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FORWARD

During the last four years, Water Studies Institute (WSI) Staff members together with MSc students have implemented many research studies and international joint projects and published their results as documents or articles in refereed international journals and local, regional and international conferences. Many of these publications may be inaccessible to interested readers in Palestine. Most works are excerpts from longer articles or documents; the editors' introductory notes to each article or document provide the context and source. In order to disseminate information and knowledge among water and wastewater professionals and water research students, WSI decided to publish Birzeit Water Drops (BWD).

Birzeit Water Drops is a series of bulletins that will be published quarterly and will include the Water Studies Institutes' publications, main findings of the MSc thesis and important activities.

The first issue of BWD includes the main activities of the WSI in the last year and 5 articles that have been published in international refereed journals, but obviously does not represent the only interesting and serious work been undertaken in WSI.

WSI at Birzeit University was established in September 2001, to offer and contribute to the capacity building of the Palestinian water sector by providing knowledge, advisory services, graduate education (MSc level), research and continuous education through short-term training in water and related issues. In addition, WSI is participating in solving crucial water problems within Palestine and the neighboring countries through research projects, consulting activities and joint regional and international activities.

Currently, the Institute's organizational structure comprises a director, an administrative assistant, and five fulltime PhD holders specialized in a multitude of water, wastewater, and environmental subjects. A number of individual experts from BZU's Faculty of Science as well as from local institutions are likewise affiliated staff members of the WSI.

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Education, training, research and consultancy for the planning, provision and
management in water and environmental sectors

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Sewage Characterization as a Tool for the Application of Anaerobic Treatment in Palestine

Nidal Mahmoud, Mohammad Naser Amarneh, Rashed Al-Sa'ed, Grietje Zeeman, Huub Gijzen and Gatze Lettinga

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Sewage Characterization as a Tool for the Application of Anaerobic Treatment in Palestine

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Abstract

Adequate knowledge on sewage characteristics is a prerequisite for selection and sizing of anaerobic treatment technologies, i.e. Upflow Anaerobic Sludge Blanket (UASB) systems. Composite sewage samples were collected from three locations in Ramallah/Al-Bireh district and analysed for several chemical and physical parameters, including samples fractionation into soluble, colloidal and suspended. The results revealed that the sewage in the study area is of very high strength. This is attributed to low water consumption, industrial discharges and people's habits resulting in a high specific COD production [gCOD per capita per day (gCOD/c.d)]. Simple model calculations revealed that the process conditions in a one stage UASB reactor should be modified to overcome the sewage high solids content and low temperature during wintertime.

Keywords: Anaerobic; Palestine; Sewage characteristics; UASB; Wastewater management

1. Introduction

(Waste)water management in Palestine had been neglected for decades (Daibes, 2000). Domestic and industrial wastewater used to be collected mainly in cesspools or, to a much lesser extent, in sewerage networks. In many of the Palestinian villages and refugee camps, black wastewater is collected in cesspools, while grey wastewater is discharged via open channels. The majority of the collected wastewater from the sewered localities is discharged into nearby valleys without being subjected to any kind of treatment. It is estimated that about 30% of the West Bank population is served with sewerage networks, but less than 6% is connected to treatment plants.

As the Palestinian society is facing heavy economical burdens, the application of conventional aerobic wastewater treatment technologies is too expensive and not providing a sustainable solution for environmental protection and resource conservation. Anaerobic digestion has been widely recognized as the core of sustainable waste management (Hammes et al., 2000; Zeeman and Lettinga, 1999), which has also been recognised by the Palestinian officials (PWA, 1998). The feasibility of the upflow anaerobic sludge blanket (UASB) reactor for sewage treatment has been successfully demonstrated in many tropical countries. Experience with the application of the UASB in the Middle East countries however is still limited (Zeeman and Lettinga, 1999). The main factors dictating the applicability of anaerobic technologies for domestic wastewater treatment are the sewage temperature and the characteristics and concentration of the pollutants in this sewage (Lettinga et al., 1993). Also, knowledge about the wastewater characteristics is necessary for the design and operation of treatment facilities (Metcalf and Eddy, 1991) and to determine the

sequence of treatment systems (Levine et al., 1991). The treatability of wastewater depends strongly on the size distribution of the pollutants, since most treatment processes—physical, chemical or biological—for treatment of wastewater contaminants depend on particle size distribution (Levine et al., 1985; Ødegaard, 1999). Meanwhile, the characteristics of sewage in the West Bank, Palestine have not been subjected to good analysis [Applied Research Institute—Jerusalem (ARIJ), 1997].

This research aims at increasing the knowledge on sewage characteristics and the conceptual assessment of the technical applicability of the UASB reactor as a core technology for sustainable sewage treatment in the Middle East region, i.e. Palestine.

2. Materials and methods

2.1. Study area

Three locations were chosen for this study, all situated in the "Ramallah/Al-Bireh" district area, which is located in the central part of the West Bank and considered as one of the most important administrative centres in Palestine. Ramallah and Al-Bireh are the main urban centres for commerce and services with small and medium scale industries. According to the last census carried out by the Palestinian Central Bureau of Statistics (PCBS, 1997), the population of Ramallah and Al-Bireh are 18,017 and 27,972 inhabitants, respectively. The third location that was selected is Al-Jalazoon refugee camp, which lies about 6 k north from the centre of Ramallah and Al-Bireh, and has a population of 6144 inhabitants (PCBS, 1997).

According to the records of JWU (2000; the water supplying company), the average billed water consumption per capita is 103 l/d for the total area. The consumption for the two cities Ramallah and Al-Bireh is higher amounting to 137 l/c.d, while for Al-Jalazoon, this is only 51 l/c.d.

Sewage from Ramallah and Al-Bireh is collected in sewer systems, serving about 75% of the population. The remainder is collected in septic tanks or cesspools. The treatment plant in Ramallah, which consists of aerated lagoons followed by stabilisation ponds, is overloaded and poorly maintained. The recently built treatment plant of Al-Bireh is an oxidation ditch. In Al-Jalazoon, sewage is mainly collected in open channels running along the sides of the camp's streets and discharged to down stream wades without any kind of treatment.

3. Sampling

Samples were collected from the sewerage outfall of the three study locations: Al- Bireh City, Ramallah City and Al- Jalazoon refugee camp. Time–interval composite samples were collected every 2 h from 10:00 to 16:00 on Saturday, Tuesday and Thursday for 3 weeks in September 2000. Samples of 4 l were collected from the mentioned locations; 1-l grab sample was gathered from each location for each cycle and combined in 4-l plastic containers. All samples were preserved during the sampling time by storing them in special insulated boxes at 4 °C.

3.1. Analysis

Total suspended solids (TSS), volatile suspended solids (VSS), ammonium (NH_4^+–N), kjeldahl-nitrogen Nkj, total PO_4–P, dissolved PO_4^{3-}–P and SO_4^{2-}–S were all determined according to standard methods (APHA, 1995). Raw samples were used for measuring total COD (CODt), 4.4 μm folded paper-filtered (Schleicher and Schuell 5951/2, Germany) samples for paper filtered COD (CODp) and 0.45 μm membrane-filtered (Schleicher and Schuell ME 25, Germany) samples for dissolved COD (CODdis). The suspended COD (CODss) and colloidal COD (CODcol) were calculated as the difference between CODt and CODp and the difference between CODp and CODdis, respectively. Carbohydrates in raw, paper-filtered and membrane-filtered samples were determined photometrically according to the method described by Bardley et al. (1971) with glucose as standard. VFA were determined in membrane-filtered samples by gas chromatography. The chromatograph (Hewlett Packard 5890A, Palo Alto, USA) was equipped with a 2 m × 2 mm (inner diameter) glass column, packed with Supelco port (100–120 mesh) coated with 10% Fluorad FC 431. Operating conditions were: column, 130 °C; injection port, 200 °C; flame ionisation detector, 280 °C. N_2 saturated with formic acid at 20 °C was used as a carrier gas (30 ml/min). Settleable solids were measured after settling for 30 min in an Imhoff cone (Metcalf and Eddy, 1991). Biodegradability of raw samples was measured in 500 ml working volume batch reactors incubated at 30 °C for a period of 60 days. Each batch was filled with 450-ml wastewater, and mineral solution contains macro and mico nutrients and a buffer. The mineral composition inside the batch reactors was: *Macro nutrients* (g/l): NH_4Cl, (0.28); $MgSO_4.7H_2O$, (0.1); K_2HPO_4 (0.25); $CaCl_2.2H_2O$, (0.01); yeast extract (0.05); $NaHCO_3$ (2.5); *1 ml/l trace elements containing (g/1)*: $FeCl_2.4H_2O$ (2), H_3BO_3 (0.05), $ZnCl_2$ (0.05), $CuCl_2.2H_2O$ (0.038), $MnCl_2.4H_2O$ (0.5), $(NH_4)_6Mo7O_{24}.4H_2O$ (0.05), $AlCl_3.6H_2O$ (0.09) $CoCl_2.6H_2O$ (2), $NiCl_2.6H_2O$ (0.092), $Na_2SeO_3.5H_2O$ (0.164); resazurin (0.2); EDTA $C_{10}H_{16}N_2O_8$ (1); 36% HCL (1.0 ml/l). COD total was measured at the beginning and the end of the batch period. All samples were analysed in duplicate.

Sewage temperature was measured in situ for each grab sample by an alcohol thermometer. The ambient

temperature was measured with an alcohol thermometer placed at the Al-Bireh sewage treatment plant. Sewage temperatures during the other sampling period have been measured four times during January, February and March—winter 2000. Colour was determined by visual appearance.

