equivalent (PE) served by AWWTP was calculated using the German working sheet ATV-A 131 (ATV, 1991). The working sheet specifies the daily specific pollution loads; 120 g/PE (COD), 60 g/PE (BOD), 12 g/PE (TKN), 70 g/PE (TSS) and 3 g/PE (PO₄-P). The calculated PE served by AWWTP was 32,385 PE, which is only 88% of the total population in Albireh city (36,737 inhabitants). About 12% (4,352 PE) of the total population are not served by a central sewerage system and they do not use a cesspool. But the estimated number of people, which are not connected to sewerage system, is 17,280 PE; the difference (12,928 PE) came from Ramallah city or of industrial origin. Using the daily average of septage quantity (153 m³) received at AWWTP; the PE of pollution loads caused by septage co-treatment was calculated. Population equivalent from the average values of pollution loads (BOD, COD and PO₄) of septage revealed about 1,417 PE, while the maximum PE value was found to be 41,676 PE. These variations in PE estimates stem from variable origin of septage being from urban dwellings or coming from rural households.

Power Consumption

Receiving amounts of septage at the treatment plant beyond its design capacity implies higher power consumption rates. For this purpose, the data of daily reports at the sewage works (Albireh Municipality, 2003) were utilized. The average power consumption of the treatment plant during the study period (March-June 2003) was calculated and summarized in Table (2).

Based on the daily wastewater (WW) flow rates obtained from AWWTP monthly reports, the average daily power consumption including the unaccounted for energy was 2849 kWh leading to a specific energy demand of 0.67 kWh/kg COD. Table (2) shows variable specific energy consumption rates (kWh/kg COD); this might be due to variation in monthly organic and nitrogen pollution loads received. This implied more oxygen supply to cope with increased COD and nitrogenous oxygen demand. Also, variable hydraulic loading rates might cause increased energy consumption for lifting wastewater and recycling return sludge flows.

As explained above, septage cot-treatment exerted additional energy consumption due to additional oxygen demand in the oxidation ditches for the biological processes (hetertrophs and autotrophs). Bearing this in mind, the daily average energy costs for septage treatment was calculated at US$ 410 per day, while the cost for power consumption was around US$ 3694 per month for the maximum amount received at the sewage works. Taking the volume of 15 m³ for conventional septage suction trucks, the average cost for power consumption was calculated at a US$ 0.09 with a maximum of US$ 0.78 per m³ septage (strong septage). Higher costs (Turcotte et al., 2003) for septage co-treatment originating outside the City of Ottawa at Pickard WWTP in east Ottawa were projected to rise from the current US$ 9 to US$ 25/m³. However, the authors are aware of the difficulties of utilizing septage costs published in the literature, as our calculated costs did not include the annual capital and running costs for pumping, hauling and co-treatment of the domestic septage received at AWWTP. Recently, more cost effective disposal methods were reported by Nassar et al. (2006), where they reported that the cost of sludge treatment using reed beds in Gaza Strip was 0.60 US$/m³ compared with 1.01 US$/m³ for treatment using conventional drying beds. However, the capital costs for larger aerial demand of such natural disposal options have to be taken into consideration.

Septage Impact on Unit Operations Design

Adequate technical design (volume, aeration capacity, sludge yield) of the biological unit (aeration tanks) will

achieve an effective treatment for BOD and nutrients and reduce process troubleshooting. The German Software Package (ANAwin, 1996) based on the German working design sheet (ATV-A 131, 1990) was used to simulate the impact of septage increment percentage (%) on the unit operation design of the aeration tank at variable temperatures (13°C and 20°C; winter and summer periods). According to the working sheet, a sludge age of 25 days was selected to achieve aerobic sludge stabilization. The results are tabulated in Table (3) and depicted in Figures (2) and (3) for the summer period. Plotting septage increment (0-30%) in both primary x-axis and secondary y-axis (Figs. (2-5)) served only for more clarification.

As indicated in Table (3), the design capacity of the first train in operation is 25,000 inhabitants including pollution load of septage received, any further increment in septage volume will lead to additional volume to cope with added pollution loads. Figure (2) and (3) illustrate that 5-30% of septage addition implies overloading of the system and lead to 7-51% additional volume in the aeration tank. Similarly, an increase in the aeration capacity (8-49%) must be achieved to cope with additional loads of both organic carbon and nitrogen; otherwise deficient oxygenation will lead to build-up of nitrite, less nitrification capacity and might cause sludge foaming/bulking.

By comparing the results for the two temperatures, 13°C and 20°C, almost the same result for oxygen input, but higher volume values were obtained for the aeration tank; nitrification and denitrification zones at 13°C. Knowing the variations in aerobic and anoxic zones (V_{DN}/V_{NN}) in the oxidation ditch, is crucial variable to adjust and monitor the aeration capacity provided for the nitrification and denitrification zones, especially in winter periods to achieve a stable nitrogen removal at low temperatures.

Table 2. Average energy consumption and costs for septage cotreatment at AWWTP.

Study Year 2003	Power consumption (kWh/day)	kg COD/day Wastewater	(kWh/kg COD)	Power costs (US$/month)
March	1813	4050	0.45	15714
April	2561	4477	0.57	16811
May	3540	4319	0.82	16758
June	3481	4177	0.83	16207
Average value WW	2849	4256	0.67	16372
Average value septage	106	158		410
Maximum value septage	952	1425		3694

Table 3. Septage impact on unit operation design of the aeration tank at 20°C (summer).

Item	DWF[1] (m3/d)	Capacity (PE)	Septage increase (%)	BOD$_5$ Load (kg/d)	V_{AT}[2] (m^3)	V_{DN}[3] (m^3)	V_{NN}[4] (m^3)	Excess Sludge (kg/d)	Oxygen input OC[5]
Without septage	2885	23800	0	1428	8048	3967	4081	1288	199
With septage	3038	25567	5	1534	8647	4282	4365	1388	214
	3046	26417	10	1585	8939	4453	4486	1430	221
	3053	28633	15	1718	9691	4903	4788	1551	239
	3061	31000	20	1860	10500	5385	5115	1680	258
	3069	33433	25	2006	11328	5882	5446	1812	278
	3076	35850	30	2151	12151	6348	5803	1944	297

[1]DWF: Dry weather flow; [2]V_{AT}: Volume of aeration tank; [3]V_{DN}: Volume of denitrification zone; [4]V_{NN}: Volume of nitrification zone; [5]OC: Oxygen input (kg O$_2$/h).
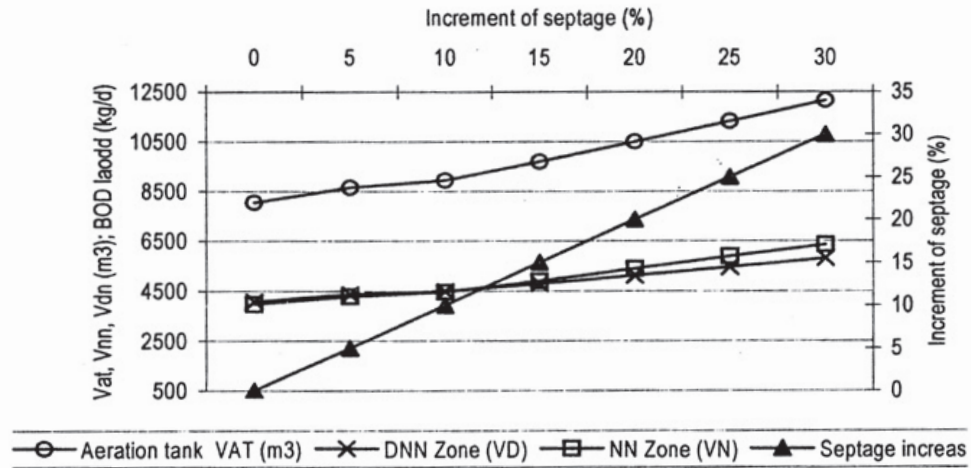
Fig. 2. Impact of septage treatment on volumes of aeration tank, VN and VD zones at 20°C.
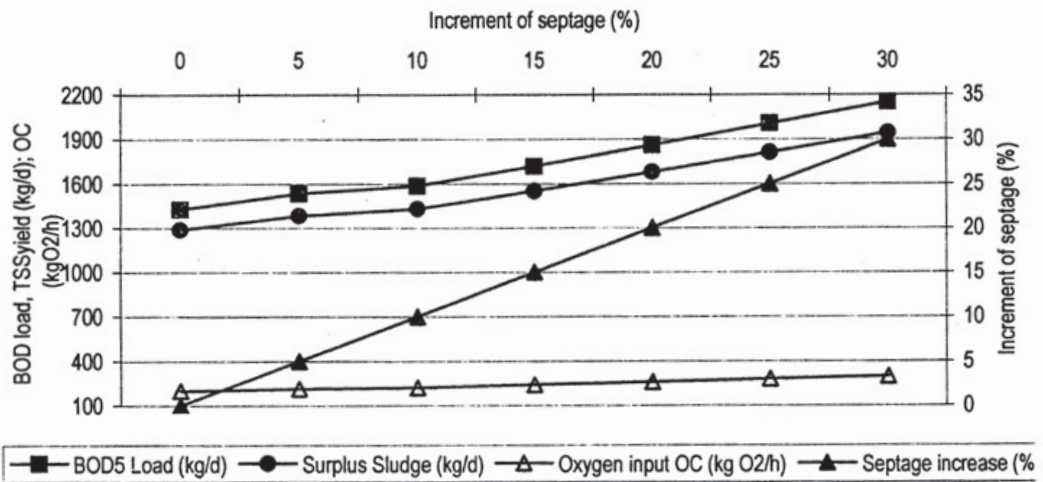
Fig. 3. Impact of septage cotreatment on aeration capacity and sludge yield at 20°C.

Table 4. Septage impact on unit operation design of the aeration tank at 13°C (winter).

Item	DWF[1] (m³/d)	Capacity (PE)	Septage Increase (%)	BOD₅ Load (kg/d)	V_{AT}[2] (m³)	V_{DN}[3] (m³)	V_{NN}[4] (m³)	Excess Sludge (kg/d)	Oxygen input OC[5]
Without septage	2885	23800	0	1428	8549	3997	4552	1368	192
With septage	3038	25567	5	1534	9185	4315	4870	1470	206
	3046	26417	10	1585	9495	4489	5006	1519	212
	3053	28633	15	1718	10294	4961	5333	1647	230
	3061	31000	20	1860	11152	5434	5718	1784	249
	3069	33433	25	2006	12032	5937	6095	1925	268
	3076	35850	30	2151	12906	6410	6496	2065	286

[1]DWF: Dry weather flow; [2]V_{AT}: Volume of aeration tank [3]V_{DN}: Volume of denitrification zone; [4]V_{NN}: Volume of nitrification zone; [5]OC: Oxygen input (kg O_2/h).

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According to the German working sheet ATV-A 131 (ATV, 1991), sufficient oxygenation capacity is necessary for a successful nitrogen removal process during storm weather flows (13 oC design parameter). During winter months (13°C), the impact of septage cotreatment on unit operations is illustrated in Table (4), Figures (4) and (5).

Similar to dry weather period, Table (4), shows that an increment range (5-30%) in septage received at Albireh sewage works resulted in an increase in the aeration tank volume and oxygenation capacity (7-51% and 7-49% respectively). In addition, fixed ratios of variable volumes for nitrification and denitrification and different aeration tank volumes were obtained.

The results depicted in Figures (3) and (4) show that during winter period the same constructional changes in the aeration tank volume must be attained to cope with prescribed national standards. Similar findings were reported by Voigtländer et al. (1996) where most planners forgot to include septage loads during the design phase, which later cause process failure especially in biological unit operations of most German sewage works.

Figure (6) illustrates the performance of Albireh sewage works during the first six months including the study period. For this analysis, it is assumed that the existing capacity of the first treatment lain has been exceeded by the daily pollution load of the served population and the septage co-treatment exacerbated the deterioration of the effluent quality. The total organic pollution load must remain under the design daily sludge lading rate (F:M = 0.05 kgBOD/kgTS) and is thus the limiting design parameter in analyzing annual unit operations.
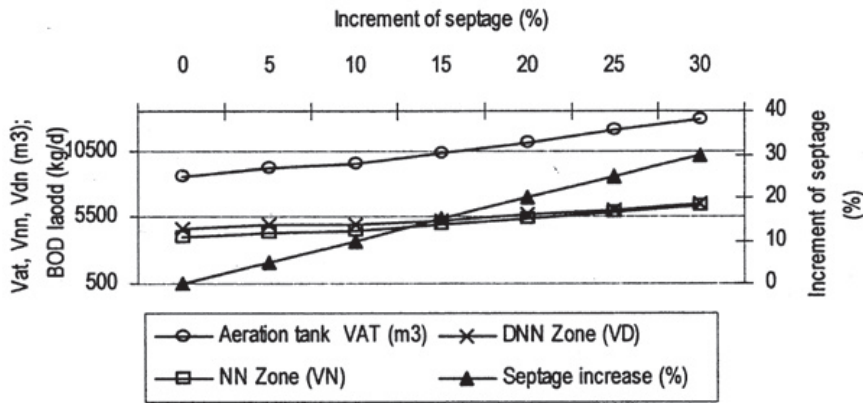

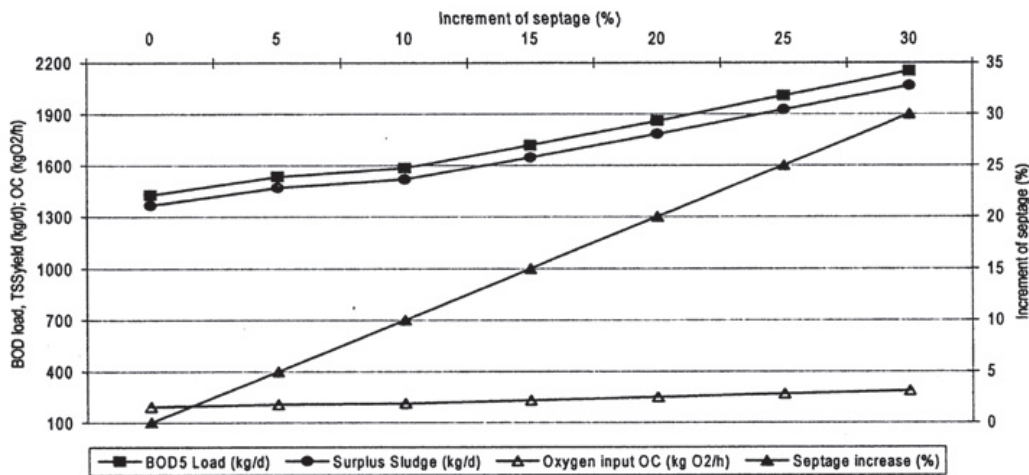Fig. 4. Septage impact on volumes of aeration tank, VN and VD zones at 13°C.

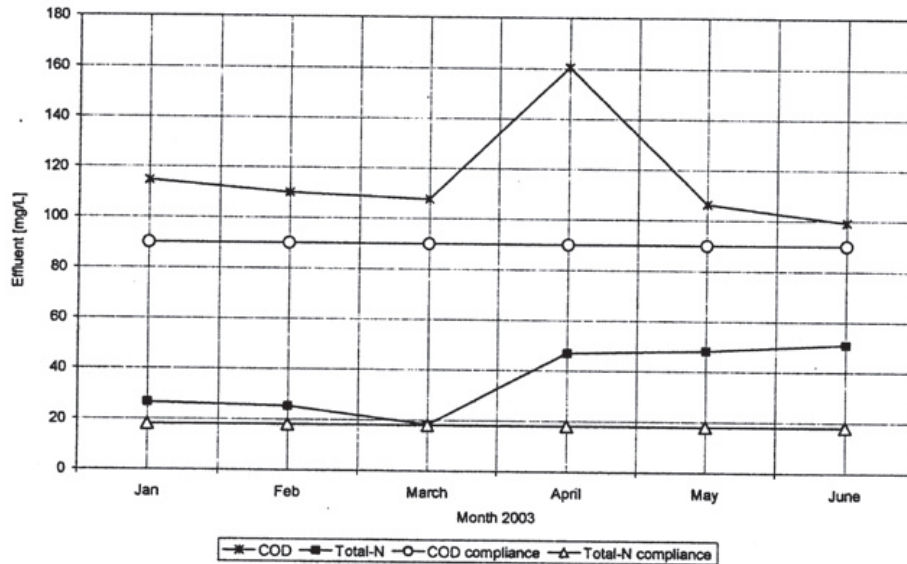Fig. 5. Septage impact on oxygen input and sludge yield at AWWTP at 13°C.

Fig. 6. Effluent COD and total nitrogen concentration compared with compliance guidelines.

As illustrated in Figure (6), should Albireh sewage works continue to achieve adequate COD and total nitrogen in the treated effluent (90 and 18 mg/l, respectively) then ongoing compliance with the criteria in the certificate of approval is unlikely. The existing situation of AWWTP revealed an overloaded capacity (32,385 PE) and improvement can only be achieved if the second oxidation ditch is put into operation. COD and nitrogen compliance is a monthly issue and removal rates of 90% and 80% have been achieved to comply with national prescribed effluent standards (TSS= 20; COD= 90; Tot. N= 18 mg/l).

Continuous co-treatment of septage will dramatically affect the issue of non-compliance related to COD and nitrogen. These results show that the German standards (ATV-A 123, 1985) beside assuming safety factors with respect to the capacity of municipal sewage treatment plants (capacity 10,000 PE and above) to receive and handle septage, exact design data and the potential impacts of septage loading rates on the efficiency and design parameters of municipal sewage works are crucial. Even for under-loaded wastewater treatment plants, the maximum septage load that a WWTP can handle without affecting its treatment efficiency should be also well known (Voigtländer and Schwerdtfeger, 1998).

4. CONCLUSIONS

The values of septage parameters in Albireh are lower than the values of USEPA septage parameters, as the source of septage in Albireh is from central unsewered urban dwellings, where a short hydraulic retention time prevailed in most septic tanks leading to weak anaerobic processes. Hence, the liquid material (supernatant) pumped from the cesspools is septage water and not a real domestic septage with almost similar municipal wastewater characteristics. Septage generation rate in Albireh city is approximately 1.2 m^3 per capita per year. Based on this, the annual volume of septage from households un-served by public sewer networks in Albireh city was calculated at 44.5 million cubic meters.

The average daily volume of septage received at Albireh wastewater treatment plant is 153 m^3. The additional population equivalent resulted from the average septage pollution loads (BOD, COD and PO_4) ranged between 1,417 PE and 41,676 PE. Co-treatment of septage exerts electrical power consumption (kWh), the energy running costs for the average values of septage reached about US$ 3,694 per month. Not taking into account the capital and other operating costs, Albireh municipality should charge septage haulers US$ 1.3 to US$ 11.68 per truck load (15 m^3) as specific costs for septage co-treatment. The impact of septage loads increments (5-25%) on the design parameters of the biological unit was assessed using the German Software Package (ANAWIN). The results revealed that substantial increment in structural (aeration tank) and unit operation design parameters (oxygenation capacity and sludge age).

However, lack of scientific data on the impact of septage co-treatment on the biological processes (nitrification, enhanced biological phosphorus removal, sludge foaming/bulking) further research including process simulation is needed to mitigate non-compliance of wastewater treatment plants.

Performance improvement of Albireh sewage works such as 90% COD and 75% nitrogen removal can be reliably achieved under capacity extension and governed by the daily organic load. Operation of an improved system will still be subject to noncompliant months during additional co-treatment of septage, which creates legal issues with subsequent actions. Septage co-treatment will dramatically affect the issue of non-compliance related to both COD and nitrogen under present operating conditions. The municipality should investigate other septage disposal alternatives and work in close cooperation with the septage haulers and the Palestinian regulatory water bodies. The recommendations may generally hold for similar climatic conditions and septage characteristics in other countries. Differences may occur in the septage type (industrial or domestic) and biodegradability (COD fractions) of septage based on pumpage intervals prior to delivery for final disposal. Further studies are needed to investigate the extent to which these factors affect sludge age, nutrient removal and biosolids settling properties, and how to achieve a sustainable septage management through low-cost disposal methods.

ACKNOWLEDGEMENTS

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2

Anthropogenic Impact on Water Resources in the West Bank/ Palestine: A case from Wadi Fara`a Stream – Nablus Area

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The article can be quoted as:

Anthropogenic Impact on Water Resources in the West Bank/ Palestine: A case from Wadi Fara`a Stream – Nablus Area

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Introduction

Water is a crucial and politically sensitive issue in the Middle East (Deborah et al., 2001). Water resources are not uniformly distributed (El-Fadel et al., 2000). Water resources in the West Bank and Gaza Strip are very limited (Collins, 1991) and currently a serious shortage problem exists (ARIJ, 1998), which would be aggravated in the near future as a result of population growth and the increasing demand (Al-Weshah, 2000), with consequent potential to trigger water contamination.

There has been a tremendous amount of literature directed toward current and probable future droughts in the region. The present climatic conditions are not promising (Issar, 1995; Houghton et al., 1996). Therefore, improper assessment of and/or planning for water resources could fail to anticipate climate variability, especially droughts. Groundwater in the West Bank of Palestine is located in three major basins (Bashir and Mimi, 2005): western, northeastern, and eastern (Allan, 2001). This article is a preliminary investigation to the existing water quality, specifically major constituents and contaminants in one catchment areas of the eastern basin (Wadi Fara'a).

Study Area

The West Bank of Palestine is located (Figure 1) west of the Jordan River and covers an area of approximately 5,600 km^2. It is the home of 1.9 million people (PCBS, 1997). The West Bank is a small area with a high population density, a diversity of natural resources, cultural heritage (MOPIC, 1999a), and strife-ridden political climate, which make its landscape and natural resources vulnerable to the impact of growing population.

The study area of the Wadi Fara'a drainage basin is located on the northeastern slopes of the West Bank within the eastern basin and has an area of 330 km^2; it is inhabited by 47,320 people. Its highest elevation is 704 m above sea level in the western parts and decreases gradually to reach 320 m below sea level near the Jordan River. The area has two groundwater basins, one in the northeast, which lies under the upper Wadi Fara'a, and the other in the east, which lies under the lower Wadi Fara'a springs (Ghanem, 1999).

The basin is fertile and is considered to be a highly sensitive groundwater recharge area compared with the remaining areas in the West Bank. The study area has 70 wells and four groups of springs (Al-Nubani, 2000) that contribute flow to the main watercourse, which irrigates about 500 donums (1 donum = 1,000 m^2) of agricultural land (ARIJ, 1998). The soil in this area can be classified as sandy, clay, and sandy-clay (MOPIC, 1999b). The soil formation is an asset for cultivation practice, where the climate of the area is hot in summer and warm in winter. This climate pattern enables the farmers to produce vegetables earlier than other areas (ARIJ, 1996). Its agricultural value, fertile soil, water availability, and climate make Wadi Fara'a an agriculturally productive area (500 donums) (MOPIC, 1999c). Its topography is gently sloping to the east. Although soil formation enhances cultivation practices, the low precipitation rates and high evaporation rates make rain-dependent agriculture less efficient. For this reason, most of the cultivated areas are irrigated by traditional methods using furrows or ponds, with an efficiency of 45%. Other modern techniques are sprinklers with efficiency of 60% to 70% and a drip system with efficiency of 80% (ARIJ, 1996).

Figure 1. West Bank location map.

There are 47,320 inhabitants in the Wadi Fara'a in addition to 120,000 inhabitants of the city of Nablus. The area has approximately 30 Palestinian communities and eight Israeli colonies. The population in Wadi Fara'a and Nablus for the year 2005 was forecasted to be 45,000 and 134,116, respectively (PCBS, 2006). (because of unstable political conditions).

The area is the home of different land-use activities. Untreated domestic water, animal waste, and solid-waste dumping sites are playing a major role in water contamination in the area. In addition to those contributors, wastewater is released to the study area from major surrounding urban areas—Nablus City (MOPIC, 1999d).

The average rainfall in the area is 450 mm/year and decreases moving from the west to the east. Because the area is located in a semi-arid region, evapotranspiration is very high and estimated to be 2,000 mm/year and the amount of recharged rainwater is minimal and estimated to be 60 million m^3 per year. The amount of runoff is approximately 4.49 million m^3 per year (Ghanem, 1999) and directly flows into the Jordan River.

Data Sources and Methods

Water samples were collected from 10 sites along the watercourse, three samples from each site (Figure 2), from the headwaters of the basin, near the first group of springs (Main Fara'a Spring) to the downstream of the area (Jifftlik Canal) in August 2001. Sample analyses were carried out in the Center for Environmental and Occupational Health Science (CEOHS) at Birzeit University/Ramallah, West Bank. The parameters total dissolved solids (TDS), Na, NO^{-3}-N, pH, Cl^-, HCO^{-3}, Ca, Mg, SO^{-4},

and K were tested to investigate the level of contamination in the stream. Parameters such as fecal coliform, N and P groups, biochemical oxygen demand, chemical oxygen demand, and dissolved oxygen were not included in this study but would have enriched the study. The reasons for not including these parameters was limited funding and time constrains. Sampling sites were spatially referenced by using global positioning system. These sites were added to the study map by using edArc-View GIS version 3.0 (Environmental Systems Research Institute Inc, ESRI, 1996, USA).

Results and Discussion

The sewage network of Nablus City discharges with an open pipe directly into the Wadi Fara'a at Al-Bathan site. This waste is diluted with the fresh water coming from the springs and continues down to the agricultural land to be used for irrigation. Untreated wastewater flows in Wadi Fara'a, contaminating water in the stream, springs, and crops. The wastewater system in the area consists of cesspits/septic tanks and open channels, as well as the industrial wastewater from Nablus City, which flows directly into the Wadi Fara'a. The many open channels of wastewater from the Wadi Fara'a refugee camp combine to make a main channel that flows directly to the south, joining the stream at the site of Al-Malaqi Bridge.

Chemical analyses of major constituents revealed that the major and minor water constituents in the Wadi Fara'a catchment basin demonstrate high-level concentrations of several inorganic compounds (TDS, Na, $NO^{-3}N$, pH, Cl^-, HCO^{-3}, Ca, Mg, SO^{-4}, and K) as given in Table 1. Although most of these compounds are of minor concern, the NO^3 levels are significant enough to be a health concern. The maximum accepted contaminant level for nitrates in drinking water in the United States is 10 mgN/L (US EPA, 2002). Excessive amounts more than 10 mgN/L can result in serious illness and sometimes death. This contaminant is especially dangerous to the health of babies because of the conversion of nitrate to nitrite in the body, which interferes with the body's ability to absorb oxygen (US EPA, 2002) and could cause shortness of breath, a symptom called *Blue Baby Syndrome*, within days.

The presence of urban areas; human activities such as agriculture, animal breeding, farming, industrial waste from the nearby city of Nablus; and the wastewater/sewage water from the surrounding developed areas all exert anthropogenic pressure on the quality of surface water and groundwater in the basin. The amount of $NO^{-3}N$ in the stream is a result of pollution coming from municipal waste, sewage, and fertilizer and pesticide application in agriculture (Favara et al., 2000). It is clear that the highest records of NO^{-3} N are in three sites: Al-Bathan, Wahat Bathan, and Al-Malaqi Bridge. In the other sampling sites, NO^3 values are more constant (<22 mg/L).

Referring to the TDS, surface water in the area can be classified (Carroll, 1962) as fresh water (0 to 1,000 mg/L), mostly in the far upper stream where TDS reach less than 400 mg/L (Main Fara'a Spring, Wadi Fara'a 100 m downstream, Ein Beda
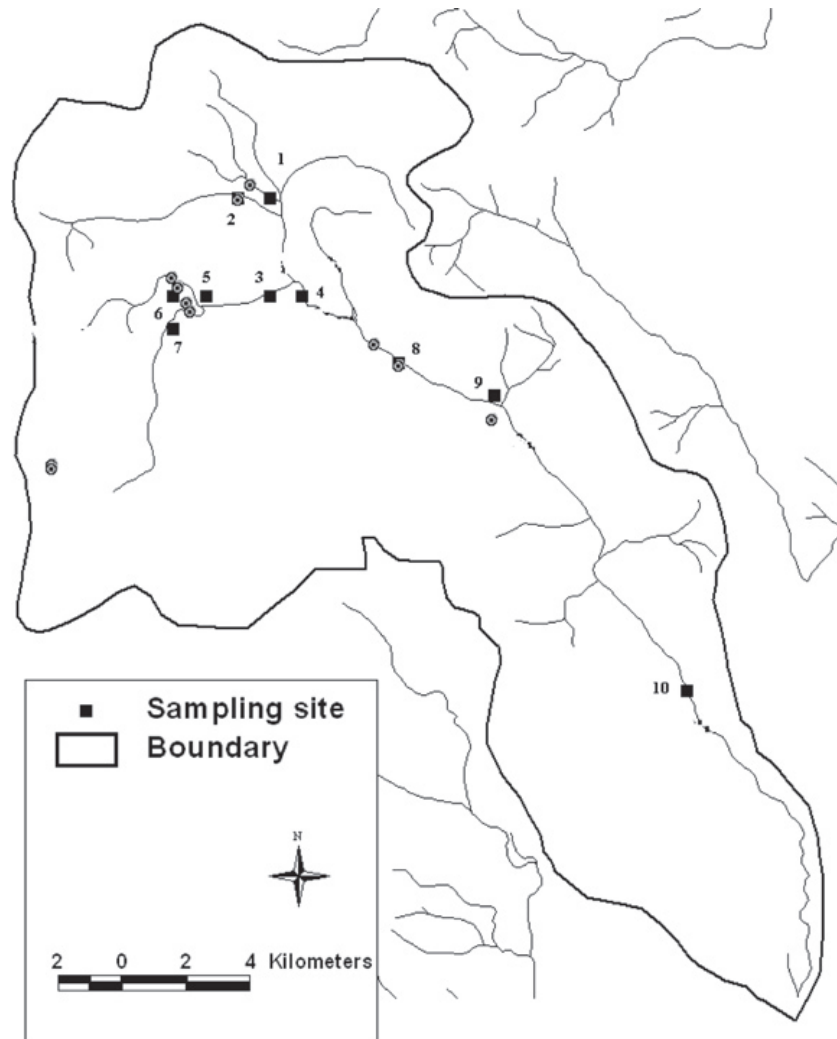
Figure 2. Sampling sites in the watershed of Wadi Fara'a.

and Subyan Spring) and in the middle of the stream where TDS reach 900 mg/L (Miska Spring and Shibli Spring); brackish water (1,000 to 10,000 mg/L) is present downstream where TDS reach 1,200 mg/L (Jifftlik Canal).

Ca and Mg stem from the dissolution of carbonate rocks; the high concentration of Ca is a result of an increasing amount of CO_2 in the water (Kacaroglu and Gunay, 1997). Mg concentration increases as moving downstream to the east towards Jordan Rift Valley because of water–rock interactions.

Na and K concentrations in the stream have the same distribution as NO^3 concentration, which reflects the fact that the existence of Na is due to wastewater and sewage diluted in the stream and also from the discharged industrial mineral waste. Na concentration is high at the far downstream end due to rock weathering and water–rock interaction. High Na concentrations results from an increasing salinity level. K is an indicator of anthropogenic effects on water due to agricultural practices using fertilizers such as KNH4 (Ghanem, 1999).

The concentration of SO_4 reflects the nature of evaporitic carbonate rocks and its source from fertilizers, animal waste, septic system, sewage, and industrial waste (US EPA, 2002). High concentration of Cl is due to evaporitic Cl-bearing rocks in the alluvium formation that contains a high amount of NaCl (Ghanem, 1999). Intensive uses of fertilizers, animal waste, septic system, industrial waste are the main source of Cl in the stream (US EPA).

The data in Table 1 show that water contamination is high in the middle of the upper part of the study area (Al-Bathan, Wahat Bathan, and Al-Malaqi Bridge) and at the far downstream end of the stream (Jifftlik Canal), which means that these contaminants are accumulating along the water courses, where they are finally used in irrigation and the remainder joins the Jordan River. It is clear that most of the agricultural land in the lower part and in the mid-part of the study area is under the threat of contaminated water coming from the upper part of the study area.

Table 1. *Water samples analysis*

Sampling site number	pH	Ec (μs/cm)	Total dissolved solids* (mg/L)	Cl (mg/L)	HCO3 (mg/L)	NO^3-N* (mg/L)	SO4 (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)
1	7	637	334	43	231	2.94	3	96	19	23	1
2	8	722	382	43	235	3.61	21	108	15	43	2
3	7	548	274	32	203	2.94	2	80	15	21	3
4	8	560	394	31	205	3.39	3	91	12	23	4
5	7	1748	921	304	382	14.68	6	92	24	229	25
6	7	1725	860	295	344	9.49	3	86	22	229	17
7	8	1852	678	336	305	15.58	5	98	21	248	22
8	7	783	415	84	248	4.52	6	81	32	41	3
9	8	701	370	61	232	3.61	5	68	39	33	4
10	7	2400	1200	529	273	4.97	4	115	100	210	16

US (EPA, 2002) drinking water quality standard: NO^3 = 10 mgN/L, Total dissolved solids = 500 mg/L
accessed 2005, Title page: Ground water and drinking water, List of drinking water contaminants
and MCLs: web page: http://www.epa.gov/safewater/mcl.html#mcls

Sampling sites name	Main Fara'a Spring	Wadi Fara'a 100 m downstream	Ein Beda	Subyan Spring	Al-Bathan	Wahat Bathan	Al-Malaqi Bridge	Miska Spring	Shibli Spring	Jiftlik Canal
Sampling site number	1	2	3	4	5	6	7	8	9	10

Most of the solid wastes are disposed randomly over the landscape, near houses, open spaces, and roadsides. The dumped waste either at designated dumping sites (60%) or random sites (40%) is mostly burned with no control or supervision and without any mitigation measures (ARIJ, 1996). Dumping sites are not designed properly to protect the surface or ground water and the waste leachate percolates into the aquifers. In addition, solid waste burning causes air pollution, which adversely affects the public health.

Conclusions and Recommendations

Human impact on environment and natural resources is affecting these resources everywhere on earth, but the level of degradation is varying. Wadi Fara'a as a case study in the West Bank shows that the level of human impact is alarming, and contamination to water resources is serious due to the fact that water is used in agriculture. By sampling water through the stream, analyzing these samples, and comparing the level of contaminants in these samples with other areas (US EPA, 2002), it became clear that the water in the study area is degraded and needs attention. Further studies are needed in other areas in the West Bank to construct water treatment plants in the most sensitive areas; action (water resource management plans and treatment plants) is needed to maintain water resources in this area where water is scarce and threatened. Inclusion of other parameters, such as fecal coliform, N, and K groups, biochemical oxygen deman, chemical oxygen demand, and dissolved oxygen, is necessary to achieve comprehensive assessment of anthropogenic impact on water resources both on stream water and groundwater.

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Sulphur and Oxygen Isotopic Characters of Dissolved Sulphate in Groundwater from the Pleistocene Aquifer in the Southern Jordan Valley (Jericho Area, Palestine)

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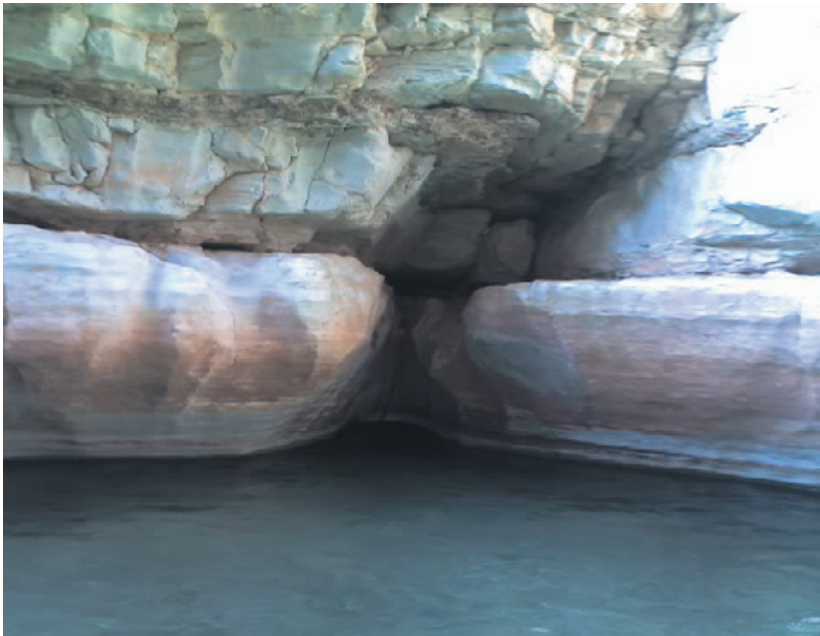
The article can be quoted as:

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1. Introduction

Sulphate (SO_4^{-2}) occurs naturally in most of the eastern aquifers in the Jordan valley rift. The concentration of sulphate as a component of the major solutes, responsible for the higher salinity in the area, increases at noticeable levels in the lower part of the valley.

Studies of Farber *et al.* [1] and Marie and Vengosh [2] suggested a continuous input of salinity and sulphate from Lisan formation as one of the main sources of high salinity in the area, depending on the hydrochemical relations among Cl^-, Mg^{2+} and SO_4^{2-}. These studies show that *in situ* leaching from the gypsum and aragonite layers has been shown to be an important control on sulphate concentrations in the groundwater of the aquifer. Pyrite has also been identified as a trace mineral in the bedrock, which contributes to the sulphate within the aquifer [3]. The previously mentioned study [1] on the lower Jordan River water shows an example of the role of pyrite, where it was found that the low $\delta^{34}S_{sulphate}$ values of about $-2\,\%o$, in the saline Yarmouk River north of Jordan valley, suggest that the pyrite or ferrous sulphide oxidation in the sediments is the original source of sulphur in these sediments. However, a few studies adopted Jericho as a unique multi-lithomorphic area, describing the formation of the Lisan Lake and the new sedimentary alluvial formation of the Samara marl and gravels formed by mountains, wadis, and sedimentary run off.

This study aimed at using stable sulphur isotopes of the sulphate to trace the main sources of sulphate contribution to the Pleistocene aquifer as a part of the whole salinity problem in the area, and to appraise the role of Lisan sediment in the process of salinisation within the aquifer.
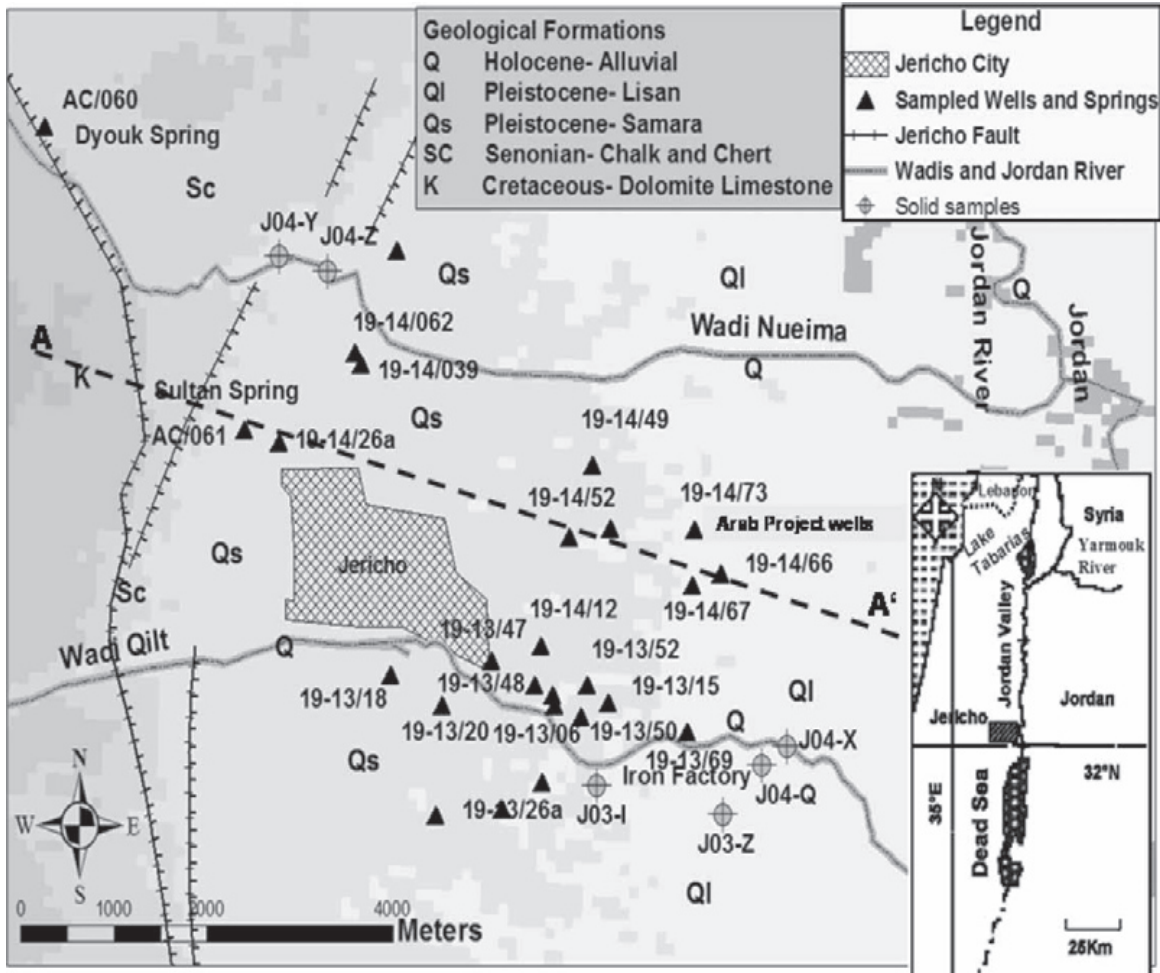
Figure 1. Study area of Jericho, sampled wells and springs are shown with different geological formation. Note: The cross section A-A' is described in figure 2.

area at the end of the eastern slope of Ramallah–Jerusalem Mountains in the west makes it a good catchment area highly abundant in water resources.