3.2. Calculations

- 1 g protein, assumed as $(C_4H_{6.1}O_{1.2}N)x$ is equivalent to 0.16 g Nkj–N, 0.16g NH_4–N and 1.5 g COD (Sanders, 2001)
- 1 g carbohydrates (assumed as $C_6H_{12}O_6$) is equivalent to 1.07 g COD (Sanders, 2001)
- Biodegradability (BD) = $100 \times (COD_{t,\ t=0\ day} - COD_{t,\ t=60\ day}) / COD_{t,\ t=0\ day}$

4. Results and discussion

4.1. Sewage characteristics

4.1.1. General observations

The results presented in Table 1 elucidate two main observations on sewage characteristics of the study locations. Firstly, the sewage of the three locations are classified of high strength, since, the mean values of COD, Nkj, phosphorus, sulphate, ammonia, TSS and VSS are very high according to the sewage strength classification proposed by Metcalf and Eddy (1991) and Henze (1997) and as compared with sewage characteristics in several countries in Europe, Asia and Latin America (Table 2). Secondly, the sewage characteristics of Al-Bireh City and Al-Jalazoon refugee camp are very similar and of domestic type, while they differ from those of Ramallah City which has much higher pollutant concentrations. The Ramallah sewage characteristics are highly influenced by industrial discharges which can clearly be observed in the measured parameters (COD, carbohydrate, TSS, VSS, protein, sulphate concentrations and high wastewater temperature), and also from visual observation of the colour variation of each collected grab sample during the same sampling day due to discharges of dying factories, food and beverage industries.

4.1.2. Anaerobic biodegradability

The anaerobic biodegradability of the sewage of the three locations measured after 60 days are presented in Table 1. Unfortunately, the test period was far too short for achieving a stabilisation of organic matter. Elmitwalli et al. (2001) found that the sewage biodegradability of Bennekom village in The Netherlands was 21% after 43 days and increased to 74% after 135 days at 30 °C. Likewise, Kerstens (2001) found high biodegradability of 76% (after 130 days' incubation at 33 °C) of the sewage of Amman City, Jordan which is, from a socio economic point of view, very close to the Palestinian cities. The previous discussion indicates that, the biodegradability of Ramallah, Al-Bireh and Al-Jalazoon wastewater is much higher.

4.1.3. Size fractionation of COD

The results of COD fractions of the three locations are presented in Table 1. The results reveal that the main fraction of COD is particulate, as the suspended, colloidal and dissolved fractions of COD of all studied areas are in the ranges 49–58%, 15–22% and 25–35% of the total COD, respectively. In view of that, the percentage particulate COD (colloidal and suspended) of total COD for Ramallah, Al-Bireh and Al-Jalazoon is 65, 75 and 71%, respectively. Wang (1994) found that the COD fraction of the particles exceeding 0.45 μm in domestic sewage represents about 70% of the total COD. Levine et al. (1985) found also that the COD fraction of the particles larger than 0.1 μm is in the range of 30–85% of the total amount of organic materials present in the pre-settled sewage.

4.1.4. Size fractionation of carbohydrate

The results of the carbohydrate fractions for the three locations are presented in Table 1. The suspended, colloidal and dissolved carbohydrate fractions are in the range of 36–74, 9–12 and 17–52% of the total carbohydrates, respectively. The suspended carbohydrate forms the major fraction for Al-Bireh and Al-Jalazoon, while the dissolved form is the major fraction in Ramallah sewage. This can be explained by the existence of food industries in Ramallah such as Coca-Cola and chocolates, which discharge their wastewater in the municipal sewer system. Likewise, Elmitwalli (2000) showed that carbohydrate is mainly present in the suspended form in the domestic sewage of the village of Bennekom, The Netherlands.

4.1.5. Volatile fatty acids

The results of VFA and COD ratios presented in Table 3 show that around 35% of the dissolved COD are in the VFA form for Al-Bireh and Al-Jalazoon, and 27% for Ramallah. The results also show that around 25% of the total COD in Al-Bireh and Al-Jalazoon are present in hydrolysed form and a higher value of around 40% for Ramallah. The acidified fraction is around 10% for all three locations.

4.1.6. Nkj–N, NH_4^+–N and proteins

The Nkj–N values for Ramallah and Al-Bireh are nearly the same, but it is lower for Al-Jalazoon (Table 1). Comparing the values of Nkj–N and NH_4^+–N showed that the NH_4^+-N is the major fraction of Nkj–N. In addition, the results presented in Table 4 reveal that the highest protein content exists in Ramallah

Table 1
Sewage characteristics of Ramallah City, Al-Bireh City and Al-Jalazoon refugee camp[a]

Parameters	Samples	Ramallah		Al-Bireh		Al-Jalazoon	
		Range	Average	Range	Average	Range	Average
COD Total	8	1518–3812	2180 (663)	1411–1844	1586 (125)	1092–1773	1489 (251)
Suspended	8	545 – 1925	1096 (456)	720–1209	919 (157)	518–990	725 (153)
Colloidal	8	107– 525	323 (101)	171–362	274 (52.4)	213–440	327 (71.3)
Dissolved	8	468–1482	761 (297)	280–464	393 (62.3)	258–613	438 (113)
Carboh. Total	5	100–231	178.4 (52.6)	99–166	131 (22.8)	59–155	93.5 (32.7)
Suspended	5	45–90	64.1 (20.2)	67–132	97.4 (25.3)	28–88	44.8 (21.3)
Colloidal	5	10–35	21.6 (10)	9–14	11.7 (1.8)	4–14	9.9 (3.7)
Dissolved	5	37–157	92.6 (55.4)	17–37	22.2 (7.4)	15–60	38.8 (17.3)
VFA as COD	2	175–199	187 (12)	155–162	160 (3.1)	100–145	123 (25.4)
Nkj as N	6	54–119	99.4 (23.2)	85–122	104 (14.7)	53–83	71 (10)
NH_4^+ as N	8	47–72	58 (8.5)	72–89	80.1 (5)	40–77	56.2 (9.5)
Proteins[b]			388		224		139
Total PO_4 as P	3	10–15	12.8 (2.2)	11–14	13 (1.5)	11–18	15 (2.4)
PO_4^{3-} as P	5	6–17	12.4 (3.8)	8–15	12.9 (2.6)	8–14	11.9 (2.4)
SO_4^{2-} as SO_4^{2-}	4	474–2060	975 (742)	129–151	138 (9.9)	143–277	213 (57)
TSS	5	510–1096	729 (197)	610–824	736 (67)	408–1048	630 (234)
VSS	5	255–892	584 (209)	492–676	617 (66.1)	364–733	480 (148)
Settleable solids	7	4–105	43.5 (41.1)	8.5–13.5	10.9 (2.2)	1.2–8	2.9 (2.4)
pH	4	7.18–8.02	7.45 (0.39)	7.16–7.44	7.26 (0.13)	7.11–7.58	7.31 (0.2)
T_{ww} Summer	8	26–40	30.9 (3.19)	24–27	25.8 (0.67)	20–25	23.4 (1.52)
Winter	4			12–13	13.13 (0.63)		
$T_{amb.}$ Summer	8			21–33	27.1 (3.17)		
Winter	4			11–17	13.8 (2.75)		
Biodegradability (%)	2	46–49	47 (1.4)	34–40	36 (3.2)	32–35	33 (1.5)
Colour	8	Reddish to black		Medium brown		Light brown	

[a] Standard deviations are presented between brackets. All parameters have been measured in duplicate and their units are in mg/l except settleable solid in ml/l; wastewater temperatures (T_{ww}) and ambient temperature (T_{amb}) (°C); pH no unit; Biodegradability (%); Proteins mg COD/l.
[b] Calculated.

Table 2
Sewage characteristics of different cities in different countries and continents[a]

Parameter	Palestine Al-Bireh[b]	Jordan, Amman[c]	Egypt rural areas[d]	Turkey, Istanbul[e]	The Netherlands, Bennekom[f]	Brazil, Campina Grande Pedregal[g]	Columbia, Cali[g]
CODt	1586	1183	824.9	410	528	727	267
CODss	919	608	–	–	225	–	–
CODcol	274	174	–	–	156	–	–
CODdis	393	401	270.2	140	147	–	112
VFA–COD	160	104–177	–	–	55	–	–
NH_4^+–N	80	80	26	30	48	34	17
Nkj–N	104	109	33.8	43	70	44	24
Total P	13	–	8.9	7.2	18	11	1.3
PO_4^{3-}–P	12.9	–	3.87	4.5	14	8	–
Lipids-COD	–	443	302	–	–	–	–
Protein-COD	224	272	–	–	–	–	–
TSS	736	420	310	210	–	492	215
VSS	617	330	277	145	–	252	108
VSS/TSS	84	79	89	70	–	51	50
Temperature		16–24	–	–	8–20	24–26	24.4–25

[a] All parameters are in mg/l except: temperatures (°C); VSS/TSS ratio.
[b] This study.
[c] Kerstens (2001).
[d] Tawfik (1988).
[e] Orhon et al., 1997.
[f] Elmitwalli, 2000.
[g] Haandel and Lettinga (1993).

Table 3
Percentages of hydrolysis and acidification of total COD and acidification of dissolved COD and VSS/TSS and CODss/VSS ratios for the sewage of Ramallah and Al-Bireh cities and AL-Jalazoon refugee camp-Palestine

	Parameter	Ramallah	Al Bireh	AL-Jalazoon
Acidified fraction	VFA/CODt	10	10	9
Acidified of dissolved	VFA/CODdis	27	36	35
Hydrolysed fraction	CODdis/CODt	39	28	25
	VSS/TSS	80	84	76
	CODss/VSS	1.88	1.49	1.51

Table 4
Percentages of carbohydrates, proteins and VFA out of total COD for domestic/municipal wastewater of Ramallah, Al-Bireh cities and AL-Jalazoon refugee camp-Palestine and Bennekom village, The Netherlands

Parameter	Ramallah	Al-Bireh	AL-Jalazoon	Bennekom, The Netherlands[a]
Carb-COD/CODt	8.8	8.9	6.7	12
Protein-COD/CODt	18	14	9	44
VFA/CODt	10	10	9	9
Sub total COD	36.8	32.9	24.7	65

[a] Elmitwalli (2000).

wastewater followed by Al Bireh and the lowest concentration is found in Al-Jalazoon wastewater. This might be justified by the presence of the main district (chicken) slaughterhouses in Ramallah City.