2.1 *Geology*

The Rift Valley faults are the major structures that affect the geology and hydrology of the whole Rift Valley. The stratigraphy consists of carbonates, chert, chalk, gravel, sandstones and evaporates, which range in age from the Triassict to the Holocene in the east near the rift. The ancient lower Cretaceous formations are mainly composed of limestone, sandstones, and marl layers. The youngest formations are of Pleistocene to Neogene Holocene age [4]. The major geological formations exposed in the study area are shown in figure 1 [5–8].

2.1.1 Cenomanian (Hebron and Bethlehem formations) [K]. This includes the Middle Cenomanian (Hebron formation), Aminadav in the Israeli terminology. This formation is exposed in a very small area to the west of Sultan. It is composed of brittle karistified gray dolomite, dolomitic limestone and gray limestone. At its base, it is formed of hard dolomite and dolomitic limestone with some silicification. The lithology is uniform since dolomite and dolomitic limestone are found throughout the sequence of Hebron formation. The porosity of this formation is mainly secondary because the rocks are well jointed and karstified. The Upper Cenomanian (Bethlehem formation) is exposed in a small part to the north-west of the Jericho area, at the foot of the mountains. It is built of two formations: Weradim as its upper part and Avnon as its lower part. Avnon consists of limestone, chalky limestone, and marl that act as a confining aquiclude for the Hebron formation beneath. The Weradim formation is formed by hard dolomite with some limestone. Bethlehem formation is frequently highly jointed and fractured, making this formation a good aquifer.

2.1.2 Turonian–Jerusalem formation. This formation is of Turonian age. It is built of three formations (Derorim, Shivta, and Nezer formation according to Israeli terminology). In the western and north-western part of the study area, only the formations of its upper part, Nezer and Shivta, are exposed. Its lithology is characterised by karstified limestone and dolomite with marl and clay mainly near the bottom. Sometimes occurrence of chalk is evident on the top of this formation.

2.1.3 Senonian-Abu Dis formation (Sc). This formation is part of the Senonian age. It is composed of Menuha Mishash and Ghareb formations (Israeli nomenclatures). This Meshash formation is mainly exposed in the western part of the Jericho district, near the Sultan area. It consists of chalk and chert, the chalk usually white, but in some areas, dark coloured because of the presence of bituminous materials. In general, chalk often appears to be a fracture-flow aquifer but because of its clayey nature, it is considered as an aquiclude. It is structurally cut by minor faults [4]. The thickness of this formation ranges between 40 and 150 m.

2.1.4 Neogene and Quaternary formation. Alluvial formations range from Pleistocene, Holocene to recent age. The Neogene and Quaternary successions are built mainly of marine and continental clastic formations, marine and limnic chalk, evaporates and magmatic rocks [9]. These formations are limited mostly to the Jordan Rift Valley itself. The thickness varies between a few hundred metres on the rift shoulders to a few thousand in the deep depo-centres. The sequence is divided into two groups: the Tiberias Group of Neogene age at the base and the Dead Sea group (or the Jordan Valley group in Jordan) of Plio–Pleistocene–Holocene age at the top. The study area as a part of lower Jordan valley belongs to the second group subdividing into two main formations.

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(A) Plio–Pleistocene formation is composed of three sub-formations.
    (1) *Samara formation (Qs)* crops out along the western part of the Jordan Valley floor, at the base of the marly cliffs lining the Jordan River. It was deposited as marginal sediments along the Jordan Valley. The formation consists of conglomerates, sandstones, and silts, and is subdivided into two members.
      (i) *Coarse Clastic member (NQs (b))*, which is formed as a result of wadi fan deposits, dominates the western part of the study area consisting of gravel and conglomerate with a thickness of about 35 m, and
      (ii) *Silt member (Qs (a))*, which exists further east of the coarse clastic member, covers a large part of the study area and is within Jericho city, consisting of more fine particles of silt and clay, with a thickness of about 20 m.
      The two members show interfingering relationships with the Lisan formation. The Samara formation covers the major part of the Jericho area west and inside Jericho city. It includes three local faults of up to 3 km long with 35 m thickness layer in certain variations.
    (2) *Lisan formation (Ql)* is exposed in the eastern part of the study area as well as in the whole Jordan valley rift and the Wadis. It consists mainly of laminated aragonite-chalk, gypsum and clay, with some sandstone and pebble beds. The section contains hypersaline and brackish fauna. The Lisan formation acts as an aquiclude [7].
(B) The Holocene formation (Q) comprises recent alluvial deposits in the Wadis and associated flood plains of ephemeral streams. These sediments are found in the eastern part of the study area lining and surrounding the Jordan River. In the study area, this formation has five members that vary in its lithology from one location to another; these members consist of conglomerate, gravel, stream, soil, and Sabha soil.

3. Hydrogeology of the Jericho area

The whole sub-basin is mainly fed by inflows of excess water from the surface runoff across the Wadis and the neighbouring aquifers, namely the lower Cretaceous Kurnub sandstone aquifer and the Albian to Turonian limestone and dolomite aquifer, also known as the lower and upper aquifer. The annual precipitation amount in the main recharge zones, for the aquifer, in Jerusalem and Ramallah mountains is about 540 mm [2]. The main local aquifer systems in the study area are described in figure 2.

3.1 *Regional Mountains aquifer*

This upper Cretaceous aquifer is of Cenomanian to Turonian age, composed of karstified rocks as a typical character of the aquifer system, and represents one of the most important water resources in the region. The thickness of the upper Cretaceous aquifer ranges between 170 m in the west of the study area and 200 m in the upper Jerusalem area. The aquifer is divided into two sub-aquifers: (i) the lower confined sub-aquifer includes the Kefira and the Givat Yearim Formations (lower Beit Kahil formation), and (ii) the upper sub-aquifer includes the Aminadav (Hebron formation), Veradim (Bethlehem formation) and Bina formations (Jerusalem formation). The outlets of this sub-aquifer are in the Jericho springs, Wadi Qilt Springs, and Wadi Nu'emeh Springs in the lower part of Wadi Makuk close to the Jericho fault.
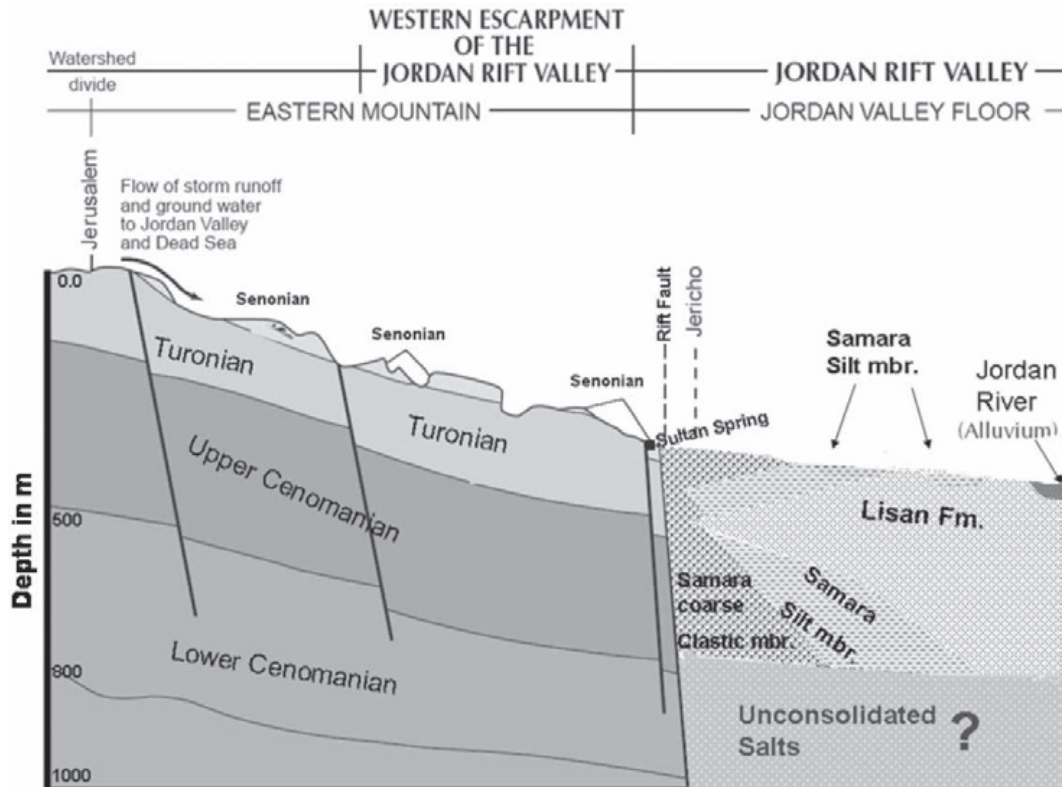
Figure 2. Schematic hydrogeological cross-section in the study area, modified after Rosenthal [10].

3.2 *The Jordan Valley deposits (Dead Sea group)*

Two Dead Sea group aquifers are located in the Jericho area. These are:

(a) *The Holocene or sub-recent alluvial aquifer*, which is mainly distributed in the Jordan Valley and neighbouring areas. It is built up of sub-recent terrigenous deposits formed along the outlets of major wadis. These alluvial fans are still under accumulation after large floods and consist of debris from all neighbouring lithologies and are deposited according to their transport energy. The transport normally takes place along alternating channels. Thus, permeable horizons alternate with impermeable lithologies within the deposits. The total thickness with a maximum near the rift margins thins out towards the centre of the rift basin. The alluvial aquifer often directly overlies the Pleistocene gravel aquifer and is hydraulically interconnected with this aquifer.

(b) *The Pleistocene Samara Lisan aquifer/aquiclude*, which includes three members: Samara coarse clastic, Samara silt, and Lisan of the Pleistocene Samara aquifer, with a lateral facies succession from terrestrial/fluvial to deltaic/limnic and limnic/brackish lake environments. They reflect the Plio–Pleistocene depositional conditions of the Lisan Lake. The Lisan – the marl, gypsum, and silt lacustrine unit – is generally considered an aquiclude, void of exploitable water. It is mainly distributed towards the middle of the graben. The Samara formation consists of two members: a silt member underlying or interfingering with Lisan and a coarse clastic member further to the West that predominantly consists of gravel, interbedded with clay, sand, and marl horizons.

The natural recharge by rain is almost negligible. Therefore, the aquifer is mainly fed by inflows of excess water from neighbouring aquifers – the lower Cretaceous Kurnub sandstone aquifer and the Albian to Turonian limestone and dolomite aquifer also known as the lower and upper aquifer – and from runoff in the wadis on the Eastern slopes of the West Bank. The aquifer supplies agriculture in the Jordan Valley between Jericho and Fari'a Graben.

4. The problem of salinity

In general, the Lisan formation is a major source of soil and water salinity in the Jordan Valley [10]. The permeability of the Lisan formation is generally very low and can be considered as an aquiclude [10]. However, because of a laminated structure of alternative marl, gravel, and limestone layers (figure 3), of embedded sand and silt beds up to 30 cm, and of evaporitic materials such as gypsum and other salts, an extended network of pathways for water has been formed resulting in high porosity and permeability. Moreover, the Lisan and Samara formation horizontally interfinger along the Jericho aquifer system [4].

The transmission properties show that the aquifer varies from low potential (less than $10 \, m^2/day$) to fair potential (between 10 and $50 \, m^2/day$) [11]. The shallow aquifer, consisting of alternating marl and gravel layers and being in direct contact with the Lisan layers, receives Lisan leachate water, which causes an increase in salinity [10]. The steep dip of the shallow aquifers in general along the Jordan Valley has caused deep circulation of the recharging groundwater, bringing it into contact with the salty formations at depth [11]. Recent drilling
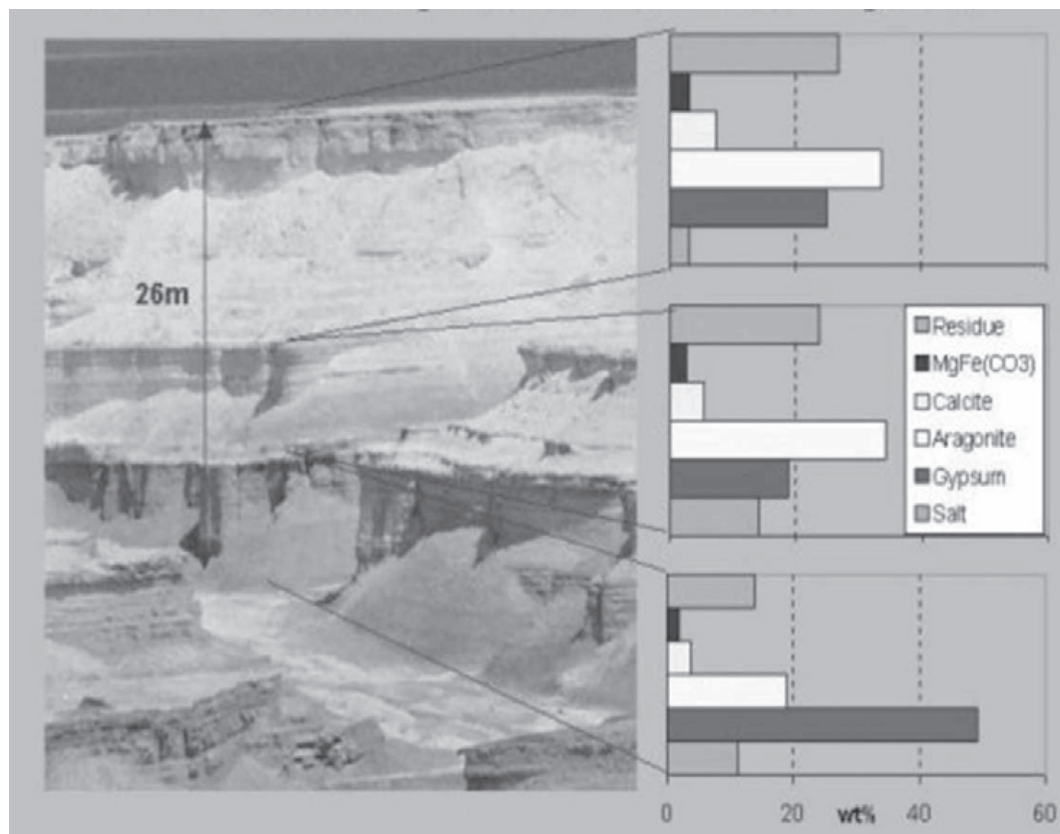

Figure 3.   Lisan formation (main component).

in the Pleistocene aquifer has shown that salinity increases with depth. Salinity data obtained from one well in Jericho show that the chloride content increases from 380 mg/l at 30 m depth to over 2000 mg/l at 162 m depth [11]. The main component of the salinity may result from flushing-off of soluble salts from the soil zone by excess irrigation water [2]. The water quality of the Pleistocene aquifer has deteriorated because of the encroachment of saline water from the fringes of the alluvial fans into the heavily pumped areas, and this has eventually led to the abandonment of several wells in the Jordan Valley. Owing to the heavy pumping in the Jordan Valley, a considerable decline of water table levels has been observed. The principle result is an increase in groundwater salinity. It has been observed that high chloride concentrations prevail in the heavy pumping areas (1000–2000 mg/l), whereas sulphate shows values between 200 and >300 mg/l. Much lower concentrations of chloride and sulphate occur in the areas near the wadis [12]. At certain distances from the heavy pumping areas further to the west, the salinity measured was at 500–1000 mg/l [12]. In this study, sulphur and oxygen isotope analyses of dissolved sulphate are used to assess the role of Lisan evaporates in the salinisation process by tracing the groundwater sulphate sources according to their isotopic composition.

5. Sampling and analytical methods

In order to characterise the water chemistry and the sulphur isotopic signature of dissolved sulphate in the Jericho aquifer system, 21 water samples (conductivity <5 mS/cm) from springs and wells were collected (figure 1). Two water samples from AC/60 and AC/61 correspond to springs, which have relatively fresh calcite-bearing water, in addition to a well close by (19–14/26a) that has the same type of water. Two wells (19-14/62 and 19-14/39) were located to the north of the study area within the alluvial formation of Wadi Nueima, 10 wells were distributed along Wadi Quilt (five west of the Wadi and five wells more close to the east of the Wadi), whereas the rest of the wells are located more to the east of the investigation area. The samples were collected between October and November 2003. On-site measurements for physicochemical parameters (pH, temperature, electrical conductivity, and redox potential) were done. The dissolved sulphate was directly precipitated as barium sulphate for the isotope analysis. To assess the importance of the possible influence of the lithological formation from Lisan and Samara at the isotope composition of dissolved sulphate in the studied aquifer, the sulphur isotope composition of two solid samples from Samara in Wadi Nueima north (J04-Y and J04-Z), and four solid samples from Lisan in Wadi Quilt east and south (J04-X, J04-I, J03-Z, and J04-Q) were also analysed. For this, samples were dissolved with distilled water (100 g/500 ml) at room temperature and then filtered with a Millipore filter of 0.45 μm pore size. Major anions of elutes and water samples were analysed by HPLC. Concentrations of the major cations of these solutions were determined by ICP-OES, and the trace elements were analysed by ICP-MS. Due to the high chloride content, most samples needed dilution, and therefore, most trace elements fell under the detection limits. Alkalinity was measured by titration.

For sulphur isotope analysis, the dissolved sulphate was precipitated as barium sulphate by the addition of barium chloride; the sulphate precipitate was then filtered, washed, and dried. The sulphur isotopic composition was determined with an isotope ratio mass spectrometer (Finnigan MAT delta C), coupled with an elemental analyser (Carlo Erba 1108). Oxygen isotope composition of sulphate was measured by a high-temperature pyrolysis, coupled with a continuous flow isotope ratio mass spectrometer (Finnigan MAT XL-Plus). The δ-notation is expressed in terms of δ^{34}S per mil relative to the Vienna Canyon Diablo Troilite standard and as δ^{18}O relative to Vienna Standard Mean Ocean Water standard. The isotope ratios were

Table 1. The concentration of sulphate and chloride, and the S and O isotopic signatures of dissolved sulphate in groundwater from wells and springs in the study area as well as of eluted sulphate from samples of the Lisan and Samara formations.

Site	Well code	pH	T (°C)	Depth m b. GOK	Electrical conductivity (mS/cm)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	$\delta^{34}S_{sulphate}$ (‰)	$\delta^{18}O_{sulphate}$ (‰)
Arab Project66 (East)	19-14/066	7.04	26.6	85	5.39	1614.0	300.9	−9.7	13.5
Arab Project67 (East)	19-14/067	6.99	26.4	73	5.84	1861.7	183.4	−2.2	12.3
Arab Project73 (East)	19-14/073	6.99	26.4	80	3.89	1125.0	95.9	6.0	16.3
Fahmi Nahas48 (Qilt West)	19-13/048	7.18	23.0	57	1.471	246.5	70.0	5.7	16.1
Fahmi Nahas47 (Qilt West)	19-13/047	7.20	22.8	74	1.454	231.5	77.2	6.9	16.3
Sabiru Rantizi (Qilt East)	19-13/006	6.88	23.2	57	2.33	449.5	117.6	3.5	16.8
Fahed Hishmi (Qilt East)	19-13/015	7.08	24.6	63	2.35	554.1	60.8	9.7	17.3
Zuhdi Hashwa (Qilt East)	19-13/052	7.15	23.4	160	2.59	590.3	166.0	−5.9	17.3
Salah Arouri (Qilt West)	19-14/012	7.14	22.6	65	1.279	186.5	59.2	4.6	16.9
Basil Husaini20 (Qilt West)	19-13/020	7.16	23.7	83	1.16	277.1	110.1	3.6	16.8
Basil Husaini18 (Qilt West)	19-13/018	7.20	22.1	90	1.146	161.9	58.6	−1.3	17.0
Ibrahim Daek (Qilt East)	NW	7.00	24.2	No data	3.23	837.5	167.7	7.7	16.6
Iron Factory (Qilt East)	19-13/26a	7.22	24.7	No data	1.939	441.0	90.0	−5.1	3.3
Ein Sultan (West)	AC/061	7.56	21.3	No data	0.637	34.4	17.2	8.7	15.0
Ein Dyouk (West)	AC/060	7.14	21.0	No data	0.637	34.9	16.7	6.0	9.9
Awni Hijazi (East)	19-14/052	6.88	25.3	82	3.11	831.1	72.1	12.5	14.0
Saeed Aladeen (North)	19-14/062	6.89	24.4	120	2.72	729.0	40.6	6.7	14.9
Mohammed Masri (North)	19-14/038	6.80	25.5	110	2.27	547.8	39.6	5.9	12.0
Samed (West)	19-14/26a	7.20	23.9	120	1.233	120.9	22.6	10.0	11.3
Arab Project69 (East)	19-13/069	7.02	26.3	132	4.05	1173.0	103.8	3.8	13.9
Abdallah Araikat (North)	19-14/049	6.68	25.5	90	2.47	581.8	92.7	9.5	12.7
J04-Y (Wadi Nueima)								6.9	1.4
J04-Z (Wadi Nueima)								9.1	9.1
J04-X (Wadi Quilt)								9.8	15.5
J04-I (Wadi Quilt)								12.1	15.2
J03-Z (Wadi Quilt)								13.1	16.3
J04-Q (Wadi Quilt)								16.4	16.6

calculated using NBS-127, IAEA-S1, IAEA-S2, IAEA-S3, and internal laboratory standards for calibration. Reproducibility of the samples, calculated from standards systematically interspersed in the analytical batches, was 70.2 %; the error of a double measurement was 0.4 ‰ for δ^{34}S and 0.5 ‰ for δ^{18}O. All chemical, sulphur, and oxygen isotope analyses were carried out at the UFZ-Departments of Isotope Hydrology and Hydrogeology.

6. Results

The δ^{34}S and δ^{18}O values of dissolved sulphate from wells, springs, and elutes as well as the concentrations of sulphate and chloride are shown in table 1. The eastern wells show sulphate concentrations that varied between 100 and 320 mg/l and chloride concentrations between 800 and 1800 mg/l, whereas the wells to the west were less mineralised between 20 and 90 mg/l for sulphate and 100 and 750 mg/l for chloride.

The δ^{34}S values of sulphate, eluted from the Lisan samples J04-X, J03-I, J03-Z, and J04-Q ranged from +9.8 ‰ to +16.6 ‰, whereas δ^{18}O varied around 16 ‰. In contrast, the sulphate for the two Samara samples J04-Y and J04-Z were more depleted with δ^{34}S signatures of +6.9 and +9.1 ‰ and δ^{18}O signatures of +1.4 and +9.1 ‰. Most of the samples including springs and wells range between −2.2 to +12.5 ‰ in δ^{34}S and +3.3 to +17.3 ‰ in δ^{18}O, which is close to the eluted sulphates from the Lisan and Samara formation (figure 4). However, the
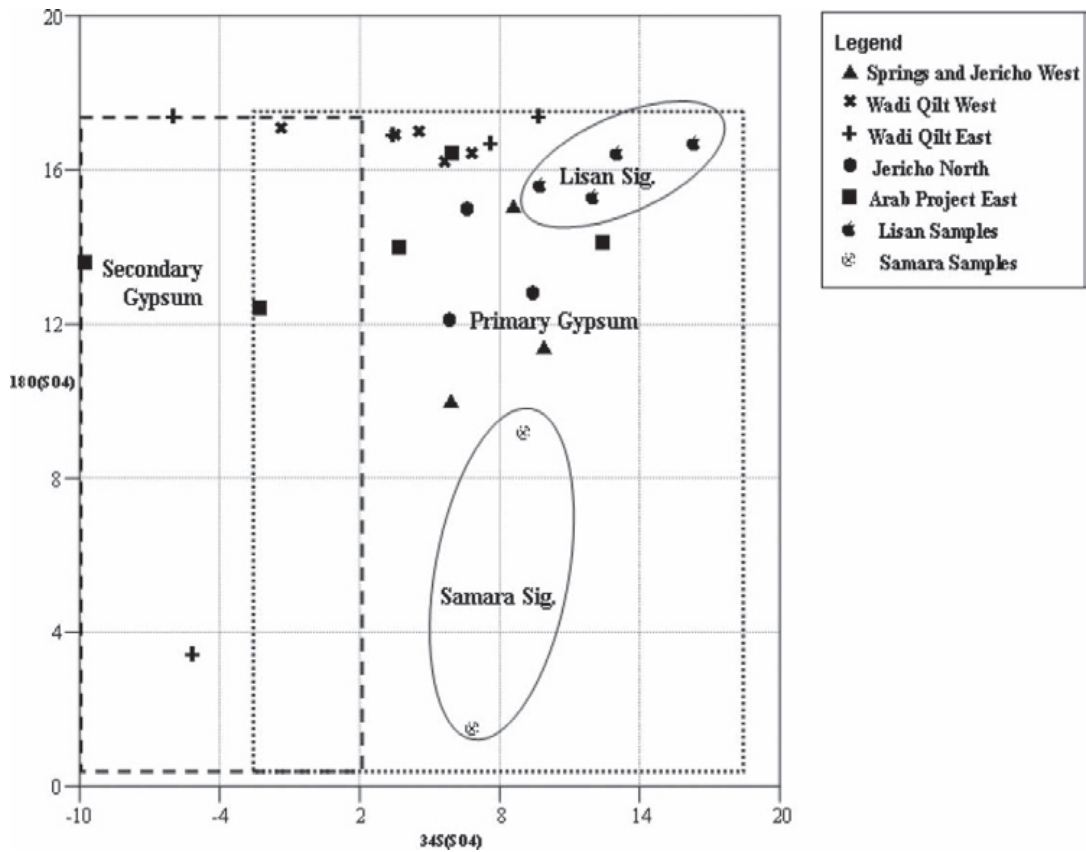

Figure 4. The isotopic signatures of sulphate in groundwater and in elutes from solid samples. Primary and secondary gypsum dissolution as well as the Lisan and the Samara formation are marked within the δ^{34}S–δ^{18}O relation.

wells lying further to the east and south-east, particularly the Arab project wells (highly brine signatures), show a high depletion of $-10\,\%_o$ in δ^{34}S parallel with high sulphate concentrations.

7. Discussion

Sulphur isotopes are used in hydrology to trace natural and anthropogenic sources of sulphur, in particular, to study the cycling of sulphur in agricultural watersheds, the sources of salinity in coastal aquifers or sedimentary strata, groundwater contamination by landfill leachate plumes, and acid mine drainage having a signature of groundwater sulphur from $-10\,\%_o < \delta^{34}$S $> +35\,\%_o$ [13]. The δ^{34}S values of groundwater are highly variable and depend on the nature of the sulphur inputs to the water. Sulphur takes many forms in groundwater, but is mainly found in the form of sulphates and sulphides. The main source of sulphate is from the dissolution of gypsum and anhydrite. Some dissolved organic sulphur, elemental sulphur, and mineral sulphur might also be present in groundwater [13].

Due to the isotopic signatures, the sulphate from groundwater samples can be related to the signatures of Lisan, Samara, and flooding water. High sulphate concentration in the groundwater from the Pleistocene aquifer is mainly a result of Lisan sediment dissolution, which contributes to the system in the form of salt leachate [2]. The *in situ* water–rock interaction is considered as one of the main contributors in the process of salinisation, where the isotopic signature of δ^{34}S$_{sulphate}$ and δ^{18}O$_{sulphate}$ for most of the samples are coincident within the range of the primary and secondary gypsum signature (figure 4). The relation of Lisan signature,
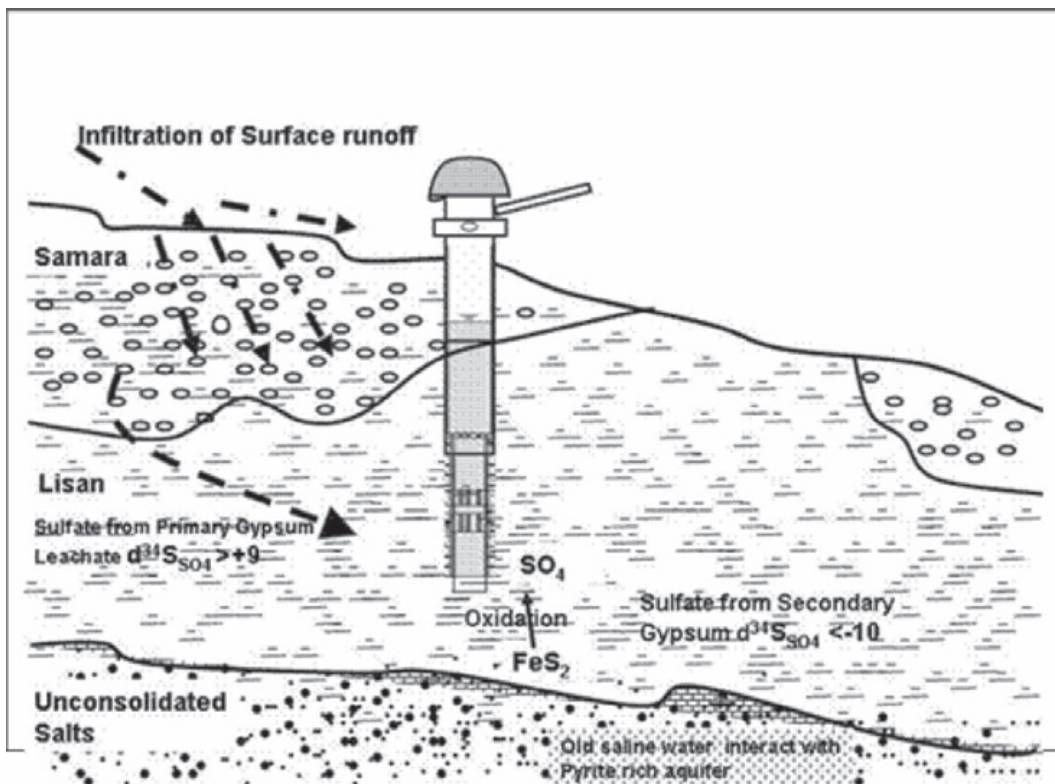

Figure 5.   Illustration of the two main different sources or mechanisms of contribution of sulphate into the groundwater from Pleistocene aquifer, in Jericho area.

which falls in the same range, points to the Lisan formation as a source of sulphate, which reflects the dissolution of sulphate from Lisan gypsum and aragonite.

The seepage water from the upper surface runoff and irrigation backflow infiltrates through the Lisan and Samara layers, forming a saline leachate (relatively less chloride content) that contains sulphate with positive $\delta^{34}S_{sulphate}$ signatures (figure 5).

However, some wells in the eastern part of the study area show more depleted sulphur signatures reaching $-10‰$. These depleted signatures highlight an additional sulphate source.

Gavrieli [14] reported a range between $+14$ and $+28‰$ in $\delta^{34}S$ for the primary gypsum layer in Lisan, and a more depleted ^{34}S signature of $-26‰$ for the disseminated secondary gypsum within the aragonites of the Lisan. Thus, the obtained depleted values in this study could be mixed signatures between these sulphates from the two gypsum sources. Farber et $al.$ [1] also suggested a mixing between two different sulphate sources in the southern Jordan valley. They distinguish between a hypersaline brine with a $\delta^{34}S$ signature of $+6$ to $+10‰$ and a sulphate-rich groundwater of >200 mg/l, depleted in ^{34}S, to $-17‰$ in Wadi Malih further to the north of Jericho. However, the results from Pleistocene groundwater in Jericho do not indeed reflect any influence or a mixing between such two sources. In the west and middle of Jericho, the data show positive $\delta^{34}S$ values that bear the eluted solid sample signatures of Lisan, but with relatively low chloride content (figure 6) and high Na/Cl and Br/Cl molar ratios [12]. This does not plead for the presence of the suggested saline effluent. Moreover, the groundwater in the east, more depleted
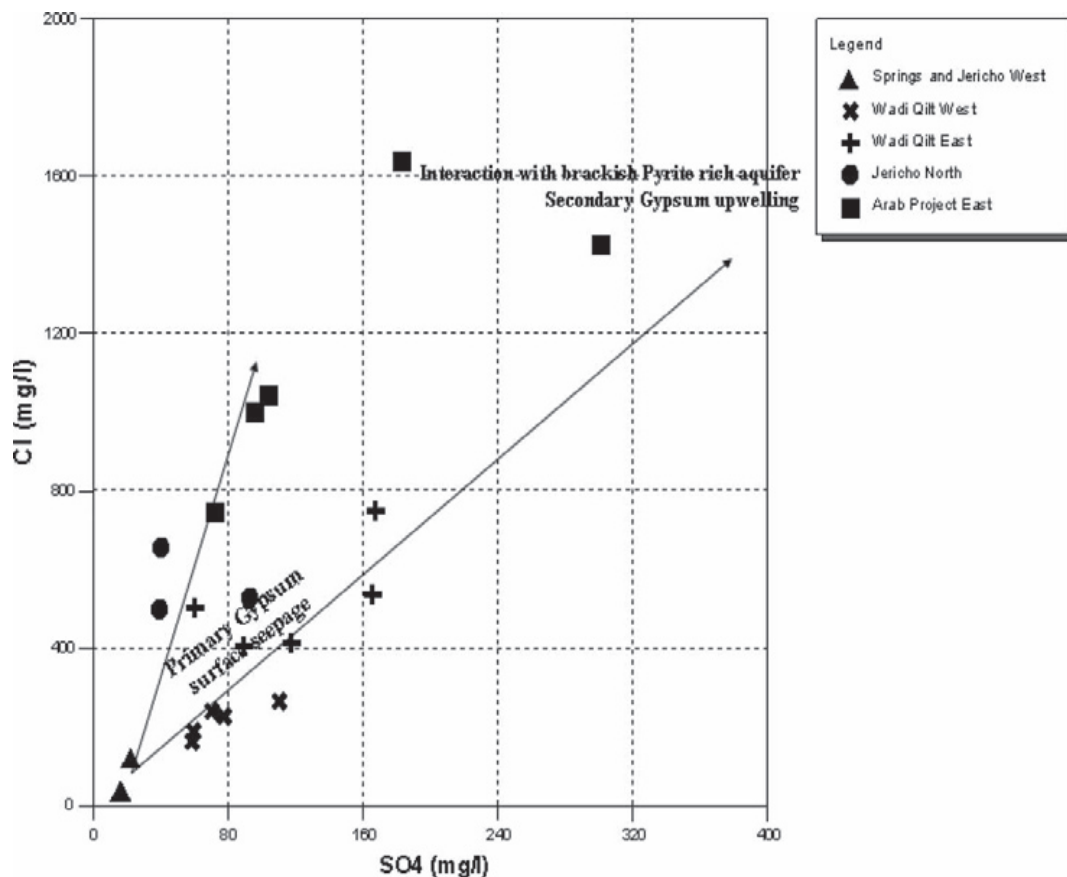

Figure 6.   Chloride vs. sulphate in mg/l. The figure shows two different contributions for sulphate related to the chloride content.
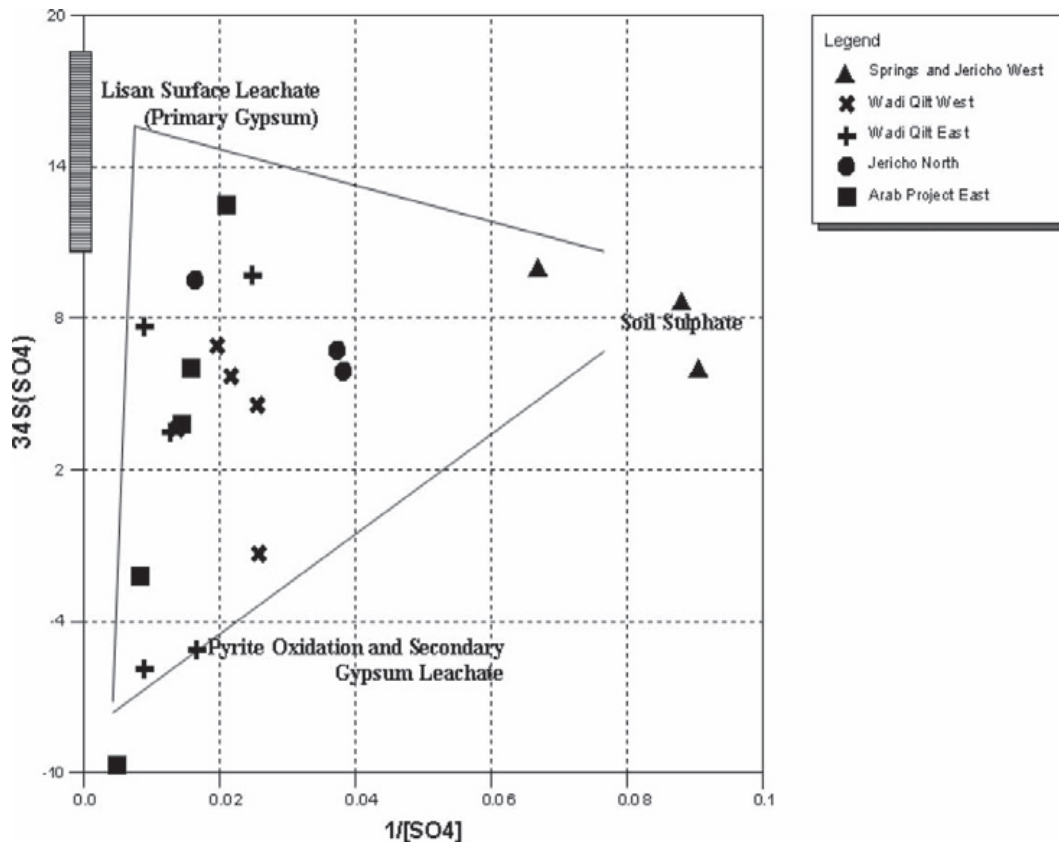
Figure 7. $\delta^{34}S_{sulphate}$ vs. $[SO_4^{2-}]^{-1}$. The sulphate depleted in ^{34}S indicates pyrite oxidation, whereas that enriched in ^{34}S indicates sulphate from primary gypsum in Lisan and Samara formations.

in ^{34}S, contains a relatively high chloride content of more than $1800\,mg/l$ (figure 6), and the sulphate concentration reaches $320\,mg/l$ (figure 7) with Br/Cl and Na/Cl molar ratios of 0.006 and 0.4, respectively [12]. These different signatures in the west and the east of the study area, and the differences in solute content and molar ratios suggest two different inputs of sulphate to the system, with a degree of mixing between them. In such cases, the isotopic signatures could not definitely confirm the sources of any estimated sulphate-rich brine.

The relation between sulphate and $\delta^{34}S$ (figure 7) can assess these two inputs showing where some of the signatures, especially wells from the Arab project, have high sulphate content depleted in ^{34}S. This contradictory relation, in which sulphate concentrations get higher and are relatively depleted in ^{34}S, supposes a mixing of primary and secondary gypsum dissolution, leaching upward under heavy abstraction, and admixing of upper surface leachate of primary gypsum. A previous hydrochemical study showed that the water samples from some of the eastern wells were relatively enriched with ferrous [12]. This result indicates an additional possible source of sulphate originating from pyrite oxidation [13]. The groundwater in the wells to the east might interact with deeper pyrite-rich aquifer (high chloride content), which is in contact with the deep salty rocks for a prolonged period of time. This groundwater, welling up from an anoxic sulphide-holding environment, enters the shallow aerobic environment of the upper aquifer where sulphide oxidation occurs.

The sulphate from deep sources, represented by depleted ^{34}S and partly by ^{18}O in some wells to the east, and the presence of ferrous in the water from these wells, suggest a sulphate pool

that is derived from disseminated secondary gypsum and/or from other sulphur compounds coning up from a deep anoxic environment and being oxidised in the shallow aquifer. Both of the abovementioned sources indicate an interaction between the upper groundwater layer and a deeper saline layer.

8. Conclusion

The rising of sulphate in groundwater in the Pleistocene aquifer in the lower Jordan valley (Jericho area) is mainly caused by disseminated and leached gypsum from Lisan and Samara layers that cover the area.

We suppose two different sources or mechanisms of contribution of sulphate into the groundwater in the area. The processes are: (1) Surface seepage leachate with the enriched ^{34}S of primary gypsum, and (2) Upwelling saline water rising up under heavy abstraction (especially in the eastern wells) with high sulphate content depleted in ^{34}S.