4.1.7. Total phosphorus and ortho-phosphate

The measured values of both total phosphorus and ortho-phosphate are presented in Table 1. The results show that the values of total phosphorus are approximately equal to the values of ortho-phosphate for the three locations, which is in conformity with Butler et al. (1995).

4.1.8. Sulphate

The sulphate concentration in the sewage of the three studied locations (Table 1) is very high according to the classification proposed by Metcalf and Eddy (1991). This especially applies for Ramallah where the sulphate concentration range is 474–2060 mg/l. The reason for that is the presence of several industries consuming large quantities of sulphur and sulphuric acid, especially a number of dyeing factories. The water consumption records of the JWU reveal that the water consumption of the dying factories in Ramallah City during the year 2000 was 108,000 m^3, which represented around 10% of the total water consumption of the city. The major problem associated with the anaerobic treatment of sulphate-rich wastewater is the production of sulphide. Since sulphide can lead to several problems such as toxicity, bad smell, corrosion, deteriorated quantity and quality of the biogas and reduction of the COD removal efficiency. In practice, anaerobic treatment always proceeds successfully for wastewater's with chemical oxygen demand (COD) to sulphate ratios exceeding 10. At COD/sulphate ratios lower than 10, process failures of anaerobic reactors have been reported (Hulshoff Pol et al., 1998). Accordingly, the high sulphate content of Ramallah sewage might suppress its anaerobic treatment as the COD/sulphate ratio can be as low as 0.74. Nevertheless, calculation of the maximum possible H_2S production reveals that the H_2S will always be below the IC_{50} concentration (50% inhibition concentration) of 250 mg H_2S–S, which indicates the occurrence of only partial inhibition during anaerobic sewage treatment. Moreover, the high sulphate content is harmful to the sewerage system. As H_2S gas may be oxidised to H_2SO_4 that causes damages to cement containing constructions such as manholes and pipes (Metcalf and Eddy, 1991).

4.1.9. TSS and VSS

The TSS and VSS values of the three locations are high (Table 1). The results presented in Table 3 reveal high values of VSS/TSS for the three locations. Apparently, the data presented in Table 2 indicate that the VSS/TSS ratios of sewage in Palestine, Jordan and Egypt are high in comparison with Turkey, Brazil and Columbia. This might be due to difference in people's habits. The high CODss/VSS of Ramallah wastewater indicates high lipids content, possibly due to discharge of slaughterhouses wastewaters.

4.1.10. COD mass balance

The results presented in Table 4 indicate that a high fraction of biodegradable COD should be lipids (25–50% of total COD is estimated to be lipids) as proteins, carbohydrates and lipids are the main biopolymers in sewage (Levine et al., 1991). This is obvious from the low values of COD subtotal and the large difference when we compare the subtotal COD in the studied areas with the sewage of Bennekom, The Netherlands. However, the sulphide COD was not accounted for.

4.1.11. Grey wastewater

Regarding Al-Jalazoon refugee camp, it was believed that only grey wastewater is disposed in the open channels (Amarneh, 2001). This study shows that Al-Jalazoon wastewater is of high strength and is similar to Al-Bireh wastewater COD. The high content of NH_4^+–N and Nkj in the sewage of Al-Jalazoon indicates the discharge of black wastewater with the grey water. The sulphate is originating from the drinking water (~55 mg SO_4^{2-}/l), proteins and the detergents, which contains sulphate rich compounds like sodium lauryl sulphate, ammonium sulphate, etc.

4.1.12. Specific waste production

The calculated specific waste production for Ramallah and Al-Bireh cities in terms of COD, N and P are presented in Table 5. In order to obtain a reference waste, the household waste production, source and composition for some countries (Germany, Denmark and Sweden) compiled from several literature sources by Henze (1997) are presented in Table 6, in addition to other data for the Dutch society (Kujawa-Roeleveld et al., 2000). The data in both tables show that the COD specific waste production in the waterborne waste of Ramallah and Al-Bireh is substantially higher than the reference wastes (Table 6). These values are as high as the total (solid and waterborne) specific waste of the reference countries and in Ramallah it can even be two times higher. This suggests that the high COD content of sewage in Palestine and other countries in the Middle East, like Jordan (Table 2), is not only due to low water consumption, but also due to industrial discharges (Ramallah) and/or people's habits. Discarding the remaining food and used cooking oil in kitchen sinks is believed to play a central role in increasing sewage strength in Palestine. Henze (1997) shows that the application of 'clean tech cooking' can reduce the COD load of grey water from 55 gCOD/c.d to 32 gCOD/c.d.

The data in Table 6 show that kitchen waste contributes around 35% to the COD content of the household traditional waterborne wastes, and can even be much higher in cases where more solid waste is directed to the sewer system. The COD content of wastewater can be significantly reduced by separating part of the kitchen wastes [clean tech cocking described by Henze (1997)] and toilet wastes (Zeeman and Lettinga, 2001; Henze and Ledin, 2001; Henze, 1997). Likewise, separation of the toilet wastes (physiological wastes) from the waterborne route will lead to a significant reduction in nitrogen and phosphorous. The N specific waste production of Ramallah and Al-Bireh is similar to the reference wastes. The P specific waste production is similar to Holland, but different from those reported for Denmark, Sweden and Germany. Moreover, the presented data reveal that 77–85% and 47–60% of the waste waterborne N and P content originates from urine.

Table 5
Specific production (g/c.d) and composition of waterborne household wastes in Ramallah and Al-Bireh cities, Palestine

	Ramallah	Al-Bireh
COD	166–418	155–202
N	5.9–13.0	9.3–13.4
P	0.7–1.9	0.9–1.6

Notes: calculated based on billed water consumption of 137 l/c.d of which 80% ends up in the sewer system (Nashashibi and van Duijl, 1995) and the measured parameters shown in Table 1. Pollutants due to industrial discharges are neglected

4.2. Application of the UASB reactor in Palestine

The final removal efficiency and conversion of organic compounds to methane gas in UASB systems depend on both physical and biological processes. For sewage, removal of suspended solids occurs by physical processes like settling, adsorption and entrapment. The subsequent hydrolysis and methanogensesis of the removed solids depends on the process temperature and the prevailing sludge retention time (SRT). Zeeman and Lettinga (1999) developed a model for the calculation of the HRT when a certain SRT is a pre-requisite [Eq. (1)].

$$HRT = (C\ ^{*}SS/X)^{*}R^{*}(1\text{-}H)^{*}SRT \quad (1)$$

Where,
HRT: hydraulic retention time
C: COD concentration in the influent (g COD/l)
SS: fraction of the influent suspended solids
X: sludge concentration in the reactor (g COD/l); 1 g VSS = 1.4 g COD
R: fraction of CODss removed
H: fraction of removed solids that are hydrolysed
SRT: sludge retention time (days)

Table 6
Production and composition of total (solid and waterborne) and traditional total waterborne household wastes, g/c.d for some countries in western Europe)

Param.	Denmark, Sweden and Germany[a]						Holland[b]
	Total		Source of waste				Total
	Solids and water-borne	Water-borne	Physiological total (urine)	Kitchen, liquid	Wash and bath	Kitchen solids	Water-borne Total (physiological <urine>)
COD	220	130	75	45	10	90	102 (56)
N	13.3	13	11 (10)	1	1	0.3	12.9 (12.5<11>)
P	4.5[c]	2.5[c]	2 (1.5)	0.2	0.3	2	1.7 (1.4<0.8>)

[a] Henze (1997).
[b] Kujawa et al. (2000).
[c] The phosphorous load from the washing of clothes will be increased by some extra 1–1.5 g P/c.d, if phosphate rich detergents are used (Henze, 1997).

The previous model was used for the calculation of the required HRT for the application of a one-stage UASB reactor for sewage treatment in Al-Bireh City. The following input data were taken into consideration:

$R = 0.80$, Mahmoud (2002) found around 80% suspended COD removal efficiency in a UASB operated at $V_{up} = 0.50$ m/h; $R = \frac{\text{CODss influent} - \text{CODss effluent}}{\text{CODss influent}} \times 100\%$

$H = 0.15$; 15% of the TS are hydrolysed at process conditions of 15 °C and 75 days SRT [winter conditions] (Elzen and Koppes, 2000)

$X = 15$ g VSS/l = 21 g COD/l

SS = 0.58, (this study)

$C = 1.586$ g COD/l (this study)

SRT = 30 days, expected minimum SRT to achieve methanogenic conditions during winter time (Elzen and Koppes, 2000)

Accordingly, the model calculation revealed that a minimum HRT of 22 h is required for the application of a one-stage UASB reactor in Palestine to overcome the wintertime. The calculated HRT is long in comparison with HRTs generally applied in tropical countries (6–12 h). The long HRT to be applied is due to the high concentration and the relatively low temperature in winter. It is worth mentioning that we have recently researched (Mahmoud, 2002) a novel technology consisting of a high loaded UASB integrated with a digester with sludge re-circulation to solve the technical applicability of the UASB system in the Middle East during the short period of winter. Promising results have been obtained which showed that the UASB-digester system could be successfully operated at a much lower overall equivalent HRT. In this system, the influent suspended solids are partially captured in the UASB reactor and conveyed to the digester, which is operated under optimal process conditions with respect to temperature and SRT. The methanogen enriched digested sludge is recirculated to the UASB reactor to improve the methanogenic capacity of the UASB reactor, and thus methanogenize the influent VFA.

5. Conclusions and recommendations

The results of this study reveal that the sewage in Palestine is characterised by high strength and solids content. Accordingly, the application of a one-stage UASB reactor in Palestine is only possible if designed at a prolonged HRT due to low solids hydrolysis during wintertime. However, reform in the household sanitation habits will reduce the solids content, and therefore, influence the selection of the proper treatment technology. In addition, the factories should apply a pre-treatment step before discharging their wastewaters in the municipal sewerage system. This highlights the urgent need for issuing an environmental act and enforcing the implementation of environmental regulations. On the other hand, those industries that use high amounts of sulphate can recover the sulphur element, which will reduce the treatment cost via application of the concepts of cleaner production.

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References

Amarneh, M., 2001. The Role of Wastewater Characteristics on the Selection of Anaerobic Treatment Technology. MSc thesis, Birzeit University, Palestine.