The high sulphate content, in relation to negative $\delta^{34}S_{sulphate}$ in the groundwater from the eastern wells seems to originate from pyrite oxidation, which also wells up under heavy abstraction and is oxidised in the aerobic environment in the upper layer. Therefore, this isotopically depleted sulphate could also result from a mixing process between the disseminated secondary gypsum with more depleted ^{34}S and the primary gypsum with more enriched ^{34}S by groundwater uprising under the described conditions.

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Management of Shared Aquifer Systems; a Case Study

Ziad Mimi and Amjad Aliewi
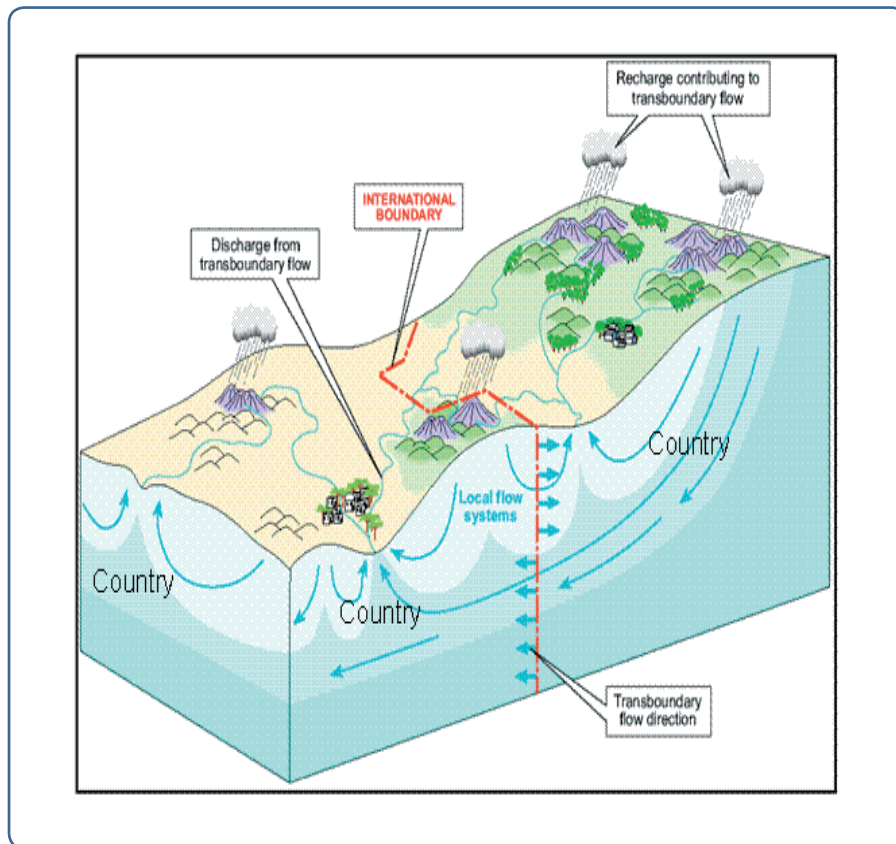
Management of Shared Aquifer Systems; A Case Study

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ABSTRACT

Next to issues of land, water resources are the major bone of contention in the peace negotiations between Israel and the Palestinians. Per capita annual renewable freshwater resources in the region are among the lowest in the world. This paper will attempt to identify an appropriate framework for management of shared aquifers underlying Israel and West Bank that comprise hydrological, legal, institutional, and socio-economic and environmental issues. The article calls for the application of international water law in the resolution of water disputes in the negotiating process. The challenging task for negotiators is to translate water law principles into operating rules and procedures for the equitable apportionment of waters from shared water resources. The paper introduces a multi-criteria decision tool as a possible approach to the problem of allocating the waters of the Mountain Aquifer between all riparian parties. A general mathematical model was derived in which the proportional entitlements of the Mountain Aquifer were determined. The model yields the following results (40%, 60%) where 40% represents the Israeli and 60% the Palestinian entitlements.

Key words: Equitable allocation, transboundary waters, groundwater basins, hydro-politics, Palestinian-Israeli water conflict, water conflict, multi criteria decision tool.

Classification: Civil Engineering, Water Resource

MANAGEMENT OF SHARED AQUIFER SYSTEMS: A CASE STUDY

BACKGROUND

Shared fresh water resources have been the source of international friction and tension for many years in many places. World-wide, approximately fifty percent of all land area is contained within international drainage basins, and more than 200 rivers are shared by two or more nations. These geographical facts have led to the geopolitical reality of disputes over shared international rivers and aquifers. Shared water resources are especially strong sources of conflict in the Middle East particularly the Jordan River shared by Israel, Jordan, Palestine (West Bank and Gaza), Syria and Lebanon and the shared aquifers between Palestine and Israel (Mountain Aquifer and the Gaza Coastal Aquifer) (Figure 1). In the Middle East, water has been the root, means, and cause of war. The control and allocation of water has evolved into an issue of "high politics," and it has been explicitly made a part of the ongoing peace negotiations [1].

Shortage of water is among the most serious problems facing the Israel–Palestinian region. It is possibly one of the most intractable issues of the multidimensional dispute between Israel and the current precursors of the Palestinian State. The region has one of the smallest annual per capita renewable water resources in
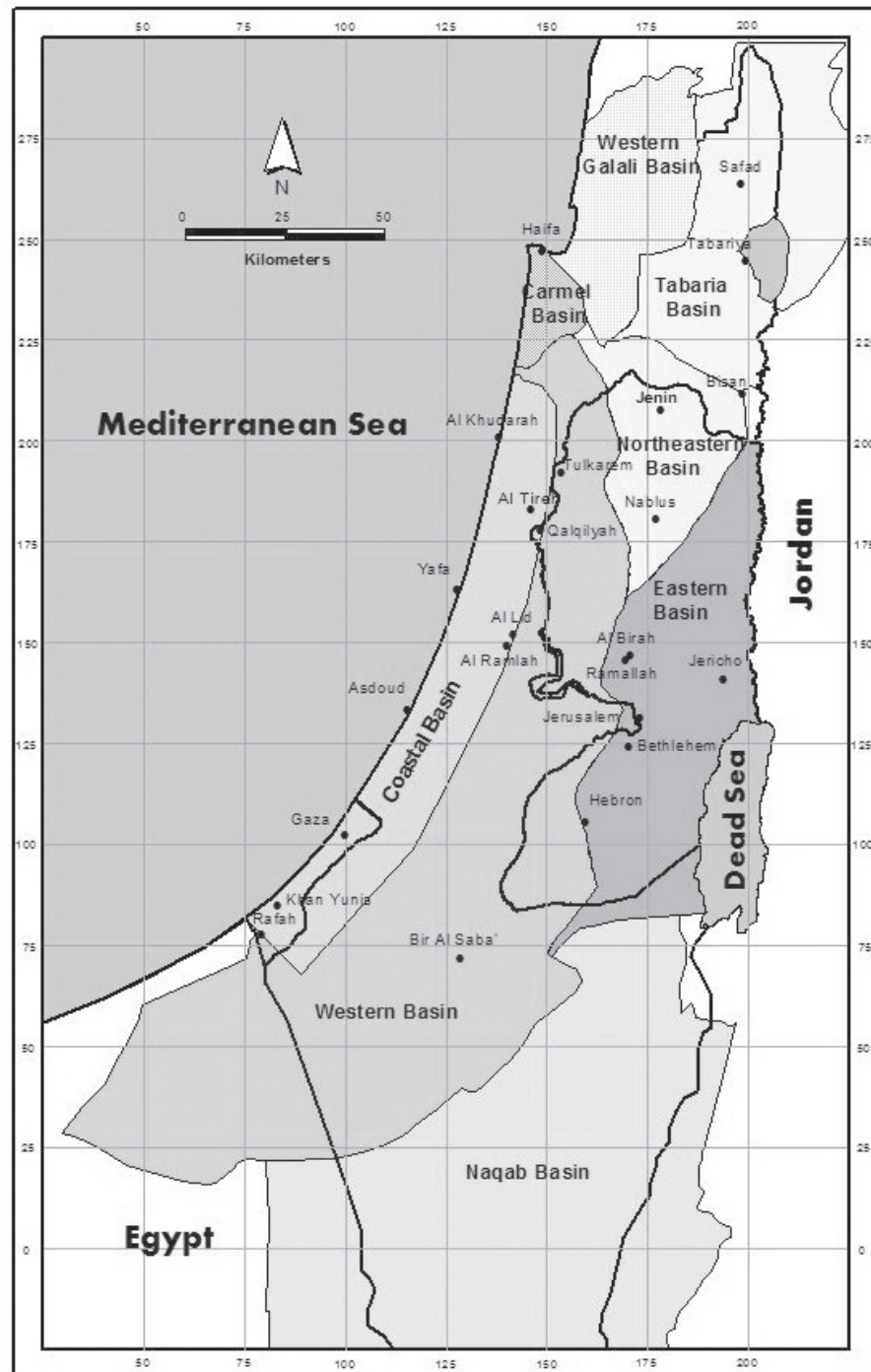

Figure 1. Shared aquifers between Palestine and Israel

the world. Water scarcity has always been the dominant factor in populations of the Middle East. The climate of the Israeli–Palestinian area west of the Jordan–Dead Sea trough is strongly affected by the desert regions to the south and east. Approximately 60 percent of that area is categorized as arid or semi-arid. Average annual rainfall ranging from 400 to 800 mm in the northern and western part of the area, and sharply declining to the south and east, occurs mainly between November and March. The remainder of the year endures a hot dry season with practically no significant rainfall. Under such circumstances, conflict about the division of the scant water resources of the region is second or equal to the territorial dispute between Israel and the emerging Palestinian State. This is particularly true considering the glaring differences between the annual per capita water consumption in the Israeli and the Palestinian sectors.

Lack of appropriate cooperation and coordination for shared water resources at regional and interregional levels is a source of concern. This issue is highly affected by the prevailing political situation in the region, as well as within adjacent regions. Mutual cooperation and coordination in managing the shared surface and groundwater basins would help to achieve sustainable development within the region. It is therefore vital that the Israelis and Palestinians attempts to improve cooperation regarding shared water development and management. A cooperation mechanism must be developed to reach an equitable development and management of their shared waters. An essential requirement for this cooperation is a legal regime or framework. This must be developed soon. A balanced legal framework for such cooperation, if developed and adopted, will greatly facilitate the development of cooperation agreements and thus help sustainable development of the shared water resources.

Unless both sides cooperate and jointly manage their shared water they both stand to lose, in terms of the long-term viability of their water systems. In other words, the only real choice both sides face is between a lose–lose situation if they do not cooperate, and a potential win–win situation if they do. This paper will attempt to identify an appropriate framework for management of shared aquifers underlying Israel and West Bank that comprise hydrological, legal, institutional, and socio-economic and environmental issues.

MANAGEMENT OF SHARED AQUIFERS

Framework for management of shared aquifers should comprise institutional, socio-economic, hydrological, legal, and environmental issues.

Institutional Aspects

In the absence of institutional arrangements for shared aquifer systems, countries sharing one or more aquifers are encouraged to forge international cooperation in the management of such groundwater basins by establishing commissions or other frameworks, through an appropriate legal instruments. Such frameworks can be derived from international treaties and agreements or local legislations and practices or both. Harmonized legislation can play an effective role in achieving inter-governmental cooperation. Current trends in national legislations for the management of aquifer systems suggest that harmonization could take place with respect to: status of groundwater ownership, regulation of drilling and abstraction including groundwater mining, protection and pollution control measures, and user participation in decision making. In essence, there is a need for coordination to regulate abstractions and minimize mutual harms arising from competitive pumping of shared aquifers, regardless of the magnitude of recharge to an aquifer. It is believed that the current use of the Western Aquifer Basin causes a lot of harm to the Palestinians and it is critical that appropriate institutions be created to implement the equitable and reasonable utilization of this source of water.

Socio-Economic Aspects

Water resources have strategic importance for socio-economic and agricultural development, improved welfare and public health, alleviation of poverty and improved food security. Growing pressure and lack of coordinated management of shared water and related land resources can result in loss of water resources, productive land and life-supporting eco-systems. In the absence of joint management there is risk of high social and economic costs and loss of resources and benefits. On the other hand, joint management should lead to identification of mutual opportunities for development and investments for socio-economic development with poverty alleviation, based on efficient and equitable utilization of shared water.

Environmental Aspects

Excessive pumping or mining of shared aquifers can cause adverse environmental impacts and harm all sharing parties by causing costly drop of water levels and possible water quality deterioration. Thus, growing dependence on shared water with lack of joint management of the shared water aquifers can result in loss of water resources, productive land and life-supporting ecosystems. In order to minimize environmental risk, and threats to terrestrial and freshwater ecosystems, operational Environmental Impact Assessment procedures for protection and monitoring of shared water should be developed and applied.

Hydrological Aspects

Sound management of groundwater resources clearly requires a thorough understanding of the hydrogeology of aquifers under consideration. Therefore, a unified and consistent knowledge base is a prerequisite for the management of shared aquifers. Without knowledge base one cannot estimate the resources of shared aquifers and assign resources between countries. The following data was extracted from either Israeli or Palestinian studies.

About one-third of Israel's water consumption, some 600 million m^3/year, of water is produced from the Upper Cretaceous aquifers (often referred to as the Mountain Aquifer). Groundwater recharged along the high ridges of the anticlinorial axis diverge into three directions along the structural slopes: to the west (so called Western Basin Aquifer) towards the Coastal Plain, to the east (so called Eastern Basin) towards the Jordan–Dead Sea trough, and to the north (so called Northeastern Basin) draining towards Valley of Jezreel. Groundwater flows from the recharge areas along the high ridges populated by the Palestinians across the 1967 "green line" boundaries into Israel. Groundwater in the three basins will be considered a transboundary water resource between Israel and the future Palestinian State, and in the light of general scarcity of water resources in the region, will be subject to contentious negotiations.

Groundwater resources of the main aquifers and basins juxtaposed against the overall consumption are shown in Table 1. The 6000 km^2 Western Mountain Basin extends from the Judean Desert northward to the Carmel Mountain foothills, and from near the center of the Mountain Belt westward to the Coastal Plain. The basin is underlain by a thick sequence of layered limestone, dolomite, chert, chalk, and marls of the Eocenian age, and the Upper Cretaceous Judea, and Mount Scopus Groups. Over a small percentage of the area in the west, these units are overlain by sand, gravel, and conglomerate of the Quaternary Kukar Group [2].

Table 1. Groundwater Resources and Overall Water Consumption [2]
(in million m^3/year).

Water Resources	Annual Recharge	Israeli Consumption	Settlements' Consumption	Palestinian Consumption	Total Water Consumption
Western Basin	366	344	10	22	376
North Eastern Basin	145	103	5	30	138
Eastern Basin	172	40	35–50	69	144–159
Gaza Coastal Aquifer	55	0	5–10	110	115–120

Precipitation recharges the groundwater system at an average volume of 366 million m^3/yr, along the crests of the Anticlinorium territory, which is the central axis of the Mountain Belt, populated traditionally by an overwhelmingly Palestinian majority. Groundwater flows from the recharge zones in a general westward and northward direction across the pre-1967 border toward Ras Elain and Timsah (Taninim) Springs, and well fields along the western edge of the basin in Israel. Groundwater is the principal source of freshwater and is supplied to wells and springs through fractures and caverns in two principal aquifers: the Turonian–Cenomanian age aquifer and the deeper Albian age (Lower Cretaceous) aquifer.

The Northeastern Basin is the northernmost part of the Mountain Belt delimited geomorphologically by the Valley of Jezreel. The basin covers an area of about 1044 km^2, and is underlain by a thick sequence of layered limestone, dolomite, chert, chalk, and marl of the Eocenian age Advat, and the Upper Cretaceous Judea and Mount Scopus Groups.

Groundwater is recharged by precipitation at an average volume of 145 million m^3/yr along the northern end of the Anticlinorium region, which is populated traditionally by an overwhelmingly Palestinian majority and flows generally in a northeast direction across the pre-1967 Israeli border. Groundwater is supplied to wells and springs by two principal aquifers: the Eocene aquifer and the Turonian–Cenomanian aquifer.

The Eastern Mountain Basin covers an area of about 3080 km^2 and includes the eastern part of the Mountain Belt and the steep Western Escarpment of the Jordan Rift Valley. Its entire area is within the West Bank territory, except for a sliver of 50 km^2 in Israel. The Jordan Rift Valley forms the eastern boundary of the basin. Groundwater is recharged by precipitation at an average volume of 172 million m^3/yr and flows generally in a southeastward direction toward the Jordan Rift Valley. Groundwater is the principal source of freshwater in the basin and is supplied to wells and springs by three principal aquifers: the Turonian aquifer, the Upper Cenomanian aquifer and the Lower Cenomanian aquifer [2].

Legal Aspects

International water law and international institutions must play a leading role in solving water conflicts and reducing the associated risks of conflict. International water law may be the acceptable basis of an agreement for the riparian of any basin.

In 1966, the International Law Association (ILA) adopted the Helsinki Rules on the Uses of International Waters of International Rivers; the set of articles represented one of the earliest attempts at codifying customary international law pertaining to transboundary water resources. In 1991, the International Law Commission (ILC), an organization created by the United Nations, developed the Helsinki Rules and completed the drafting and provisional adoption of 32 articles on the law of the Non-Navigational Uses of International Watercourses. In 1997, the United Nations General Assembly adopted a Convention on the Law of the Non-Navigational Uses of International Watercourses. It was opened for signature and ratification for three years. However, the Convention did not acquire the required number of ratifications.

Until recently, however, international law on the use of shared water resources has largely focused on surface water. Matters relating to shared aquifers have been relatively ignored. One reason for the negligence of groundwater is the inadequate understanding on the part of decision makers and legislators of the physical interrelationship between surface and groundwater resources and of groundwater as an integral part of the hydrologic cycle. Today, most legislators and decision-makers continue to regard groundwater sources as distinct from surface water sources with respect to ownership and usage. Therefore, they omit this resource from the legal regime of international water law. It follows that the first step in the evolution of the legal regime for groundwater is the acknowledgement of the interrelationship between surface water resources and groundwater.

International groundwater law and treaty practice are still young. There are only a few treaties and agreements that contain provisions dealing with groundwater at various multinational levels, namely, continent, region, and catchment basin and bilateral levels. Furthermore, there has been no international ruling on groundwater to date. However bodies, such as the ILA, are carrying out work. The ILA has produced some useful legal instruments, including the Helsinki Rules and the Seoul Rules. In recent decades, the sharing of groundwater resources has received the attention of the international community. This attention has resulted in comparatively rapid advances in groundwater law.

Most notable in the development of international law applicable to groundwater was in 1997 when the United Nations General Assembly adopted the Convention on the Non-Navigational Uses of International Watercourses. As a product of the United Nations, the Watercourse Convention constitutes the first official codification of international law applicable to groundwater resources. The Convention specifically includes groundwater within its scope by defining "watercourse" (the unit subject to regulation) as "a system of surface waters and groundwater constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus."

Despite this progressive development, a careful review of the Convention reveals that while the applicable rules and norms are reasonably developed, the types of groundwater subject to those norms are limited. In defining a watercourse,

the Convention provides strict criteria for determining whether one or another type of groundwater is encompassed by the Convention. As will be seen, the Convention fails to account for both the Mountain Aquifer and the Coastal Plain Basin.

The definition provides that only groundwaters that are part of a "system of surface waters and groundwater" and "constituting by virtue of their physical relationship a unitary whole" are encompassed by the Convention. This approach advocates a unitary or comprehensive management scheme of interconnected surface and groundwater. While self-limiting, it nonetheless acknowledges the important interrelationship of surface and underground water within the hydrologic cycle. When considered in the international context, it appears that for the Convention to apply, it is not necessary for a particular aquifer or for an interrelated surface body of water to traverse an international boundary so long as the system, or any one of its interrelated components (*i.e.*, an interrelated aquifer or river or lake), traverses or flows along an international border. Despite the expanse of the terminology, the definition also imposes very specific limitation on the scope of the Convention. In particular, it restricts the Convention only to "systems," and only to systems that have a "physical relationship" between the inter-linked components.

Based on these criteria, it appears that for an aquifer to be subject to international law, it must be physically related to a surface body of water [2]. This is further underscored by the definition, which specifically excludes from the Convention groundwater that is unrelated to any surface water. In comments attached to the draft Convention submitted to the United Nations, the Convention's drafters noted that "[i]t follows from the unity of the system that the term 'watercourse' does not include … groundwater … unrelated to any surface water" [3]. This intentional exclusion was rationalized on the basis that unrelated groundwater cannot have any untoward effects on any other watercourse [2].

Another definitional limitation under the Watercourse Convention lies in the phrase "flowing into a common terminus." The expression was included, in part, to provide a geographic limitation whereby two different watercourses connected by a canal could not be regarded as a single watercourse for the purposes of the Convention [3]. When applied to groundwater resources, however, the phrase further limits the types of shared groundwater that falls under the scope of the Convention. It specifically excludes groundwater flowing to a terminus different than that of hydraulically related surface water body. While not necessarily ubiquitous, this scenario is not uncommon. Moreover, the phrase probably excludes a single aquifer unrelated to any surface water since the term "common" implies there must be more than one water resource whose flow direction is being assessed.

Considering the above criteria, both the Mountain Aquifer and the Coastal Plain Basin would be excluded from the scope of the Watercourse Convention. While the Mountain Aquifer traverses the political border between Israel and the Palestinian Territory in the West Bank, it has no physical relationship with any surface body of water, and is, in fact, unrelated to any other identifiable water resource. The Mountain Aquifer, therefore, is not part of a "system of surface waters and groundwater and does not flow to a terminus common with another water resource."

Moreover, the aquifer flows toward three divergent termini — the water in each of the basins flows in a different direction — thus further excluding it from the definitional criteria for groundwater encompassed by the Convention.

Despite the non-applicability of the Watercourse Convention to the Israeli–Palestinian dispute over groundwater resources, there are other sources of international law that may provide guidance for addressing the dispute. There are now a growing number of examples in which riparian states use the waters of a shared aquifer. From these examples of state practice, as well as from generally accepted norms of international water law, concepts can be extrapolated to provide guidelines for the use, management, and conservation of shared groundwater resources. Of these guidelines, the most notable include the doctrine of hydrological unity, and the principles of equitable and reasonable use, no substantial harm, and good faith negotiations.

The international water law by itself is nonbinding and lacks enforcement mechanisms. This is true, but it may also be the "best we have got" as a guide for negotiations and contain "checks and balances" that, if approached in good faith, would protect the interests of all parties. Questions remain about the relative importance of these guidelines and means of enforcement [4, 5]. In some ways, the more challenging task for negotiators is to translate those guidelines into operating rules and procedures to determine the equitable apportionment of waters from shared water resources.

The principle of equitable allocation is one of the most important developed by ILA and the Helsinki statements. At the same time, it is one of the most difficult to define, given the multitude of variables that should be taken into account [1]. The principle of equitable allocation means that each basin state is entitled to a reasonable and equitable share in the beneficial use of shared water. "Equitable" does not mean equal use. Rather, it means that a large variety of factors, including population, hydrology, climate, existing uses, and so on, must be considered in the allocation of water rights. Table 2 lists the diverse factors that the International Law Association associated with equitable water use [3, 6].

Table 2. Factors Associated with Equitable Water Use.

Factor	Definition
F1	The geography of the basin, including in particular the extent of the drainage area in the territory of each basin state.
F2	The hydrology of the basin, including in particular the contribution of water by each basin.
F3	The climate affecting the basin.
F4	The past utilization of the waters of the basin, including in particular existing utilization.
F5	The economic and social needs of each basin state.
F6	The population dependent on the waters of the basin in each basin State.
F7	The comparative costs of alternative means of satisfying the economic and social needs of each basin states.
F8	The availability of other resources.
F9	The degree to which the needs of a basin state may be satisfied, without causing appreciable harm and substantial injury to a co-basin state.

It is to be noted that each factor is not to be considered in isolation, but looked at together with all the other factors, without any of them being given priority. This theory neither purports to identify fixed criteria in the sharing of international water, nor to protect existing water rights. Rather it aims at establishing a mechanism for cooperation and negotiation with a view to reaching an agreement [4].

While these guidelines offer a basis of law by which states are to conform their conduct, compliance is often subject to state interests and interpretation. What one state may consider equitable and reasonable, another state may think unjust. Thus, application of these principles to a specific dispute, such as that between Israel and the Palestinians, is best left to an unbiased tribunal or third party.

AN APPROACH FOR ALLOCATING THE WATERS OF THE MOUNTAIN AQUIFER

There has been much written in recent years about the application of water law in shared surface water, as well as the development of different allocation schemes based on the interpretation of these "laws" or using other criteria. These publications include Gleick [1], Caponera [4], Elmusa [5], and Mimi and Swalhi [7]. On the other hand, few have tried to apply the water law to shared groundwater, as has Moore [8]. The approach presented here provides one possible approach to the problem of allocating the waters of the shared aquifers underlying West Bank and Israel. The approach translates the principle of equitable utilization into a set of procedures to determine the riparians' entitlements to the shared Mountain Aquifer.

The nine equity factors (Table 2) were applied yielding alternative nine equity standards (Table 3). These equity standards served as benchmarks against which various possible allocation outcomes were measured. The equity factors and the derivation of the equity standards summarized in Table 3 are stated below.

It should be emphasized that the particular equity factors used in this research and their derivative allocation standards were selected for illustrative purposes only and are not claimed to be exhaustive; as many or as few factors as are deemed relevant can be incorporated into the approach. Moreover, the following numerical example is to demonstrate the workings of the decision tool. It is not claimed that the entitlements as calculated here are those that should be adopted in practice.

Table 3. Alternative Equity Standards (Share in Percent).

Equity Standard No.	F1	F2	F3	F4	F5	F6	F7	F8	F9
Palestine Share	89	51	82	18	32	40	96.6	70	32
Israel Share	11	49	18	82	68	60	3.4	30	68
Total	100	100	100	100	100	100	100	100	100

Factor F1 - Geography

The geography of the basin determines the amount of rainfall caught and, consequently, the total volume of ground water recharge and presents a measure of the inflow to the aquifers (influenced by such factors as the climate regime, topography, geology, soil characteristics, vegetation cover, and drainage network of the catchment). Thus, the proportion of the catchment area (feeding area) lying within each state represents only one measure of the inflow to the shared aquifers coming from these states. Table 4 presents one estimate of each riparians' share of the feeding area and the equity standard derived from this factor.

Table 4. Recharge Areas Lying within Israel and West Bank (km^2) [2].

Aquifer	Safe yield Mcm/y	Total recharge area	Recharge area within Palestine	Recharge area within Israel
Western Basin	366	1800	1400	400
North Eastern Basin	145	700	650	50
Eastern Basin	172	2200	2150	50
Total	683	4700	4200	500
F1 Equity Standard (Percent)		100	89	11

Factor F2 - Hydrology

The groundwater hydrology of the shared aquifers can be related to the storage area of each aquifer. Table 5 offers one estimate of the storage areas' contribution to the shared aquifers and the equity standard derived from this factor.

Table 5. Storage Areas Lying within Israel and West Bank (km^2) [2].

Aquifer	Safe yield Mcm/y	Total storage area	Storage area within Palestine	Storage area within Israel
Western Basin	366	2500	50	2450
North Eastern Basin	145	700	650	50
Eastern Basin	172	1950	1950	0
Total	683	5150	2650	2500
F2 Equity Standard (Percent)		100	51	49

Factor F3 - Climate

The climate affecting the basin is related to many climatic factors such as precipitation, evapotranspiration, temperature, and humidity that should be considered. In this research precipitation was considered as shown in Table 6 (other factors could be considered as well).

Table 6. Average Annual Rainfall over the Shared Aquifers (Mcm/y) [9].

Aquifer	Total rainfall on shared aquifer	Rainfall over Palestine	Rainfall over Israel
Western Basin	1042	761	281
North Eastern Basin	535	437	98
Eastern Basin approximation	1122	1020	102
Total	2699	2218	481
F3 Equity Standard (Percent)		82	18

Factor F4 - Utilization

Israel is currently the dominant user of the waters of the shared aquifers. Table 7 presents the existing utilization of the Jordan River basin and the equity standard derived from this factor.

Table 7. Overall Water Consumption of Shared Water Resources [2].

Water Resources	Israeli Consumption	Settlements' Consumption	Palestinian Consumption	Total consumption
Western Basin	344	10	22	376
North Eastern Basin	103	5	30	138
Eastern Basin	40	50	69	159
Total		552	121	673
F4 Equity Standard (Percent)		82	18	

Factor F5 - Economic and Social Needs

The economic and social needs of Palestinians and Israelis can be quantified by estimating the projected water demands form all sources for domestic, industrial, and agricultural sectors for both the two riparians as summarized in Table 8.

Table 8. Projected Water Demands (million m^3) [10, 11].

	Palestine	Israel	Total
Water demand for the year 2025 (million m^3)	1290	2800	4090
F5 Equity standard (Percent)	32	68	100

Factor F6 - Population

Palestine and Israel have a high rate of population growth that is likely to intensify freshwater conflicts in the future. A much higher population level will inevitably lower per capita water availability, which might exacerbate freshwater tensions in the region. Table 9 represents the projected population for both Palestine and Israel and the equity standard derived from this factor.

Table 9. Projected Population for the Year 2015 (millions) [12].

	Palestine Share	Israel Share	Total
Population 1998	2.7	6.0	8.7
Population 2015	5	7.6	12.6
F6 Equity standard (Percent)	40	60	100

Factor F7 - Comparative Costs of Alternatives

Alternative water resources refer specifically to sources such as desalination and imported water that are not presently exploited. The impact of these alternatives on the equation of equitable apportionment depends on their availability and comparative costs of harnessing them [5]. Both desalination and importation of water could be available alternatives since all riparian states have ground brackish water and enjoy sea front on the Mediterranean Sea. Moreover, there are numerous schemes that have been proposed for transporting water via pipelines and canals from the "water rich" countries in the Middle East like Turkey, to poorly endowed countries.

The comparative costs are a yardstick of the parties' ability to harness alternative resources. The party that is more capable of paying for water and tapping the desalination option than other riparian states would be entitled to a smaller share of the common waters (just within the confines of this factor). In this research, GDP was taken as measure of comparison to reach the equity standard as shown in Table 10. The Palestinians would be entitled to a larger portion of the common waters than Israel, proportional to GDP (GDP per capita for Israel is about 28 times higher than Palestine).

The comparative costs can be restated as the relative ability of the consumer to pay for higher priced alternatives supplies such as desalinated water. Based on the present consumer prices in all riparian states as well as on various estimates of desalination costs, the following can be inferred. In Israel, desalinated brackish and saline water is affordable for municipal use and economic for agriculture, while desalinated seawater is affordable for domestic use and may be economical for some crops. Palestinians would be heavily burdened by the costs of desalinated water [13].

Table 10. GDP for the Jordan River Basin Riparians (millions U.S. $) [12].

	Palestine Share	Israel Share	Total
GDP (1998)	3589	100525	
F7 Equity standard (Percent)	96.6	3.4	100

Factor F8 - Availability of Other Resources

Renewable water resources, water demands and Water Stress Index (WSI) for Israel and Palestine are presented in Table 11. The WSI is the ratio of water withdrawal or demand to water availability. The state that has less WSI would be entitled to a smaller share of the common waters (just within the confines of this factor). Accordingly, Table 11 was compiled to obtain the equity standard.

Table 11. Non-shared Renewable Water Resources and Water Demands for Israel and Palestine [10, 11].

	Palestine	Israel
Total non-shared renewable water resources (million m^3)	215	1104
Water demand for the year 2025 (million m^3)	1290	2800
WSI (for the year 2025)	600	254
F8 Equity standard (Percent)	70	30

Factor F9 - Appreciable Harm

The words "appreciable harm" have created definitional problems to all riparian states [5]. Goldberg [13] defined appreciable harm as the costs that can be objectively measured as result of denial of allocation. The implication of this factor is obvious: to achieve equitable division no riparian can deny water to a co-riparian if that denial causes appreciable harm. Water must be reallocated to stop the infringement. To assess the significant harm in this research, the following statement for the ILC cited in Goldberg [13] may be helpful: *"harm must be capable of being established by objective evidence. There must be a real impairment of use, i.e. a detrimental impact of some consequence upon, for example, public health, industry, property, agriculture, or the environment in the affected state."* In other words, appreciable harm can be gauged by its impact on the social, economic, and environmental needs. Accordingly, if the appreciable harm factor is broadened to focus on the social and economic needs, it will become effectively identical with Factor F5 (economic and social needs) discussed previously. Therefore, Factor F9 (appreciable harm) will have the same equity standards derived for Factor F5.

OPTIMAL ALLOCATION OUTCOME TO THE SHARED GROUND WATER RESOURCES

It could be argued that the equity factors discussed above should be given greater prominence when determining states' entitlements. But which factors? To answer this question, and to facilitate the development of a realistic weight for each factor, a questionnaire has been designed and sent to fifty water experts all over the world together with definition of the factors. The water experts, who work in water institutions, universities, and non-governmental organizations, include professional economists, irrigation engineers, water resources experts, and lawyers. The questionnaire summarized the international water law, the problem, and the approach of the research. The main task for the experts was to assign a weight for each of the nine equity factors (the summation of all weights should be one hundred). Twenty-nine experts responded and filled the questionnaire. There was no relation between the answers of the experts and their geographical location. Table 12 presents the average weight for each equity factor obtained from the collected answered questionnaires.

Returning to the nine alternative equity standards (Table 3), there is no manifestly "best" division of waters; the standards do not converge on any one particular allocation outcome. The task, then, was to identify that outcome which did the "least upset" to the nine equity standards taken together, *i.e.* to distinguish an optimal allocation outcome which, while not the best when measured against each equity standard in isolation, was the least worst of all outcomes when all nine were taken equally into account.

Each equity standard listed in Table 2 can be written as $F_i = (X_{i1}, X_{i2})$ that specifies the proportional shares of the shared aquifers allocated to the riparians, where i refers to the equity standard, X_{i1} represents the Israeli and X_{i2} the Palestinian shares. The sum of the two shares equals 100 percent. To illustrate, the first and second alternative equity standards can be written respectively as F_1 (11, 89) and F_2 (49, 51).

Any allocation outcome can be written as $X_j = (X_1, X_2)$ that specify the proportional entitlements of the shared aquifers allocated to the two riparians, where X_1 represents the Israeli and X_2 the Palestinian entitlements. The sum of the two entitlements equals 100 percent.

The optimal allocation outcome can be written as $X_j^* = (X_1^*, X_2^*)$ and can be defined as the one that minimizes the square of the summation of the distances (d) measured outward from itself to all equity standards. The objective function

Table 12. Weight of Alternative Equity Standards [1].

Equity Factor	F1	F2	F3	F4	F5	F6	F7	F8	F9
Average weight (percent)	16	15	10	16	10	7	14	10	2
Range	13–17	12–16	12–15	14–18	8–12	8–11	9–15	5–11	1–6

[1] Table compiled by the authors based on the collected questionnaires.

was derived (Equation 1) to satisfy the above stated criterion (minimizes the square of the summation of the distances). The mathematics of the objective function considered the weight of the equity factors.

$$\text{Minimized} = \sum_{i=1}^{9} W_i \sum_{j=1}^{2} (X_{ij} - X_j^*)^2 \tag{1}$$

where:

i = 1,…9 refers to the equity standards

j = 1,…2 refers to the riparian countries

d = square of the summation of the distances between the allocation outcome and the equity standards

X_j^* = the entitlements of the jth country from the shared water (percentage)

W_i = is the weight of the ith equity factor (percentage)

X_{ij} = is the share of the ith equity factor for the jth country (percentage).

To find the optimal allocation outcome (X_j^*) from set of possible allocation outcomes where the objective function has its smallest value (*i.e.* to optimize Equation 1), the point where the first derivative of the equation equals zero was found. Accordingly, the first derivative of Equation 1 was found and equaled to zero $\left(\dfrac{\partial d}{\partial X_j^*} = 0\right)$. This leads to Equation 2, which is the optimal solution of Equation 1.

$$X_j^* = \frac{\displaystyle\sum_{i=1}^{9} W_i \, X_{ij}}{\displaystyle\sum_{i=1}^{9} W_i}. \tag{2}$$

Applying Equation 2 to the Mountain Aquifer and based on Tables 3 and 12, the optimal allocation outcome specifies the proportional entitlements of the Jordan River basin waters allocated to the five riparians. The equation yields the following results (40%, 60%) where 40% represents the Israeli and 60% the Palestinian entitlements.

As noted earlier, the aim of this exercise is not to provide a definitive solution to the question of all riparians' entitlements. Rather, it is to demonstrate a methodology by which such entitlements can be calculated. Ultimately, the choice of standards to include is one for the negotiating parties themselves, should they decide to use this decision tool in support of their negotiations. In the final analysis it is only through direct negotiation that an eventual agreement can be reached and it is not the task of this paper to prejudge the outcome of that process.

CONCLUSIONS

The scarcity of water in the Jordan River basin makes water allocation one of the central issues to be resolved in the Arab–Israeli conflict. In this basin, the international water laws that regulate riparian rights are not well observed. This article calls for the application of the international water law that can play a positive role in the resolution of water disputes in the negotiating process.

The methodological approach presented in this paper may be one way of approaching the problem of water allocations of the Mountain Aquifer and hopefully will provide some input into the negotiating process. It may be controversial and raise many objections; however, it is presented as food for thought.

The procedures described in this paper for determining the optimal allocation outcome used nine operational definitions of the ILC equity factors; clearly, these definitions were not exhaustive. One of the first tasks for negotiators, therefore, is to define and utilize such other factors as are deemed relevant to this particular water sharing problem.

Assuming this methodology was adopted as a decision support tool in the context of the Middle East peace process negotiations, it would be up to the parties to decide which of the ILC equity factors are applicable to the Mountain Aquifer to determine the appropriate utilization of these factors. They may reject any or all the equity standards used in this analysis, or include others not considered here.

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5

Solids Removal in Upflow Anaerobic Reactors, a Review

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The article can be quoted as:

Mahmoud, N., Zeeman, G., Gijzen, H. and Lettinga, G. (2003) "Solids Removal in Upflow Anaerobic Reactors, a Review", Bioresource Technology, **90**: 1–9.

Solids removal in Upflow Anaerobic Reactors, A Review

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Abstract

This desk study deals with the mechanisms and parameters affecting particles separation from wastewater in mainly upflow anaerobic reactors. Despite the fact that the functioning of upflow anaerobic sludge blanket (UASB) systems depends on both physical parameters and biological processes, the physical parameters have been barely reported in the literature. The reason is that the underlying mechanisms are very complex and depend on various interrelated parameters. In addition, the lack of a serious attempt to gather the entire physical theme into one picture has resulted in just a superficial understanding of this field of science. Better understanding of the interaction and role of these parameters is essential for the development of anaerobic treatment technologies. In this study, the various parameters that might affect the solid liquid separation process by filtration through the sludge bed of a UASB have been elaborated. These parameters have been classified into (1) reactor operational conditions (temperature, organic loading rate, hydraulic retention time and upflow velocity), (2) influent characteristics (influent concentration, influent particle size and influent particle charge) and (3) sludge bed characteristics (particle size distribution, extracellular polymeric substances, and charge). The overall output of this study includes (1) a literature review, (2) structuring of this field of science, and (3) highlighting fields where research is needed.

Keywords: Anaerobic treatment; Charges; Extracellular polymeric substances (EPS); Hydraulic retention time (HRT); Organic loading rate (OLR); Physical characteristics; Particle size distribution (PSD); Solids removal; UASB; Upflow velocity

1. Background

The functioning of upflow anaerobic sludge blanket (UASB) systems depends on both physical parameters and biological processes, which determine the final removal efficiency and conversion of organic compounds. While the biological processes have been widely reported by the literature, the physical parameters and the physical–chemical mechanisms of solids removal have been scarcely reported. The mechanisms are complex and depend on various interrelated operational parameters. Better understanding of the interaction and role of these parameters is required for the development of anaerobic technologies. This desk study aims at investigating the mechanisms and parameters affecting the particle separation from wastewater, with the focus on upflow anaerobic reactors. The interactions of the various interrelated parameters and their relations to solids removal are discussed.

2. Parameters affecting solids removal in upflow reactors

Several parameters are likely to have an effect on particles removal in the sludge bed of a UASB. The major parameters are related to (1) reactor operational conditions (temperature, organic loading rate (OLR), hydraulic retention time (HRT) and upflow velocity), (2) influent characteristics (concentration, particle size distribution (PSD) and charges) and (3) sludge bed characteristics (PSD, exopolymeric substances, charges, sludge hold up). These parameters and their effects are discussed in the following paragraphs.

2.1. Reactor operational conditions

2.1.1. Temperature

Temperature affects the particles removal through influencing the wastewater viscosity and conversion of organic matter. The influence of temperature on the performance of classical filters "inert filtering media based filters" is discussed. The inert based filters have fixed bed and bioconversion is negligible as compared with biological filters like UASB.