APHA, 1995. Standard Methods for the Examination of Water and Wastewater, eighteenth ed.

Applied Research Institute—Jerusalem (ARIJ), 1997. The Status of Environment in the West Bank. Bethlehem, Palestine.

Bardley, R.A., Krone, R.B., Asch, M., 1971. Shearing effects on the settling of activated sludge. J. San. Eng. Div. Proc. Am. Soc. Civ. Eng. 97, 59–79.

Butler, B., Friedler, E., Gatt, K., 1995. Characterizing the quantity and quality of domestic wastewater inflows. Water Sci. Technol. 31 (7), 13–24.

Daibis, F., 2000. Towards sustainable development in the water sector: a perspective from Palestine. Water Sci. Technol. 42 (1–2), 81–86.

Elmitwalli, T., Soellner, J., Keizer, A., de Bruning, H., Zeeman, G., Lettinga, G., 2001. Biodegradability and change of physical characteristics of particles during anaerobic digestion of domestic sewage. Water Res. 35 (5), 1311–1317.

Elmitwalli, T., 2000. Anaerobic treatment of domestic sewage at low temperature. PhD thesis, Department of Environmental Technology, Wageningen University, Wageningen, The Netherlands.

Elzen, J. den Koppes, J., 2000. Controlling Scum Formation During Anaerobic Sewage Treatment Under Middle East Conditions, MSc thesis, Department of Environmental Technology, Wageningen University, Wageningen, The Netherlands.

Hammes, F., Kalogo, Y., Verstraete, W., 2000. Anaerobic digestion technologies for closing the domestic water, carbon and nutrient cycles. Water Sci. Technol. 41 (3), 203–211.

Henze, M., 1997. Waste design for households with respect to water, organics and nutrients. Water Sci. Technol 35 (9), 113–120.

Henze, M., Ledin, A., 2001. Types, characteristics and quantities of classic, combined domestic wastewaters. In: Decentralised Sanitation and Reuse; Concepts, systems and implementation. Eds. Piet Lens, Grietje Zeeman & Gatze Lettinga. IWA publishing.

Hulshoff Pol, W.L., Lens, P.N.L., Stams, A.J.M., Lettinga, G., 1998. Anaerobic treatment of sulphate rich wastewater. Biodegrad 9, 213–224.

Jerusalem Water Undertaking (JWU), 2000. Records of Jerusalem Water Undertaking Files. Ramallah, Palestine.

Kerstens, S., 2001. Anaerobic wastewater treatment of strong sewage, one stage and two stage systems, MSc thesis, Department of Environmental Technology, Wageningen University, Wageningen, The Netherlands.

Kujawa-Roeleveld, K., Zeeman, G., Lettinga, G., 2000. DESAH in grote gebouwen. EET-KIEM nr 98115 rapport (in Dutch).

Lettinga, G., de Man, A., Last, A.R.M., Wiegant v. der, W., Knippenberg, K., Frijns, J., van Buuren, J.C.L., 1993. Anaerobic treatment of domestic sewage and wastewater. Water Sci. Technol. 27 (9), 67–73.

Levine, A.D., Tchobanoglous, G., Asano, T., 1985. Characterisation of the size distributions of contaminants in wastewater: treatment and reuse implications. J. Water Pollut. Control Fed., 57 (7) 805–816.

Levine, A.D., Tchobanoglous, G., Asano, T., 1991. Size distributions of particulate contaminants in wastewater and their impact on treatability. Water Res., 25 (8) 911–922.

Mahmoud, N., 2002. Anaerobic Pre-treatment of Sewage Under Low Temperature (15 °C) Conditions in an Integrated UASB-Digester System PhD thesis, Department of Environmental Technology, Wageningen University, Wageningen, The Netherlands.

Metcalf and Eddy, 1991. Wastewater Engineering-treatment, Disposal, Reuse, third ed. McGraw Hill.

Nashashibi, M., van Duijl, L.A., 1995. Wastewater characteristics in Palestine. Water Sci.Technol. 32 (11), 65–75.

Ødegaard, H., 1999. The influence of wastewater characteristics on choice of wastewater treatment method. Proc. Nordic Conference on: Nitrogen Removal and Biological Phosphate Removal, Oslo, Norway, 2–4 February, 1999.

Orhon, D., Ateo, E., Sözen, S., Çokgör, E.U., 1997. Characterization and COD fractionation of domestic wastewaters. Environ. Pollut. 95 (2), 191–204.

Palestinian Water Authority (PWA), 1998. Strategy for Water Management in Palestine (Draft).

Sanders, W.T.M., 2001. Anaerobic Hydrolysis During Digestion of Complex Substrates. PhD thesis, Department of Environmental Technology, Wageningen University, Wageningen, The Netherlands.

Tawfik, A., 1998. Wastewater Treatment for Rural Areas and Small Communities and Reuse for Irrigation and Aquaculture. MSc thesis, Tanta University, Egypt.

Wang Kaijun, 1994. Integrated Anaerobic and Aerobic Treatment of Sewage. PhD thesis, Department of Environmental Technology, Wageningen University, Wageningen, The Netherlands.

Zeeman, G., Lettinga, G., 1999. The role of anaerobic digestion in closing the water and nutrient cycle at community level. Water Sci. Technol., 39 (5) 187–194.

Zeeman, G., Lettinga, G., 2001. Objectives of DESAR-Decentralised Sanitation and Reuse. 30. Abwassertechnisches Seminar 13. DECHEMA-Fachgespräch Umweltschutz DESAR Kleine Kläranlagen und Wasserwiederverwendung. Berichte aus Wassergüte- und Abfallwirtschaft. Technische Universität München, Germany.

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Comparison between Algae-Based and Duckweed-Based Wastewater Treatment:Differences in Environmental conditions and Nitrogen Transformations

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Comparison Between Algae-Based and Duckweed-Based Wastewater Treatment:Differences in Environmental Conditions and Nitrogen Transformations

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ABSTRACT

In a laboratory batch experiments, duckweed (*Limna gibba)*-based and algae-based wastewater containers have been monitored during 15 days of incubation in two experiments with different initial total nitrogen concentrations of 50 (experiment 1) and 100 mg-N/L (experiment 2). Clear differences in environmental conditions were observed. High dissolved oxygen (DO) concentrations were observed in algae-based compared to duckweed-based containers. In algae-based containers DO range was between 2.1 to 6.6 mg/L and 1.2 to 4.3 mg/L in experiment 1 and 2 respectively. Whereas for duckweed-based containers DO ranged between 1.1 to 3 mg/l and 0.5 to 2.1 mg/L. Higher pH values were measured in algae-based due to algal photosynthetic activity compared to duckweed-based containers where duckweed mat prevented sunlight penetration and hence algal development. In algae-based, pH range was between 7.9 to 8.6 and 8.1 to 8.4 in experiments 1 and 2 respectively, and 7.3 to 7.5 and 7 to 7.6 in duckweed-based containers. Depending on initial nitrogen concentrations, duckweed-based containers removed between 42%-62% of total nitrogen and between 56%-95% of Kjeldahl nitrogen from the wastewater, while algae based containers removed between 45%-48% and 48%-58% of total nitrogen and Kjeldahl nitrogen respectively. Nitrogen loss, probably due to denitrification and ammonia volatilisation, represents 40% of the total nitrogen content of algae-based and duckweed-based containers. However in duckweed-based containers only 28% of N-loss were observed in containers with higher initial N-content. This study demonstrates that there were differences in environmental conditions in algae-based and duckweed-based containers, which have caused differences in nitrogen transformation mechanisms.

KEYWORDS

Algae, duckweed, environmental conditions, nitrogen removal, nitrogen transformations, wastewater treatment.

INTRODUCTION

Sustainable technologies for wastewater treatment, within the economical and technological capabilities of developing countries, need to be developed. These technologies should aim to reuse not only water but also the nitrogen content. Both conventional waste stabilisation ponds (WSP) and duckweed covered ponds offer possibilities for nitrogen reuse, either through effluent irrigation or through animal feed production. Conventional waste stabilisation ponds are inexpensive and are known for their ability to achieve good removal of pathogens and organic pollutants. Effluent from WSP characterised with high algal concentrations of about 200 mg TSS/L, cause severe clogging problems in advanced (drip) irrigation systems (Pearson *et al*., 1995).

Duckweed based ponds (DBP) are stabilisation ponds with floating mat of small plants introduced to the pond surface. These small plants are generally called duckweed. Different studies have shown that duckweed systems are capable of treating wastewater (Alaerts *et. al.*, 1996; Reddy and DeBusk, 1985). The advantage of duckweed systems for nutrient recycling and utilisation is based on the high growth rate of duckweed (Hillman, 1961; Landolt, 1986) and its high protein content of up to 40% of plant dry weight (Rogers *et al.*, 1978; Culley *et al.*, 1981; Mbagwu and Adeniji, 1988). A DBP systems might have several advantages over WSP systems: algal blooms are prevented by the presence of a duckweed mat, while nitrogen in the water can be effectively reduced by regular harvesting of the duckweed biomass. Three different mechanisms, apart from duckweed uptake, have been reported in literature for nitrogen removal in ponds system: ammonia volatilisation, ammonia assimilation into algal biomass and biological nitrification coupled with denitrification. However, it is not clear which process is responsible of more nitrogen loss. As far as we, know there are no studies comparing algae and duckweed wastewater treatment systems for nitrogen transformations and removal efficiencies. This study was designed to find out the differences in the environmental conditions in algae and duckweed wastewater treatment containers and to compare the differences of both systems in nitrogen transformations and removal efficiencies.

MATERIALS AND METHODS

Experimental set-up

Two batch experiments (1&2) with different initial total nitrogen concentrations (50 and 100 mg N/L respectively) were conducted to determine the differences in environmental conditions and nitrogen transformations in algae-based and duckweed-based containers. Two batches, of wastewater taken two days apart, from the effluent of the anaerobic pond at the pilot plant at Birzeit University, were used. Nitrogen content of wastewater was adjusted to the desired nitrogen concentration by adding NH_4Cl. Physico-chemical characteristics of wastewater used in experiment 1 & 2 are shown in Table 1.