2.1.1.1. Viscosity. It is often observed that the performance of classical filters, such as deep bed filter, and sedimentation tanks is better in summer than in winter, given comparable operational conditions (Metcalf and Eddy, 1991). The reason may be that increasing wastewater temperature decreases its viscosity, and consequently decreases the hydraulic shearing force on the particles. At low temperature, the viscosity of liquids will be higher, which implies that more energy is required for mixing in, for example, CSTR systems. In the treatment of water and wastewater the degree of mixing is measured by the velocity gradient, G. The velocity gradient is best thought of as the amount of shear taking place, the higher the G value the more turbulent the fluid. The velocity gradient is a function of the power input into a unit volume of water (Eq. (1)).

$$G = \sqrt{\frac{P}{\mu * V}} \tag{1}$$

where: G, velocity gradient (s^{-1}); P, power input (W); V, volume of water in the reactor (m^3); μ, dynamic viscosity (Pa s).

Eq. (1) was developed based on the idea that more power input creates more turbulence, which leads to better mixing (Metcalf and Eddy, 1991). Based on this equation, the effect of increasing the water temperature on the factor G and therefore the fluid mixing is calculated (Table 1).

The data presented in Table 1 reveal that increasing the wastewater temperature leads to more hydraulic turbulence in a reactor. Regarding upflow reactors where no forced mixing is applied, the upflow velocity and the gas production provide mixing. Increasing the wastewater temperature will not only enhance mixing by reducing viscosity, but also more biogas will be pro-

duced and hence much more turbulence would be expected. On one hand, increasing temperature will enhance the sedimentation and better contact between sludge and solids can be expected which could lead to better entrapment and adsorption. On the other hand, increasing temperature might lead to detachment of captured solids.

2.1.1.2. Conversion of entrapped solids. The rate of anaerobic conversion of complex organic matter is, in most cases, limited by the hydrolysis step (Pavlostathis and Giraldo-Gomez, 1991). Hydrolysis has mostly been described with first-order kinetics as shown in Eq. (2) (Eastman and Ferguson, 1981; Pavlostathis and Giraldo-Gomez, 1991).

$$\frac{dx_{\text{degr.}}}{dt} = k_{\text{h}} \cdot X_{\text{degr.}} \tag{2}$$

where: k_{h}, first-order hydrolysis rate constant (d^{-1}); $X_{\text{degr.}}$, biodegradable substrate (kg COD/m^3); t, time (d).

The hydrolysis rate constant is highly dependent on temperature, since hydrolysis is a biochemical reaction catalysed by enzymes, which are very sensitive to temperature (Sanders, 2001). The temperature effect on the hydrolysis rate constant can be described by the Arrhenius equation (Eq. (3)) (Veeken and Hamelers, 1999).

$$k_{\text{h}} = A \, e^{-E/RT} \tag{3}$$

where: k_{h}, hydrolysis rate constant (d^{-1}); A, the Arrhenius constant (d^{-1}); E, activation energy (kJ mol^{-1}); R, the gas law constant (J mol^{-1} K^{-1}); T, the absolute temperature (K).

It can be concluded that the operational temperature has a substantial effect on the conversion of organic matter and consequently the characteristics of the sludge bed. The results of Lawler et al. (1986) demonstrate the effect of anaerobic digestion on the PSD of sludges. When digestion works well, particles of all sizes are reduced with a special removal of small particles (conversion into gaseous form), i.e. the specific surface area will be reduced. When digestion does not work well, large particles are broken and small particles are created which results in a larger specific surface area. Therefore, the total surface area increases in the acidogenic stage and it decreases in the methanogenic stage. The surface area of the particles affects the physical behaviour of sludge, e.g. the dewaterability by providing frictional resistance to the withdrawal of water and a surface to which water can bind. Since, digestion affects the PSD of the sludge, the degree of digestion and hence the temperature and the sludge retention time (SRT) are expected to highly influence the sludge capacity for solids removal, i.e. filtration, in case of upflow reactors. Moreover, it is likely that a higher conversion rate will reduce the chance that a captured particle will be detached. On the other hand, at higher conversion rate

Table 1
Relation between temperature and turbulence in the reactor

Temperature (°C)	Viscosity (μ) of water in the reactor (Pa s)	% Increase of G from 15 °C (%)
15	1.14×10^{-03}	–
20	1.00×10^{-03}	7
25	8.90×10^{-04}	13
30	7.98×10^{-04}	19
40	6.53×10^{-04}	32

higher gas production is expected which might counteract the removal efficiency.

2.1.2. Organic loading rate

Several authors reported that up to a certain limit, the treatment efficiency of complex wastewaters, e.g. potato maize, slaughterhouse, in high rate anaerobic reactors increases with increasing OLR. A further increase of OLR will lead to operational problems like sludge bed flotation and excessive foaming at the gas–liquid interface in the gas–liquid–solid (GLS) separator, as well as accumulation of undigested ingredients. As a result, the treatment efficiency deteriorates (Sayed, 1987; Ruiz et al., 1997; Kalyuzhnyi et al., 1998). Also accumulation of biogas in the sludge bed was noticed, forming stable gas pockets that lead to incidental lifting of parts of the bed and a pulse-like eruption of the gas from this zone (Kalyuzhnyi et al., 1998; Elmitwalli et al., 1999).

The OLR can be varied by changing the influent concentration and by changing the flow rate (Eq. (4)). Changing the flow rate implies changing the HRT and the upflow velocity.

$$OLR = \frac{Q * COD}{V} = \frac{COD}{HRT} \qquad (4)$$

where: OLR, organic loading rate $(kg\,COD/m^3\,d)$; COD, chemical oxygen demand $(kg\,COD/m^3)$; Q, flow rate (m^3/d); V, reactor volume (m^3); HRT, hydraulic retention time (d).

When the solids removal efficiency in upflow reactors is related to the OLR, it becomes crucial to distinguish between these parameters. For this reason, OLR is an inadequate design parameter to assure good performance of anaerobic reactors. Increasing the loading rate by reducing HRT down to a certain value will reduce the solids removal efficiency, probably due to increasing of upflow velocity (see Table 2: cases I and II; Fig. 1). Since, increasing the influent concentration can increase the OLR, it becomes more essential to maintain an adequate upflow velocity to assure good mixing (Table 2: cases I and III; Section 2.1.4).

The undesirable phenomena, which manifest when treating wastewater with high-suspended solids, occur due to at least one of the following situations:
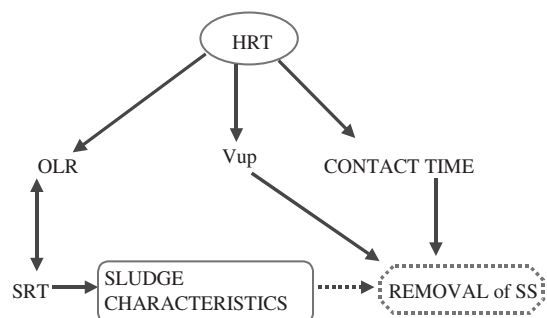

Fig. 1. The operational parameters which are expected to affect the solids removal in upflow reactor. Where: OLR, organic loading rate; SRT, sludge retention time; V_{up}, upflow velocity; HRT, hydraulic retention time; SS, suspended solids.

- High influent concentration; this will cause gas pockets formation, while the upflow velocity is low to create adequate turbulence in the sludge bed (poor mixing).
- Low HRT is accompanied by high upflow velocity (V_{up}), which will lead to wash out of influent solids and of viable biomass.
- High solids loading rate, which imposes low SRT, will change the sludge bed composition (microbial, physical, and chemical) and cause accumulation of floatable substances (proteins and lipids).

2.1.3. Hydraulic retention time/sludge retention time

Wang (1994) reported that, during anaerobic sewage treatment in a 170 m^3 hydrolysis upflow sludge bed (HUSB) reactor, HRT in the range (2.5–5 h) does not seriously affect the removal rate of the suspended solids. Differently, GonÇalves et al. (1994) show that the removal efficiency decreased with decreasing HRT accompanied by increase of upflow velocities (see Section 2.1.4). It might be argued that the HRT is an inadequate parameter for describing solids removal in upflow reactors (Fig. 1). The effect of HRT could manifest as a result of its direct relation to the liquid upflow velocity (V_{up}) and also to the solids contact time in the reactor and so the possibility of solids to coalesce or to be entrapped in the sludge bed. Moreover, the HRT is a major parameter, which determines the SRT (Zeeman and Lettinga, 1999). The SRT can indirectly

Table 2
Effect of changing OLR parameters on the removal efficiency (data compiled from Kalyuzhnyi et al., 1998) during anaerobic treatment of raw potato maize wastewater in a UASB reactor at 35 °C

	COD (g/l)	OLR (g COD/l d)	HRT (d)	V_{up} (m/d)	Reduction in treatment efficiency (%)
Case I	8.3	$4.37 \rightarrow 13.8$	$1.9 \rightarrow 0.65$	$0.34 \rightarrow 0.98$	$79 \rightarrow 67.1$
Case II	13.1	$5.24 \rightarrow 7.28$	$2.5 \rightarrow 1.8$	$0.25 \rightarrow 0.35$	$80 \rightarrow 80$
Case III	18	$3 \rightarrow 13.89$	$6 \rightarrow 1.25$	$0.11 \rightarrow 0.51$	$80 \rightarrow SF$

influence the solids removal as through changing of the physical–chemical and biological characteristics of the sludge bed in addition to biogas production.

2.1.4. Upflow velocity (V_{up})

The upflow velocity is one of the main factors affecting the efficiency of upflow reactors (Metcalf and Eddy, 1991; GonÇalves et al., 1994; Wiegant, 2001). The upflow velocity affects the sludge retention as it is based on the settling characteristics of sludge aggregates. Therefore, the upflow velocity could be a restrictive factor with respect to the required reactor volume when treating very low strength wastewater and wastewaters with high-suspended solids (Wiegant, 2001). The upflow velocity has two opposing effects. On one hand, increasing upflow velocity increases the rate of collisions between suspended particles and the sludge and thus might enhance the removal efficiency. On the other hand, increasing the upflow velocity could increase the hydraulic shearing force, which counteracts the removal mechanism through exceeding the settling velocity of more particles and detachment of the captured solids and consequently deteriorates the removal efficiency.

GonÇalves et al. (1994) treated sewage anaerobically at 20 °C in an upflow anaerobic reactor (no GLS) operated at upflow velocities of 3.2, 1.7, 1.6, 0.9, 0.75 and 0.6 m/h, corresponding to HRTs of 1.1, 2.1, 2.3, 2.8, 3.3 and 4.3 h, respectively. They showed deterioration of removal efficiency as upflow velocity increases, varying from a value of 70% SS removal at 0.75 and 0.9 m/h to 51% at 3.4 m/h. The removal efficiency at an upflow velocity of 0.60 m/h was, contradictory to these observations, only 60% because of starting of methane production due to increase of HRT and accordingly the SRT. An increase in up flow velocity from 1.6 to 3.2 m/h resulted in a relatively small loss in SS removal efficiency, from 55% to nearly 50%, which indicates the role of adsorption and entrapment (GonÇalves et al., 1994; Zeeman et al., 1996). de Man et al. (1986) found a significantly lower SS removal when the upflow velocity becomes higher than 0.50 m/h during sewage treatment in a granular sludge-UASB reactor. Wiegant (2001), however presented data summarised from literature revealing no significant clear trend in the solids removal at increasing the upflow velocity in the range of 0.50–1.50 m/h during sewage treatment in UASB reactors. These contradictory results might be explained by the occurrence of short-circuiting in the sludge bed (Wiegant, 2001).

The upflow velocity should be high enough to provide good contact between substrate and biomass, as it should be enough to disturb the gas pockets gathered in the sludge bed. The higher V_{up} is believed to facilitate the separation of gas bubbles from the surface of biomass (Hang and Byeong, 1990).

2.2. Influent characteristics

2.2.1. Influent concentration

Wang (1994) noticed, during the operation of a pilot scale HUSB, that fluctuation in the influent concentration from ∼180 to 700 mg COD/l at constant HRT of 2.5 h, resulted only in a slight variation in effluent COD. Consequently, the removal efficiency increased from 20% to 60%. Similar results were reported by Chernicharo and Machado (1998), Zeeman and Lettinga (1999) and Elmitwalli et al. (2000). It can be concluded that there is a certain lower limit in the effluent solids concentration. Therefore, reactor performance could be clearer if described not only in terms of removal efficiency but also in terms of influent and effluent characteristics. Actually the available knowledge, about effluent characteristics, is very limited, e.g. PSD, anaerobic and aerobic biodegradability and particles origin. In case the solids originate from the sludge, then the solids are stabilised, or from the influent itself then further technological development can enhance the solids removal efficiency.

The noticed increase of removal efficiency with increasing influent concentration could be due to at least one of the following reasons:

- Change in influent characteristics (increasing the percentage of settleable solids) as a consequence of for instance difference in the hydraulic regime of the wastewater stream, thus more turbulence in diluted streams and/or due to difference in the water ionic strength,
- Increase the collision opportunity of the influent solids with the sludge in the sludge bed,
- A certain amount of sludge washout that controls the amount of solids in the effluent, rather than the solids in the influent.

2.2.2. Influent particle size

There is no standard procedure to classify particles in wastewater as soluble, colloidal or suspended. Ødegaard (1999) defined the soluble fraction as the particles with a diameter $d < 1$ nm, the colloidal 1 nm $< d < 1$ μm, and the suspended with $d > 1$ μm. While, Wang (1994) considered the soluble, colloidal and suspended to have a diameter $d < 0.45$ μm, $0.45 < d < 4.4$ μm, and $d > 4.4$ μm, respectively.

The effluent quality from inert based filters is highly related to the influent characteristics (Landa et al., 1997). It is well known that the treatability of wastewater depends strongly on the size distribution of the contaminants, since rates of sedimentation, adsorption, diffusion, and biochemical reactions are all influenced by particle size (Levine et al., 1985; Kaminski et al., 1997). The settling velocity of particulate matter is roughly proportional to the square of the particle size in accor-

dance with Stokes' law (Eq. (5)) (Metcalf and Eddy, 1991).

$$V_s = \frac{g(\rho_s - \rho)\phi^2}{18\mu} \qquad (5)$$

where: V_s, settling velocity (m/s); g, acceleration due to gravity (m/s^2); ρ_s, density of particle (kg/m^3); ρ, density of water (kg/m^3); ϕ, diameter of particle (m); μ, dynamic viscosity (Pa s).

The pollutants that must be removed from wastewater are complex mixtures of particulate and soluble constituents (Levine et al., 1985; Lawler, 1997). The particles in raw domestic sewage range in size from less than 0.001 to well over 100 μm and the size in settled sewage is usually less than 50 μm (Levine et al., 1985). The specific size distribution of particulate organic matter in raw or settled municipal wastewater depends on several factors such as the nature of the community, climate, the length of the sewers and flow regime in there, and whether influent pumping is used (Levine et al., 1985). Ødegaard (1999) surveyed the contaminant distribution in Scandinavian countries (Sweden, Finland and Norway) and revealed that 70% of the organic matter of domestic sewage in these countries is suspended, 10–15% is colloidal and 15–20% is soluble.

Particle removal in filter media involves two distinct steps: transport and attachment (Fig. 2). The particle is firstly transported to the filter media by mechanisms such as diffusion, interception and sedimentation, before attachment takes place (Prasanthi, 1996). The transport mechanism of a particle is directly dependent on its size (Jackson, 1980; Levine et al., 1985; Kaminski et al., 1997). The removal efficiency of particles smaller than ~1 μm increases with decreasing size and is accomplished by diffusion (Jackson, 1980). While, the removal efficiency of particles $>\sim$1 μm, increases rapidly with particle size due to increase of gravitational force, in addition to interception and straining (Kaminski et al., 1997). However, once captured, they will be subjected to greater shearing forces with increasing particle size. The previous discussion explains why particles in the vicinity of 1 μm are very difficult to remove in filters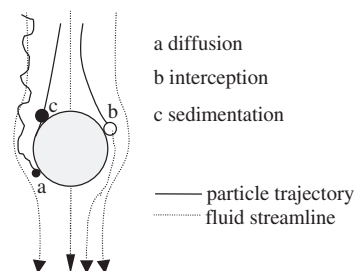 (Boller and Kavanaugh, 1995). Wang (1994) found that a high loaded UASB system, called the HUSB reactor, could remove the majority of the solids larger than 4.4 μm (expressed as the suspended COD), and only part of the smaller colloidal particles (expressed as COD colloidal).

2.2.3. Influent particle charge

Domestic sewage contains hydrophilic and hydrophobic particles. Roughly speaking, these particles consist of hydrophilic organic and hydrophobic inorganic colloids. The reason for the hydrophilic property of the organic colloids is that on their surface there are water absorbing or binding groups such as amino groups (–NH$_2$), hydroxyl groups (–OH) and carboxyl groups (–COOH) (Fig. 3). The charge of the hydrophilic particles is usually caused by dissociation of the ionisable end groups, while the charge of the hydrophobic particles is due to adsorption of anions from the water phase (Henze et al., 1995). Elmitwalli et al. (2001b) showed that particles in domestic sewage have a negative charge, which only slightly increases (less negative) as a result of digestion. The sludge solids are also negatively charged, which might partly justify the limitations of colloidal particles removal in a UASB system.

2.3. Sludge bed characteristics

The physical–chemical characteristics of the sludge bed play a central role in its capacity to remove solids. The interaction between digestion conditions, the sludge physico-chemical characteristics and solids removal is hypothesized in Fig. 4. These relations are discussed in the following subsections.

2.3.1. Particle size distribution

The effluent quality from classical filters is highly related to the specific size of the filtering media (Landa et al., 1997). Most studies indicate that smaller media size give more efficient removal. Meanwhile, this also could lead to more rapid head-loss development. Decreasing the media size increases the surface area, while decreasing the average pore diameter (Jackson, 1980). All these factors will tend to increase the removal efficiency, but this increase is counterbalanced by an increase in the hydraulic shear (Landa et al., 1997). The

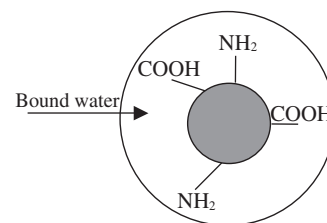Fig. 2. Transport mechanisms (adapted from O'Melia and Tiller (1993) and Stumm and Morgan (1996)).

Fig. 3. A colloidal hydrophilic protein particle surrounded by water (Henze et al., 1995).
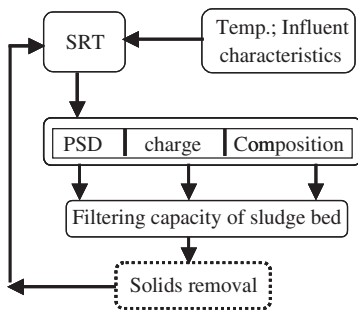
Fig. 4. Scheme of interaction hypothesis for physical removal of solids in a UASB reactor. Where: SRT, sludge retention time; PSD, particle size distribution.

effect of PSD on the performance of the upflow anaerobic sludge bed reactors is not yet clear.

2.3.2. Extracellular polymeric substances

Extracellular polymeric substances (EPS) are high molecular weight compounds produced by microorganisms under certain conditions. Such biopolymers are believed to originate from different sources: (1) biological synthesis and excretion and (2) lysis of bacterial cells (Morgan et al., 1990; FrØlund et al., 1996), and also from the adsorption of organic matter from the incoming wastewater, e.g. cellulose and humic acids (Urbain et al., 1993), on floc surfaces (Morgan et al., 1990). The chemical composition of the EPS matrix is reported to be very heterogeneous with carbohydrate and protein as the major compounds (Morgan et al., 1990; FrØlund et al., 1996). The components of EPS extracted from activated sludge were found to be different for plants with different process design (Eriksson and Alm, 1991; Urbain et al., 1993; FrØlund et al., 1994). Chemical composition of the EPS extracted from anaerobic sludge differs from activated sludge, with protein being the most dominant fraction in anaerobic samples compared with carbohydrate in the latter (Morgan et al., 1990).

Morgan et al. (1990) investigated the differences between biopolymers extracted from activated sludge, sludge from fluidised bed and anaerobic filter and UASB digested flocculent sludge and granules. The yield of extracted polymeric material was found to differ significantly depending on the nature of the sludge sample. All the anaerobic samples, in particular the digested and the granular, yielded significantly less EPS than the activated sludge. The samples from the fluidised bed, the anaerobic filter and the UASB reactors yield intermediary amounts of EPS compared with the activated sludge and granular sludge. Activated sludge samples produced 70–90 mg EPS/g SS compared with 10–20 mg EPS/g SS for granular sludge which is a remarkable difference.