TABLE 1: Physico-chemical characteristic of wastewater used in experiment1 & 2.

Parameter	Experiment 1	Experiment 2
Kj-N (mg/L)	51	98
NO_3^--N (mg/L)	0	0
COD (mg/L)	298	333
Total-P (mg/L)	2.23	2.93
pH	7.9	7.9
DO (mg/L)	0.2	0.2
Temperature (^oC)	19.5	19.5

Duckweed-based containers were commenced with 25.5 g fresh weight of *L. gibba* which resulted in a density of 400 g fresh weight/m^2 or 17.5 g dry weight/m^2. Algae containers were seeded with algae to a final concentration of 10 mg/L that were centrifuged from the stabilisation ponds at the pilot plant at Birzeit University. The increase in initial nitrogen and phosphorus content by the algae matter was assumed to be negligible (maximum 1% and 3% based on the assumption that the nitrogen and phosphorus contents of algae are 5% and 1% of the dry weight respectively). This represents approximately 1.0 and 0.5% of the designated initial nitrogen concentration of 50 and 100 mg/L respectively. Three replicates of plastic

containers for each treatment (12-litre volume, 28.5-cm diameter and 30-cm depth) were used as containers for incubation. The experiments were conducted at the laboratory conditions (20°C) and containers were illuminated with metal halide lamps with a photoperiod of 12 hours. The light intensity was 6200 Lux. Water loss by evaporation from algae-based and evapotranspiration from duckweed-based containers was compensated for by addition of de-mineralised water (approximately 100 ml/container every 2 days). Each experiment was subsequently monitored for the period of incubation. Duckweed was harvested once at the end of the fifth day and duckweed density was restored to its initial value of 400 g fresh weight/m^2.

Sampling and analysis

Dissolved oxygen (DO), pH and temperature in containers were measured in the afternoon, approximately 8 hours after starting the light period. DO was measured using DO175 (HACH), while temperature and pH values were measured using EC10 pH meter (HACH). Water samples were taken every two days at 9:00 a.m. from mid depth of each container since analysis revealed that there was no significant difference of nitrogen concentration at different depth of the container. Kjeldahl-nitrogen (N_{kj}), total nitrogen, nitrite (NO_2^--N), COD and total-P were analysed according to standard methods (APHA, 1992). Nitrate (NO_3^--N) was analysed according to advanced water quality laboratory procedures manual by HACH. Fresh and dry weight (after drying at 70 °C for two days) measurements of duckweed were done at the beginning (typical representative samples), during harvesting and at the end of each experiment. Samples from dried duckweed were analysed for nitrogen and phosphorus tissue contents using titrimetric method (APHA, 1992) after peroxide digestion according to Novozamsky *et al.*, (1983). Nitrogen content in sediments were measured after collection and drying at 70 °C for two days using titrimetric method after digestion as described for duckweed. Removal coefficients for total nitrogen (Kj-N + NO_3^--N) and total-P were fitted using the exponential equation $y = z \times e^{(-k \times t)}$ where z is the intercept, k is removal coefficient day^{-1} and t is the time in days. Removal rates of duckweed were calculated based on the surface area of container.

Nitrogen mass balance

For duckweed-based containers, the following nitrogen mass balance equation was used:

$$N_i = N_f + N_s + N_{dw} + N_{loss} \text{ (mg-N/container)}$$

Where N_i is the initial nitrogen content of wastewater, N_f is the final nitrogen content in the wastewater, N_s is the nitrogen content in the sediment, N_{dw} is the nitrogen content in duckweed and N_{loss} is the nitrogen loss due to denitrification and ammonia volatilisation. For algae-based, similar mass balance equation was used but without the component of N_{dw}. Similar equations for phosphorus mass balance were used.

RESULTS AND DISCUSION

Only trivial differences were observed in temperature in duckweed and algae-based. The average temperature was about 20 °C in algae-based and duckweed-based containers in experiment 1 and 2. Clear difference in dissolved oxygen (DO) and pH values were observed in algae-based and duckweed-based containers (Fig. 1&2). In algae-based the range of DO was between 2.1 to 6.6 mg/L and between 1.2 to 4.3 mg/L in experiment 1 and 2, respectively, and between 1.1 to 3 mg/l and 0.5 to 2.1 mg/L in duckweed-based containers. The absence of algae in duckweed-based containers due to the shading provided via duckweed mat led to a reduction of DO levels. Oxygen production from suspended algae was absent, whereas the duckweed mat may reduce oxygen diffusion from the air into the water phase. Duckweed might supply some

oxygen to the water via transport of oxygen through the root zone (Moorhead and Reddy, 1988) but this contribution is expected to be minor. The high pH values that are usually observed in algae-based due to algal photosynthetic activity did not occur in duckweed-based containers. In algae-based, pH range was between 7.9 to 8.6 and between 8.1 to 8.4 in experiments 1 and 2, respectively, and between 7.3 to 7.5 and between 7 to 7.6 in duckweed containers.

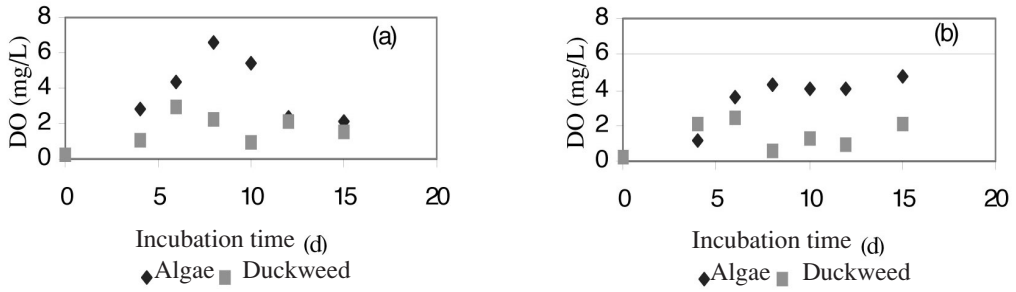


Fig. 1: DO concentrations (mean of three replicates) with time of incubation of experiment 1 (a) and experiment 2 (b).

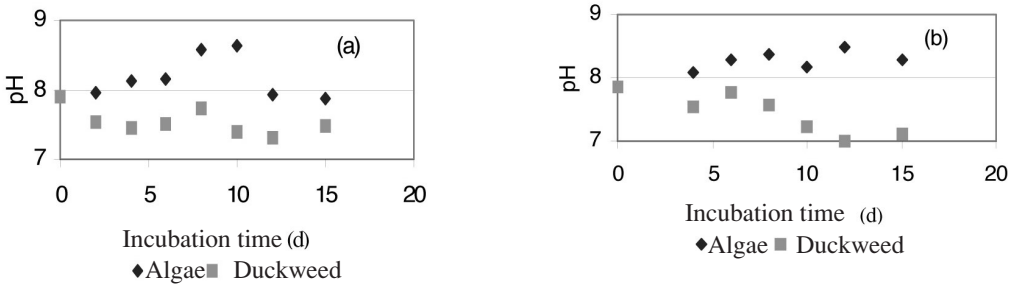


Fig. 2: pH values (mean of three replicates) with time of incubation of experiment 1 (a) and experiment 2 (b).

The observed differences in the physico-chemical and environmental conditions in the two systems are likely to affect nitrogen transformations and removal processes in the containers. Nitrate concentrations in duckweed-based containers were higher than that in algae-based throughout the experimental run although dissolved oxygen concentrations in algae-based were higher. In experiment 1, NO_3^--N concentrations after 15 days of incubation in algae-based and duckweed-based containers were 5.3 and 14.8 mg/L respectively. In experiment 2 the concentrations were 3.2 and 11.9 mg/L. The shallow depth of algae-based and duckweed-based containers (30 cm) favoured the development of aerobic conditions, which enhanced nitrification process. Nitrite concentrations were very low and can be neglected. Depending on initial nitrogen concentrations, duckweed-based containers removed between 42%-62% of total nitrogen and between 56%-95% of Kjeldahl nitrogen from the wastewater while, algae based containers removed between 45%-48% and 48%-58% of total nitrogen and Kjeldahl nitrogen respectively. The higher removal of total and Kjeldahl nitrogen in duckweed-based containers was attributed to nitrogen uptake by duckweed and subsequent removal via duckweed harvesting. In algae-based, the higher final content of Kjeldahl nitrogen in wastewater compared to duckweed-based containers was attributed to the presence of algal biomass. After 15 days of incubation, 40% of the total nitrogen content of algae-based was unaccounted for (loss via denitrification and ammonia volatilisation) in 50 and 100 mg/L initial nitrogen concentration. The same percentage of nitrogen was lost in duckweed–based containers with 50

mg/L initial nitrogen concentration, while only 28% was lost in the container with initial nitrogen concentration of 100 mg/L. The percentage of N present in different nitrogen components after 15 days of incubation from the total N present at the start of the experiments 1 and 2 are presented in Fig. 3 and 4 respectively.

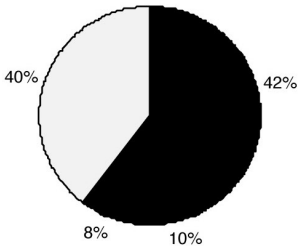
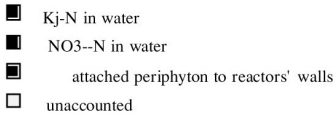


Fig.3 a



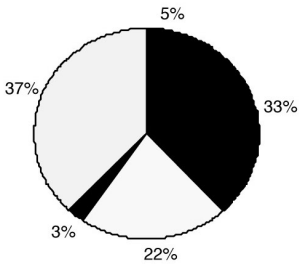


Fig. 3b

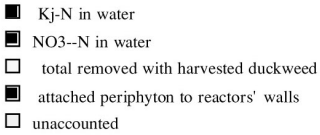


Fig. 3: Percentage of N present in different components in algae-based (3a) and duckweed-based containers (3b) obtained after 15 days of incubation from the total N present at the start of experiment 1

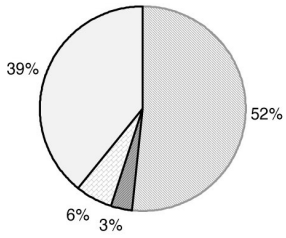
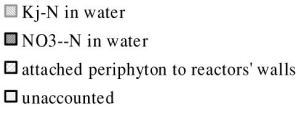


Fig. 4a



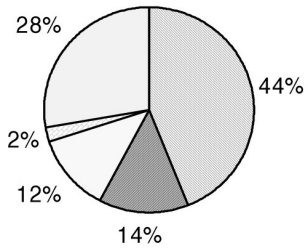


Fig. 4b

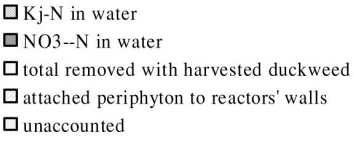


Fig. 4: Percentage of N present in different nitrogen components in algae-based (4a) and duckweed-based containers (4b) obtained after 15 days of incubation form the total N present at the start of experiment 2

Removal efficiencies of nitrogen in duckweed-based containers was consistent with the values reported for other duckweed systems (Harvey and Fox, 1973; Sutton and Ornes, 1975; Oron *et al*., 1987; Alaerts *et al*., 1996). Vermaat and Hanif (1998) and Krner and Vermaat (1998) reported higher nitrogen removal (in 3 to 5 cm containers depth) most probably due to the high duckweed biomass per water volume ratio of the containers used. Removal of nitrogen in algae-based in our experiments is difficult to compare with values reported in literature for waste stabilisation ponds which varies from negligible percentage (Silva *et al*., 1987) up to 95% (Middlebrooks *et al*., 1982) depending on system configuration and operational parameters of the ponds.

In duckweed-based containers, denitrification is probably the major nitrogen loss as very low ammonia volatilisation could be expected in the pH range between 7-7.5. Denitrification in duckweed-based containers in our study was higher than the reported value as unaccounted nitrogen loss of 8-10% by Alaerts et al., (1996). In algae-based, ammonia volatilisation rather than denitrification could have been the major nitrogen loss since high pH values were measured, while the prevailing aerobic conditions were not favorable for denitrification.

For experiments 1 and 2 only 7 to 8% of the total phosphorus balance were unaccounted for. The percentage of P in different P components after 15 days of incubation from the total P present at the start of experiments 1 and 2 are presented in Fig. 5 and 6 respectively.

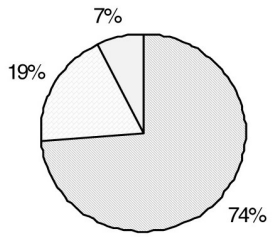


Fig. 5a
- total P in water
- attached periphyton to reactors' walls
- unaccounted

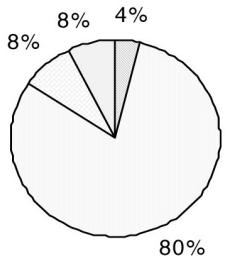


Fig. 5b
- total P in waster
- total removed with harvested duckweed
- attached periphyton to reactors' walls
- unaccounted

Fig. 5: Percentage of P present in different phosphorus components in algae-based (5a) and duckweed-based containers (5b) obtained after 15 days of incubation from total P present at the start of experiment 1

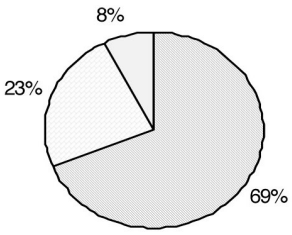


Fig. 6a
- total P in water
- attached periphyton to reactors' walls
- unaccounted

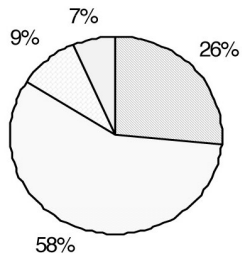


Fig. 6b
- total P in water
- total removed with harvested duckweed
- attached periphyton to reactors' walls
- unaccounted

Fig. 6: Percentage of P present in different phosphorus components in algae-based (6a) and duckweed-based containers (6b) obtained after 15 days of incubation from the total P present at the start of experiment 2

Lower values of total-P (4% and 26% of initial total P present at the start of the experiments 1 and 2 respectively) remained in duckweed-based containers compared to algae-based (74% and 69%). This is basically attributed to the P-uptake by duckweed, which accounted for 80% and 58% of initial total-P in experiment 1 and 2 respectively. P-uptake rates of duckweed in our experiments (20 mg/m^2/d) were lower than values reported in literature (Reddy and DeBusk, 1985: 87 mg P/m^2/d in summer, 18 mg P/m^2/d in winter; Zirschky and Reed, 1988: 220 mg

P/m^2/d). The lower initial total-P in our experiments was probably the main reason for the lower up-take rate.

The overall nitrogen and phosphorus removal of duckweed-based containers was more efficient in experiment 1 where nitrogen concentration was 50 mg/L. At higher concentration (100 mg/L), overall removal nitrogen removal seems to be similar in duckweed and algae-based however better removal of phosphorus were observed in duckweed-based containers. The total concentrations (Kjeldahl and nitrate after 15 days of incubation) and removal rate coefficients of nitrogen and phosphorus in wastewater at the end of experiments 1 and 2 are presented in table 2. Nitrogen and phosphorus removal coefficients in duckweed-based containers were lower than data reported by Körner and Vermaat (1998) (in 3 to 5 cm containers depth) most probably due to the high duckweed biomass per water volume ratio of their containers.

TABLE 2: Final total nitrogen and phosphorus of wastewater in experiments 1 and 2. Values represented as means of three replicates ± SE.

	Container	**Total N mg/L**	**N removal coefficient (d^{-1})**	**Total P mg/L**	**P removal coefficient (d^{-1})**
Experiment 1	Algae	26.72±0.29	0.05	1.64±0.03	0.02
	Duckweed	16.85±0.43	0.18	0.08±0.003	0.31
Experiment 2	Algae	53.98±0.60	0.05	2.05±0.04	0.03
	Duckweed	55.57±1.07	0.05	0.77±0.03	0.10

CONCLUSION

The results of this study showed that there was a clear difference in DO and pH between duckweed and algae-based. These differences caused the changes observed in nitrogen transformations. Nitrification in duckweed-based containers was higher than in algae-based despite the fact that oxygen concentration was found to be lower in duckweed-based containers. Higher percentages of Kjeldahl and total nitrogen removal in water were observed in duckweed-based containers, at 50 mg-N/L initial nitrogen concentration. Approximately, equal percentages of Kjeldahl and total nitrogen removal were observed at 100 mg-N/L. The higher removal at 50 mg-N/L was attributed to nitrogen uptake by duckweed and the absence of algal biomass in duckweed-based containers. The amount of nitrogen (in grams) that was converted to duckweed biomass was similar for 50 and 100 mg-N/L initial nitrogen concentrations.

The loss of nitrogen in algae-based was approximately 40% of the initial nitrogen concentration used (50 mg-N/L or 100 mg-N/L). The loss of nitrogen in duckweed-based containers was 28% and 37% of the initial nitrogen concentration of 100 mg-N/L and 50 mg-N/L, respectively. This loss was attributed to the combined effect of denitrification and ammonia volatilisation; however, it is not clear which process was responsible of more nitrogen loss. Nitrogen loss due to denitrification in duckweed-based containers might be the main nitrogen loss mechanism since pH measurements during the experiments were between 7-7.6; hence, ammonia volatilisation was not likely to occur. On the other hand, ammonia volatilisation in algae-based was most likely to occur, since smaller surface area was provided for attachment of denitrifiers

compared to duckweed-based containers. In addition, higher pH values between 7.9-8.6 were observed.

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REFERENCES

Alaerts G.J., Mahbubar M.R., Kelderman P. (1996). Performance of a full-scale duckweed-covered sewage lagoon. *Wat. Res.*, **30**: 843-852.

APHA (1992). *Standard methods for the examination of water and wastewater*. 18th edition, Am. Publ. Hlth. Assoc., Washington D.C., USA.

Culley D. D., Rejmankova E., Kvet J. and Frey J.B. (1981). Production, chemical quality and use of duckweeds (*Lemnaceae*) in aquaculture, waste management, and animal feeds. *J. World Maric. Soc.*, ***12***: 337-347.

Harvey R. M., Fox J. L. (1973). Nutrient removal using *Lemmna minor*. *J. WPCF*, **45**: 1928-1938.

Hillman W. S. (1961) The *Lemnaceae* or Duckweeds. A review of the descriptive and experimental literature. *Bot. Rev.*, **27**: 221-287.

Krner S. and Vermaat J. E. (1998). The relative importance of *Lemna gibba* L., bacteria and algae for the nitrogen and phosphorus removal in duckweed-covered domestic wastewater. *Wat. Res.*, **32**: 3651-3661

Landolt E. (1986). The family of *Lemnaceae* - a monographic study. *Verffentlichungen des Geobotanischen Institutes der ETH Zürich*, Band, **71**: 566 pp.

Mbagwu I. G. and Adeniji H. A. (1988). Nutritional content of duckweed (*Lemna paucicostata* Hegelm.) in the kainji lake area, Nigeria. *Aquat. Bot.*, **29**: 357-366.

Middlebrooks E.J., Middlebrooks C.H., Reynolds J.H., Watters G.Z., Reed S.C. and George D.B. (1982). *Wastewater stabilisation lagoon design, performance and upgrading*. Macmillan, NY, USA.

Moorhead K.K. and Reddy K.R. (1988). Oxygen transport through selected aquatic macrophytes. *J. Environ. Qual.*, **17**: 138-142.

Novozamsky I., Houba V.J.G., Van Eck R. and Van Vark W. (1983). A novel digestion technique for multi-element plant analysis. *Comm. Soil. Sci.Plant. Anal.*, **14**: 239-248.

Oron G., Porath D. and Jansen H. (1987). Performance of the duckweed species *Lemna gibba* on munocipal wastewater for effluent renovation and protein production. *Biotech. Bioeng.*, **29**: 258-267.