Jia et al. (1996a) examined the EPS yields in four anaerobic sludges, using acetate, propionate, butyrate and glucose, respectively, as the sole enrichment substrate. Four series of culture enrichment experiments were conducted in 135 ml glass vials, which were operated at 21 days and kept at a temperature of 35 °C. Under steady-state conditions, the sludge content of EPS's protein (EPSp) and carbohydrate (EPSc) contents were measured. The results showed that acidogenesis of glucose produced more EPSp and EPSc than acetogenesis and methanogenesis. Harada et al. (1988) found that carbohydrate degrading UASB granules were larger and had higher mechanical strength than UASB granules degrading short chain fatty acids.

Harada et al. (1988) concluded from observation with electron microscopy that EPS excreted by acidogenic bacteria assist with cell-to-cell attachment and the enhancement of mechanical strength and structural stability. Elmitwalli et al. (2000) reported that the attachment of biomass and/or entrapment of solids to a reticulated polyurethane foam media, which had been used as a packing medium in an anaerobic filter, increased the colloidal particles removal efficiency. Sprouse and Rittmann (1991) showed that the growth of an anaerobic biofilm on granular activated carbon in a fluidised bed reactor enhanced solids removal. The excretion of EPS could be the main factor that promotes the solids removal in presence of a biofilm, since the EPS are believed to enhance the biosorption of particles (Dugan, 1987; Elmitwalli, 2000). Therefore, the EPS could increase the captured solids resistance for the shearing forces.

EPS are reported to affect several physical and chemical characteristics of activated sludge, like: dewaterability (Kang et al., 1990), floc charge (Horan and Eccles, 1986), floc structure (Eriksson and Härdin, 1984), settleability (Forster, 1985; Goodwin and Forster, 1985; Urbain et al., 1993) and flocculation (Ryssov-Nielsen, 1975; Brown and Lester, 1980; Rudd et al., 1983; Barber and Veenstra, 1986; Eriksson and Alm, 1991; Jia et al., 1996a; Laspidou and Rittmann, 2002). Also the granulation of anaerobic sludge (Jia et al., 1996a,b) and the anaerobic sludge charge (Morgan et al., 1990) are reported to be effected by EPS. The precise function of biopolymers in relation to bioflocculation and their effect on sludge physico-chemical characteristics are not fully understood (Morgan et al., 1990) and sometimes the reported research results are contradictory (Urbain et al., 1993).

EPS are thought to influence the dewatering characteristics of sludge by forming a charged surface layer on sludge particles (Poxon and Darby, 1997). The interactions of these polymers between cells allow adjacent bacteria to aggregate by bridging cell surfaces electrostatically and physically and therefore, initiate floc formation which allows the sludge settlement (Tenny and
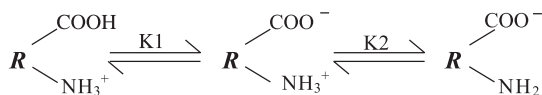
Fig. 5. Protolysis of functional amino and carboxyl groups (adapted from Stumm and Morgan (1996)).

Stumm, 1965; Morgan et al., 1990; Cloete and Steyn, 1988; Eriksson and Alm, 1991). Morgan et al. (1990) proposed that the chemical nature of the sludge surface will influence the measurable floc charge which itself affects the settling properties of the sludge.

2.3.3. Charges

The sludge surface charge is most likely a result of the EPS ionisable groups, such as amino groups ($-NH_2$), hydroxyl groups ($-OH$), carboxyl groups ($-COOH$) and/ or through the adsorption of ions from the water phase (Sutherland, 1984; Henze et al., 1995; Jia et al., 1996b; Stumm and Morgan, 1996). The charge of these groups depends on the nature of the groups and the pH (Marshall, 1967; Jia et al., 1996b; Stumm and Morgan, 1996). At neutral pH, functional groups such as carboxylic groups have a negative charge, while amino groups and the like have a positive charge (Fig. 5). Elmitwalli et al. (2001a) showed that particles in anaerobic sludge have a negative charge.

The sludge surface charge had been reported to influence many physical–chemical characteristics of sludge like: cation exchange potential (Flemming, 1995), sludge settleability (Forster and Dallas-Newton, 1980; Eriksson and Axberg, 1981; Steiner et al., 1976; Magera et al., 1976), dewaterability (Poxon and Darby, 1997) and viscosity (Forster, 1981).

The sludge surface charge most likely depends on sludge digestion conditions, since it is directly related to the quantity and composition of the EPS content. Magera et al. (1976) reported that the activated sludge surface charge is strongly dependent on the EPS chemical composition and concentration. Jia et al. (1996b) found in anaerobic batch reactors enriched solely by propionate, butyrate and glucose that the EPS and the surface negative charge of all enriched sludge were dependent on the microorganisms growth phase. Both increase when the microorganisms are in the prolific-growth phase, having high substrate concentrations and food to microorganisms (F/M) ratio and they both decrease when the microorganisms are in the declined-growth phase. The negative surface charge increased linearly with the total EPS content, in accordance with previous findings (Morgan et al., 1990). The increase of the EPS when the substrate is abundantly available had been widely reported for activated sludge as a result of increased anabolic activity (Magera et al., 1976; Gulas et al., 1979; Kurane et al., 1986a,b; Characklis and Marshall, 1990). Meanwhile, when the substrates

are utilized or the (F/M) ratio is low the bacteria metabolise the EPS for energy and/or carbon (Jia et al., 1996b). The EPS degradation under anaerobic conditions forming CO_2 and CH_4 was also reported (Ryssov-Nielsen, 1975). Using a colloid titration technique, activated sludges were found to be more negatively charged than granular sludges (Morgan et al., 1990).

Forster (1981) found by the means of electrophoretic mobility measurements that activated sludge particles have a higher mobility than anaerobic digested sludge. Consequently, the authors concluded that activated sludge will probably form an expanded matrix structure, while anaerobic sludge will be more packed with more particles per unit volume. The more highly charged particles are likely to form gel structures with poly-valent metal ions. Such a structure would have a high resistance to shear. On the contrary, Forster and Dallas-Newton (1980) found that if the negative charge of the floc surface was sufficiently large, repulsion might occur that would cause the sludge settling properties to deteriorate.

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6

WSI Updates

We must treat each and every swamp, river basin, river and tributary, forest and field with the greatest care, for all these things are the elements of every complex system that serves to preserve water reservoirs - and that represents the river of life….

Mikhail Gorbachev

The 2nd UN World Water Development Report, 2006

WSI NEWSLETTER

Workshops and Training

- Within the activities of the EMWater project and in cooperation with regional and international universities and institutions, the WSI at Birzeit University organized a regional conference on "Treatment of Wastewater and its Re-use" in the period 30 Oct. – 1 Nov. 2006 in Jordan. This regional conference is part of the "EMWater Project" funded by the European Union and partly by the German Government.

  A group of experts from Birzeit University participated in the conference: Ziad Mimi, Omar Zimmo, Isam Khateeb, as well as several masters students in the Masters Programs in Water and Environmental Engineering and Sciences.

Representatives from the WSI in the conference, Nov. 2006

During the last three years, the project conducted 4 regional studies on the water situation and the reuse of wastewater in Middle East countries, and were published as a technical book for research purposes. Also, (21) training programs were conducted in Middle East countries targeting 900 participants, in which female participation was outstanding and (70%) of the whole participants are working in the water sector.

Moreover 5 experimental stations for water distillation were established for research and training purposes in the Project's target countries: Jordan, Palestine, Lebanon and Turkey. In addition to the production of a video-tape (English, German & Turkish) to support public awareness and to be used as an educational tool in schools at the targeted countries, as well as producing a primary guide for "Policies and Standards for Re-use and Treatment of Wastewater" to be used by decision makers in Middle East countries.

- Within the activities of WaDImena project: "Social and Economic Assessment for Reuse of Treated Effluent from Al-Bireh Wastewater Treatment Plant in Irrigated Agriculture", a delegation from the WSI visited the Royal Scientific Society (RSS) in Amman-Jordan to attend a workshop on wastewater treatment plants during 4-8 March 2007. The Project is a joint effort between WSI and RSS, and is implemented by Birzeit University and funded by the International Development Research Center (IDRC)-Canada.

Photo for the delegation while visiting wastewater treatment plants in Jordan, March 2007

The delegation included representatives of the beneficiaries of the Project: Municipalities of Al-Bireh and Deir Dubwan; local societies such as: farmers, youth and women of Deir Dubwan, as well as the Palestinian Water Authority and Ministry of Agriculture. The delegation learned about the Jordanian experience in the recycling of reclaimed water for irrigation purposes and treated affluent water reclamation methods to secure safety. Moreover, the delegation undertook field visits to the treatment stations in (Ramtha, Mafreq, Madaba, and the University of Mu'tta in Karak), in addition to sites for the recycling of reclaimed water.

The delegation also participated in a workshop on "Integrated Water Resources Management" at RSS in which Dr. Rashed El-Saed presented paper on "Hygienic Assessment of Al-Bireh Reclaimed Waste Water for Industrial Crops Irrigation".

- In cooperation with the International Development Research Center (IDRC) and the German Agency for Technical Cooperation (GTZ), the Water Studies Institute (WSI) at BZU conducted a workshop on "Palestinian Experiences in the Re-use of Treated Wastewater in Agriculture" on June 2007.

Attendants in the workshop included representatives of Ministry of Agriculture, Palestinian Water Authority (PWA), Palestinian Hydrology Group, the Palestinian Agricultural Relief Committees, Al-Najah University, Applied Research Institute of Jerusalem, Birzeit Municipality, Al-Bireh Municipality, House of Water and Environment, Agricultural Cooperative Union, and Palestinian Wastewater Engineering Group.

Speakers in the Wastewater Reuse Workshop from WSI, GTZ and PWA, June 2007

Staff News

- Maher Abu-Madi participated in the "Regional Gray water Expert Meeting" that took place in Aqaba, Jordan in the period 11-15 February 2007. The meeting was held within the activities of WaDImena project under the auspices of the International Development Research Centre (IDRC), Canada, in conjunction with the Center for the Study of the Built Environment (CSBE), Jordan. The meeting gathered 33 experts from a range of public and private sector organizations, academic and research institutions, and those with a background experience in the MENA region. The purpose of this meeting was to bring together regional experts with experience in gray water to openly discuss and assess current experience and results, with a view to charting future priorities. At the end of the meeting, the experts formulated and signed a declaration that tackled:

* The state of the art of research and application on gray water treatment and reuse in the MENA region.
* The acceptance and promotion of gray water as a water demand strategy at a policy level.
* Feasibility of developing a network that would support efforts related to gray water in the MENA region.

* Highlighted findings and concrete recommendations for future research on gray water.

- Nidal Mahmoud conducted a training course entitled "Anaerobic Sewage Treatment" at the Water and Environment Center (WEC) of Sana'a University/ Yemen during the period 18-25 March 2007. The course was attended by 20 senior engineers in leading and influential positions from both governmental and non-governmental institutions. The short term training course presented scientific knowledge and practical information on the application of anaerobic digestion by UASB (Up flow Anaerobic Sludge Bed) for the treatment of municipal sewage and the recovery of energy (biogas), nutrient and water.

Dr. Nidal Mahmoud meeting the president of Sana'a University during his mission to WEC, Sana'a University (from left to right: Prof. Dr. Khaled Abdula Tamim, president of Sana'a University, Dr. Nidal Mahmoud, Water Studies Institute, Birzeit University, Prof. Dr. Abdullah Babaqi, WEC director, Sana'a University), March 2007

- Omar Zimmo attended the kick-off meeting for a new funded project by the European Commission and through the Fb6 Program - which is entitled: "Innovative processes and practices for wastewater treatment and re-use in the Mediterranean region (INNOVA): The meeting took place in Spain in the period 22-25 March 2007.

- Within the activities of PoWER Partnership, WSI - represented by Rashed Al Saed published the first three issues of PoWER Newsletter. The Newsletter is designed to enhance communication within the Partnership members and keep them current on the latest activities of the partners in education, research and training in the fields of water and sanitation.

- Ziad Mimi participated in the expert group meeting on Integrated Water Resources Management (IWRM) in the Arab region and the steering committee meeting of the Arab Water Networks (Wadi Hydrology Network, Ground Water Network and Water Ethics) that was held in Bahrain in the period 23-27 March 2007.

- Within the activities of PoWER Partnership, WSI – represented by. Maher Abu Madi and Ziad Mimi participated in the inspiring Training of Trainers Workshop on Innovation in Education which was conducted at UNESCO-IHE, Delft in the period 26–30 March 2007. The workshop included more than thirty participants from TIIWE (Taiwan), and NHRI-Nanjing (China), IITRoorkee (India), Birzeit (Palestine), UNPAR (Indonesia), Sana'a (Yemen), HRI (Egypt), Makerere (Uganda), UZ (Zimbabwe), KNUST (Ghana), Univalle (Colombia) and UNESCO-IHE. Special guests from AIT (Thailand), VWU (Vietnam), NBI-ATP (Egypt) and the SWITCH Project attended as well.

Participants in the Training of Trainers Workshop, Delft, March 2007

New Funded Projects

- The European Commission and through its Fp6 programs - has funded a new research proposal entitled: "Innovative Processes and Practices for Wastewater Treatment and Re-use in the Mediterranean Region (INNOVA)".
  The project's Consortium includes:

1. Consejo Superior de Investigaciones Científicas. (Spain), (The Coordinator)
2. National Research Institute for Agricultural Engineering, Water and Forestry, (Tunis)
3. Centre International des technologies de 1'Environnement de Tunis, (Tunis)
4. Birzeit University, (Palestine)
5. Palestinian Water Authority, (Palestine)
6. Suez Canal University, (Egypt)

7. Ankara Universities, (Turkey)
8. Institut Agronomique et Vetirinare Hassan II CHA Agadir, (Morocco)
9. Regie Autonome Multi-Services Agadir, (Marocco)
10. Centro de Investigaciones Energeticas, Medioambientales Tecnologicas, (Spain)
11. University of Natural Resources and Applied life Sciences, Vienna,(Austria)
12. Ecologic- Institute for International and European Environmental Policy, (Germany)
13. Europa Fachhochschule Fresenius, (Germany)

- The European Commission has funded a new proposal entitled: "Geographic Information System (GIS) - Curriculum Development and Training in Palestine".
  The partners in the project are:

1. Al- Quds University, (Palestine)
2. Birzeit University, (Palestine)
3. House of Water and Environment , Palestinian NGO, (Palestine)
4. Lund University, (Sweden)
5. University of Newcastle, (United Kingdom)

- The Arab Gulf Programme for United Nations Development Organization (AG-Fund) and through the House of Water and Environment Organization (HWE) - has funded a new research proposal entitled: "Environmental Assessment of Pollution Sources on the Water Environment and Palestinian Livelihood in the Northern West Bank, Palestine".

- The Arab Science & Technology Foundation (ASTF) and through House of Water and Environment Organization (HWE) - has funded a new research proposal: "Using Phytoremediation Techniques in Treating Groundwater Resources in Palestine".

Signing the consultancy contracts between WSI represented by Mr. Gassan Al – Khatib and HWE represented by Dr. Amjad Aliewi, April 2007

Coming Events

- Within the activities of the ProMembrane project and in cooperation with the Mediterranean Partner Countries (MPC) including the WSI, an international conference will be held in Sfax / Tunisia during the period 4 – 8 May, 2008. The conference aims at increasing the awareness on research activities carried out in the Mediterranean area, as well as the development of membrane technology in order to find solutions to the water scarcity of the region.

  The Conference will gather the most relevant actors in the membrane and water treatment field in the Mediterranean region. It is expected to attract a great number of participants from research institutions, universities, manufacturers, governmental authorities, end-users, specialists, as well as press and media representatives.

  Information about the conference can be found at the website: www.promembrane.info

New Defended Masters Theses

The following theses were successfully defended at the WSI from September 2006 to July 2007. Hard copies of the theses are available at the main library at Birzeit University.

NO.	TITLE	STUDENT NAME
1	Molecular Identification of Microbial Communities in Wastewater Treatment Systems	Rateb Hussein
2	Development of an Integrated UASB- Biofilter System for Domestic wastewater Treatment	Nimer Ibrahim
3	Groundwater Pollution Assessment of the North Western Auja Tamaseeh Basin (Tulkarm Area)	Nizar Samhan
4	Estimation of Runoff for Agricultural Watershed using SCS Curve number and GIS	Samah Jabari
5	Households' Affordability and Willingness to Pay for Water and Wastewater Services in Ramallah and Al-Bireh District, Palestine	Bisan Shunnar
6	Characterization of Household Wastewater Streams as a Tool for Pollution Control	Haitham Lahalih

Meeting with the alumni

Starting from this issue, the editorial team for the Birzeit Water Drops bulletin (BWD) has decided to include a new section in the bulletin under the name of "Meeting with the Alumni". This section is intended mainly to review the experiences and the scientific achievements of students and graduates in the Masters Programs in Water and Environmental Engineering and Water and Environmental Sciences at Birzeit University.

Guest. Corner: **Mrs. Basma Bashir**

Biography

Mrs. Bashir obtained her Bachelor degree in civil engineering from Birzeit University in 1985. Since then, she started to practice her role as a civil engineer in the field of civil construction despite the deteriorating political situation and outbreak of the Intifada in 1987, which reduced employment opportunities and imposed a number of restrictions on her work mainly as a woman.

In 1994, Mrs. Bashir had the opportunity to participate in a training session held at Birzeit University for five consecutive months on the theme: "Integrated Water Resources Management" under the auspices of the Dutch UNESCO-IHE Institute and Birzeit University. This was the beginning of her practical experience in the water and environmental sectors, enabling her at a later stage to work at the Applied Research Institute (ARIJ).

In mid 1995, she moved to work with the United Nations Development Program (UNDP) mainly in the Water Resources Action Program (WRAP), after which, she joined the Palestinian Water Authority (PWA). In 2002, she started her work with the Palestinian Hydrology Group (PHG) as a water specialist. During the same year and due to the continued Israeli incursions, and violations , it was impossible to obtain information related to the water sector, which strongly motivated the (PHG) to adapt the (WaSH MP) program – "Water and Sanitation, Hygiene Monitoring Program" - that deals with monitoring and controlling the Israeli violations in the water and environmental sectors, headed by Mrs. Bashir, In addition, and through the WaSH MP program, full surveys of population groups in the West Bank and Gaza Strip were conducted to collect information and provide the needed data to the concerned parties in the fields of water and environment locally and internationally in response to the needs of such communities.

**Joining the Masters Program in Water Engineering at Birzeit University**

Mrs. Bashir was awarded her masters degree in water engineering from the Water Studies Institute (WSI) at Birzeit University in 2003. When asked about her benefits from the master program, she

emphasized the importance of this program in her professional and academic life, since it nourished her with a comprehensive information about the water and environmental sectors. After graduation, Mrs. Bashir maintained good relations with the WSI, where she published a scientific paper in a refereed journal on her MA thesis entitled: "Rainfall Runoff Analysis and the Synthetic Unit Hydrograph for the Wadi Faraa Catchment". In addition, she obtained a training grant in Sweden on the theme: "Geographic Information Systems - GIS" through the TEMPUS project carried out by the WSI. This qualified her to teach the GIS course at the master programs. This has enriched her academic experience and opened new horizons for her in terms of dealing with students and researchers in the areas of water and environment.

Furthermore, Mrs. Bashir exhibited strong capacity to build effective relationships with individuals and institutions concerned in the water and environmental sectors by joining the master program that helped her to establish a voluntary network namely: "The Emergency Water and Sanitation, Hygiene Group (EWASH)", sponsored by the PHG. This network comprises a number of local and international institutions working in the water and environment domain, aiming at coordinating efforts to meet the needs of Palestinians pertaining to water and environmental information, exchanging experiences and saving efforts.

* More information about the EWASH network can be found on the website: www.phg.org/campaign.

At the end of the meeting, Mrs. Bashir expressed her pride for being one of the graduates of the masters program in Water Engineering valued the development of the two master programs: Water and Environmental Engineering and Water and Environmental Sciences, elucidating that it was a breakthough by the WSI.
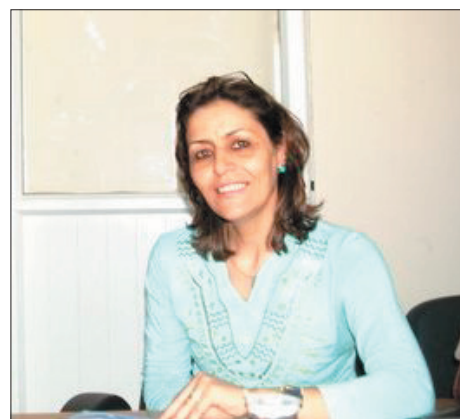
Mrs. Basema Bashir, Water Studies Institute, June 2007