Pearson H.W., Mara D.D. and Arridge H.A. (1995). The influence of pond geometry and configuration on facultative and maturation waste stabilisation pond performance and efficiency. *Wat. Sci. Tech.*, **31**: 129-139.

Reddy K. R., and DeBusk W. F. (1985). Nutrient removal potential of selected aquatic macrophytes. *J. Environ. Qual.*, **4**:459-462.

Rogers J. H., Cherry D. S. and Guthrie R. K. (1978). Cycling of elements in duckweed (*Lemna perpusilla*) in an ash settling basin and swamp drainage system. *Wat. Res.*, **12**: 765-770.

Silva S.A., Mara D.D. and de Oliveira R. (1987). The performance of five deep waste stabilisation ponds in northeast Brazil. *Wat. Sci. Tech.*, **19**: 61-64.

Sutton D.L. and Ornes W.H. (1975). Phosphorus removal from static sewage effluent using duckweed. *J. Env. Qual.*, **4**: 367-370.

Sutton D.L. and Ornes, W.H. 1977. Growth of *Spirodela polyrhiza* in static sewage effluent. Aquat. Bot., **3**:231-237.

Vermaat J. E.and Khalid H. M. (1998). Performance of common duckweed species on different types of wastewater. *Wat. Res.*, **32**: 2569-2576

Zirschky J. and Reed S. C. (1988). The use of duckweed for wastewater treatment *Journal WPCF*, **7**:1253-1258.

3

Process Performance Evaluation of the Contact Stabilization System at Birzeit University

R.Al-Sa'ed and O.R. Zimmo

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Process Performance Evaluation of the Contact Stabilization System at Birzeit University

R.Al-Sa'ed, O. R. Zimmo

Abstract: The purification capacity of the contact stabilization system at Birzeit University campus has been studied for two years. The oxidation capacity of organic matter, ammonium oxidation, and denitrification potential were determined. The reduction of chemical oxygen demand (COD) was 85%, and the effluent COD concentration was less than 110 mg/l (the average value was 88 mg/l). Suspended solids were removed with equal efficiency. The aerobic stabilization of organic solids was efficient, and no excess biosolids (sludge) had to be removed. High nitrification (70% of the influent nitrogen were nitrified) could be maintained at 15 °C, and 42% of the oxidized nitrogen was denitrified. The specific oxygenation capacity of the treatment system is relatively high and reached about 5 kwh/kg COD. The specific wastewater treatment cost is about 0.52 US$/m^3 or about 58 US$ per population equivalent per year. Based on the results obtained, batch operation and intermittent aeration of the biological process are suggested to achieve high effluent quality and to reduce power consumption.

Keywords: activated sludge, contact stabilization system, effluent quality standards, nitrification, nitrogen removal, purification capacity.

1 Introduction

In Palestine, the present water supply and sewerage systems with large wastewater treatment plants serve only the urban population. In 1997 about 78% of the total population of Palestine (West Bank) was served by public water supply, and almost 24% by public central sewerage systems (Abu Madi *et al.*, 2000). Less than 5% of collected urban sewage is partially treated in the existing overloaded central sewage works (MOPIC, 1998). In sparsely populated Palestinian rural and semi-urban communities, which form about 60% of the total population in the West Bank, different wastewater treatment options must be developed and adopted for protection of the aquatic environment.

The water quality of groundwater wells and some freshwater springs is showing signs of nitrate pollution (Mukhallalati and Safi, 1995; Alawneh and Al-Sa'ed, 1997). Among the nitrogen pollution sources are untreated municipal sewage from urban areas, domestic discharges and septic tanks from Palestinian rural communities and Israeli colonies, and excessive fertilizer usage. Control of biological nutrients (N and P) discharged from large and small point sources is of special interest in order to protect the aquatic environment from pollution.

Several attempts have been made to develop wastewater management strategies for the Palestinian urban areas (Gearheart *et al.*, 1994; Nashashibi and van Duijl, 1995; PWA, 1998). Beside applied research studies a number of biological treatment technologies for small rural communities have been introduced and installed (Mustafa, 1996; Zimmo *et al.*, 1999; Zimmo *et al.*, 2000). Most of the rural sewage treatment plants, installed to serve less than 1000 people, use the attached growth (trickling filters) and natural treatment processes preceded by septic tanks. Trickling filters and natural treatment processes are simple in operation and maintenance, require few skilled personnel and have low capital investment and annual running costs.

Rural small sewage treatment plants show a good removal rate for organic matter but are poor in nitrogen removal. In this study the process performance of the small-scale sewage works at Birzeit University campus, which uses the contact stabilization process, was examined. The treatment efficiency and other operational parameters were also investigated.

2 Experimental plant and methods

2.1 Layout, design dimensions and operation

Domestic wastewater from all the buildings, including the main restaurants and cafeterias as well as various laboratories, of Birzeit University campus is collected with a central sewerage network. Part of the collected sewage is pumped while the rest flows by gravity into the sewage treatment plant. At present Birzeit University has almost 4000 students and staff, and the amount of sewage collected and treated is about 60 m^3 per day.

Preaeration of wastewater influent is accomplished in the holding tank to freshen the sewage and control odour problems. A schematic flow diagram of the contact stabilization system is illustrated in Figure 1. From the holding tank the influent is pumped to the aeration basin, where a long period of aeration is combined with a high sludge biomass, resulting in a low organic load.

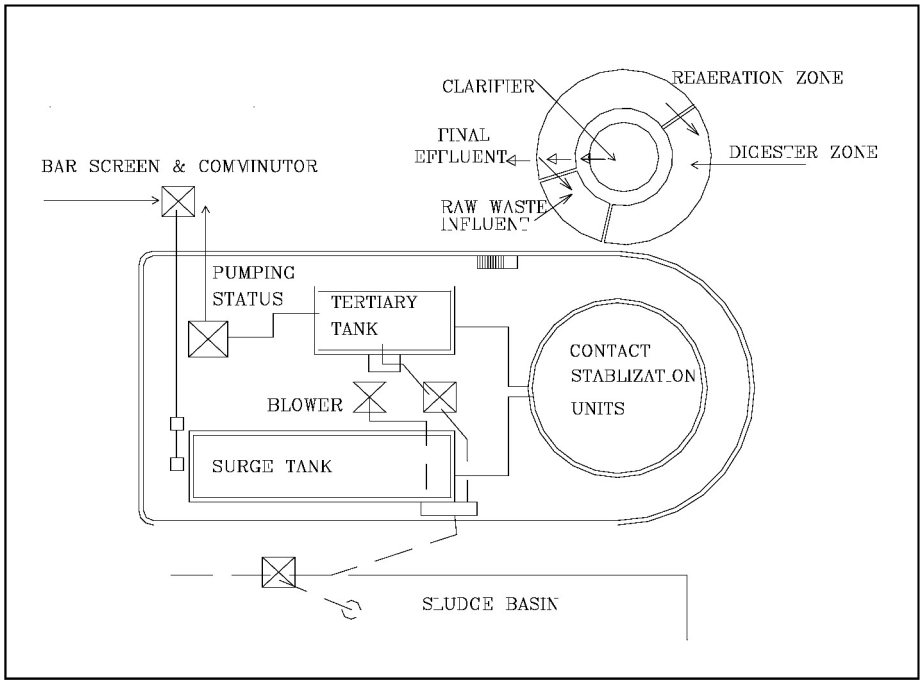

Figure 1 Schematic flow diagram of the contact stabilization system at Birzeit University.

After the biological unit the treated effluent is separated from the suspended solids in an integrated circular secondary tank. The treated effluent is further treated in a slow sand filter to remove suspended solids, viruses and microbial pathogens. Excess sludge is pumped from the preaeration zone to the aerobic digestion zone. Minimal excess biosolids are removed from the sludge stabilization tank. For safety reasons, no agricultural usage is practised. The treated effluent is used for landscape irrigation at Birzeit University campus.

3 Analytical methods

Influent and effluent samples were analysed for total chemical oxygen demand (COD), total nitrogen (TKN), ammonium (NH_4^+-N), nitrite (NO_2^--N), nitrate (NO_3^--N) and total phosphorus (tot-P). The same parameters were measured on filtered samples, where portions of the samples were filtered through GF/A glassfibre filters. Analyses were conducted according to the Standard Methods (APHA, 1992). A dissolved oxygen (DO) probe (Hach Model DO175) and a pH probe (Hach Model EC10) were used to determine DO and pH values.

4 Results and discussion

4.1 Raw wastewater characteristics

The wastewater from the campus is collected in separate sewer networks. The wastewater characteristics from Birzeit University are slightly diluted and do not reflect a typical rural domestic sewage. The reason for this is that most of the students stay for a short period of time in the university campus. Raw wastewater quality based on average values is presented in Table 1.

Table 1 Average concentrations of raw wastewater (mg/l, unless otherwise stated).

Parameter	Concentration
BOD	220
COD	488
SS	300
TKN	75
NH_4^+-N	58
NO_2^--N	0
NO_3^--N	0
Tot-N	75
Tot-P	3.4
Temperature (°C)	19
pH	7.4
Dissolved oxygen (DO)	1

4.2 Organic carbon

Total and soluble COD concentrations in the influent and effluent of the sewage works over the last two years of the monitoring programme are shown in Figure 2. During the winter season, the effluent COD concentrations are sometimes higher than in the summer period.

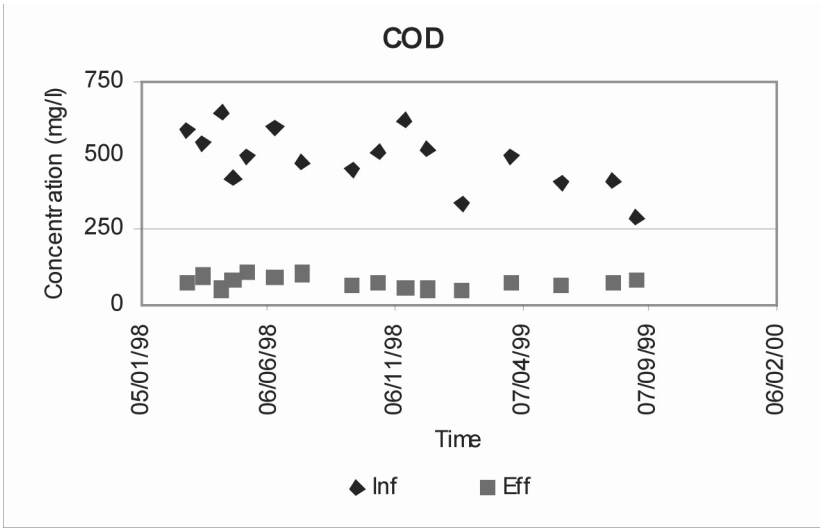

Figure 2 Influent and effluent COD concentrations during the monitoring period.

4.3 Nitrogen removal rates

Usually, the high-rate contact stabilization process does not produce good results for nitrification and denitrification. The nitrification rate is measured indirectly as the ratio of NO_3^--N to NH_4^--N in the effluent of the biological process. About 70% of NH_4^+-N is nitrified. However, only 42% of nitrate is biologically denitrified. The nitrification rate is illustrated in Figure 3. It is well known that biological denitrification cannot be achieved without nitrification. When the water temperature falls below 10 °C, the nitrification rate decreases.

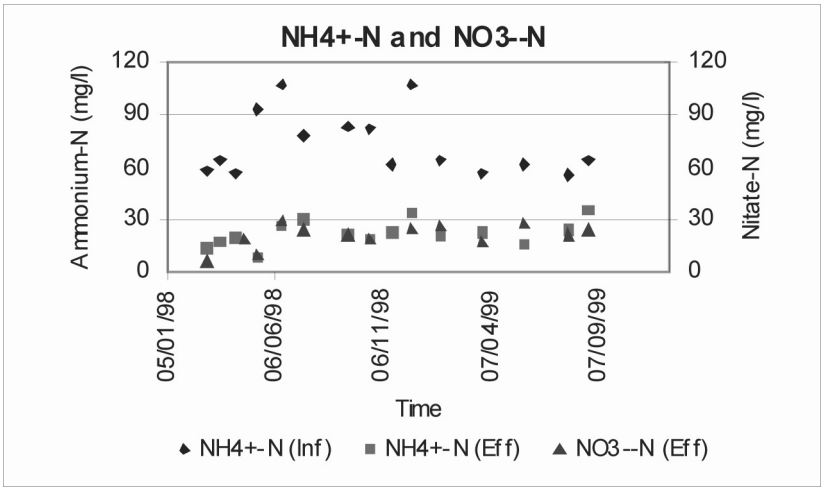

Figure 3 Ammonium (influent and effluent) and nitrate (effluent) concentrations.

The nitrification rates achieved in the contact stabilization process are low compared with those achieved in oxidation ditches and conventional activated sludge systems. This might be due to extensive hydrolysis of biomass in the sludge stabilization tank, or to a low sludge age or to a low MLSS concentration in the aeration tank. Also, competition for dissolved oxygen between carbonaceous heterotrophs and autotrophic nitrifiers in the aeration tank might be a reason for low nitrification activity. Since denitrifiers are anoxic heterotrophs, and the oxygen concentration in the aeration tank is not regulated, the denitrification process is probably negatively affected by a high oxygen concentration in the aeration tank and in the raw influent from the holding tank. Also, a low COD concentration might have affected the denitrification process. Enhancement of biological nitrogen removal can be achieved through regulation of the DO concentration and by feeding part of the stabilized sludge into the holding tank. This is under investigation.

4.4 Annual capital and running expenditure

The sewage works at Birzeit University campus was installed in 1980. Capital and operational expenditure (CAPOEX) is an important measure in the water industry, which gives an indication of the cost-effectiveness of a sewage facility. The estimation of CAPOEX of wastewater treatment alternatives helps the design engineer and decision-makers decide which treatment option to select with respect to cost effectiveness, easy operation and maintenance.

Generally, the CAPOEX items of a treatment plant consist of the annual capital and running costs. The capital investment costs are calculated using the annuity factors with respect to the annual rate of interest and the lifetime of plant processing units. The operational expenditure (OPEX) or the annual OMR includes personnel, energy, laboratory analysis, sludge management, maintenance, operation and repair.

The annual capital and running costs were estimated using an annuity factor and assuming 20% of the total capital costs for electromechanical parts and 8% annual rate of interest. The lifetimes of the civil works and the electromechanical parts were assumed to be 35 and 18 years, respectively.

The specific cost for wastewater treatment using the contact stabilization system was estimated to be about 58 US$/(PE year) or 0.52 US$/m^3. The cost of energy is about 45% of the total CAPOEX, which exceeds the average energy consumption rate for advanced sewage treatment plants. This cost can be reduced through dissolved oxygen regulation in both the holding and the biological units. Compared with the sewage costs in some member states of the European Union, the specific costs obtained from the Birzeit sewage works was within the range 56–125 US$/(PE year) (Pecher, 1995; Firk and Mertsch, 1998; Rudolph and Kraemer, 1999).

5 Conclusions and recommendations

There is a lack of data on the efficiency of present urban sewage works, and the published data on wastewater characteristics are not reliable. Moreover, little technical information on biological nutrient removal in contact stabilization systems is available. Hence, the authors studied the process performance of a small-scale contact stabilization system with special reference to organic carbon and biological nitrogen removal processes. As a result

of the monitoring programme over the last two years the following conclusions and recommendations can be made:

- The contact stabilization process has a good efficiency in BOD, COD, and SS. The average effluent concentrations were all below international prescribed quality standards. Thus it can be recommended for rural communities and semi-urban areas.
- Partial nitrification and denitrification processes were achieved. High oxygen contents and low COD to N ratios are behind low denitrification rates in the sludge stabilization tank. Low MLSS and competition between heterotrophs and autotrophic nitrifiers have a negative impact on the nitrification process in the aeration tank.
- The CAPOEX costs for wastewater treatment using the contact stabilization system are reasonable and even affordable for the Palestinian rural and semi-urban areas. However, these can be reduced if internal process modifications are made and additional process regulatory devices are installed.

References

Abu-Madi, M., Al-Sa'ed, R., Braadbart, O. and Alaerts, G. (2000) 'Selection criteria for appropriate sanitation in the Palestinian rural and semi-urban communities', *Proceedings of the International Symposium on Water Sector Capacity Building and Research in Palestine,* Birzeit University, Birzeit, West Bank, Palestine.

Alawneh, M. and Al-Sa'ed, R. (1997) 'Review on water quality in Palestine: Groundwater and surface water', *Proceedings of the 2nd Conference on Energy and Environment,* An-Najah University, Nablus, West Bank, Palestine.

Firk, W. and Mertsch, V. (1998) 'Kosten der Abwasserreinigung im internationalen Vergleich', *ATV-Schriftenreihe 12, ATV-Bundestagung*, Bremen, GFA, Hennef, Germany.

Gearheart, R., Bahri, A. and Al-Hamaidi, M. (1994) *Wastewater treatment and reuse strategy for Gaza and West Bank: Water and wastewater sector,* Palestinian Economic Council for Development and Reconstruction (PECDAR), Alram, West Bank, Palestine.

Ministry of Planning and International Cooperation, MOPIC (1998) *Regional plan for the West Bank Governorates: Water and wastewater existing situation, First edition,* Albireh, West Bank, Palestine.

Mukhallalati, L. and Safi, J. (1995) 'Nitrate pollution of groundwater in the Gaza Strip' *Proceedings of the Symposium of Birzeit Agenda on a Strategy for Water Sector Capacity Building in Palestine,* Birzeit University, Birzeit, West Bank, Palestine.

Mustafa, J. Y. (1996) 'On-site wastewater treatment, disposal and reuse', *M.Sc. Thesis, SEE014,* IHE Delft, The Netherlands.

Palestinian Water Authority, PWA (1998) *Water sector strategic planning study.* Interim Report, Albireh, West Bank, Palestine.

Pecher, R. (1995) 'Gebührensituation in Stadt and Land' *ATV-Kongress, Berichte der ATV, Heft 45,* Hennef, Germany.

Rudolf, K.-U. and Kraemer, A. (1999) 'Sewage charges: a European comparison', *European Water Management*, Vol. 2, No. 5, pp. 36–42.

Zimmo, O., Al-Sa'ed, R. and Gijzen, H. (1999) 'Comparison between algae-based and duckweed-based wastewater treatment: Differences in environmental conditions and nitrogen transformations' *Water Science and Technology*,

Zimmo, O., Al-Sa'ed, R., and Gijzen, H. (2000) 'Nitrogen transformation and wastewater treatment efficiency in algae-based and duckweed-based stabilization ponds', *Proceedings of the International Symposium on Water Sector Capacity Building and Research in Palestine,* Birzeit University, Birzeit, West Bank, Palestine.

4

Willingness of Farmers to Pay for Reclaimed Wastewater in Jordan and Tunisia

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Willingness of farmers to pay for reclaimed wastewater in Jordan andTunisia

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Abstract Despite water scarcity and high agricultural water consumption in the Middle East and North Africa region, substantial amounts of treated wastewater are discharged into seas without proper utilization. This can be attributed to either farmers' unwillingness to use or to pay for reclaimed wastewater. Therefore, a field survey was conducted in Jordan and Tunisia, which are considered as representative to the MENA region, using a prepared and pilot tested questionnaire. This study applies the contingent valuation method to elicit the willingness of farmers to pay for reclaimed wastewater. Logistic regression analysis is applied in an attempt to build a model that correlates qualitative responses of farmers to monetary stimuli. The water price seriously affects farming profitability and farmers' willingness to pay for reclaimed wastewater. Farmers prove to be unwilling to pay more than 0.05 $/m^3 of reclaimed wastewater primarily because of quality concerns, comparatively easy access to freshwater, and price.Keywords Acceptance from farmers; irrigated agriculture; reclaimed wastewater; willingness to pay.

Introduction Agriculture consumes about 87% of the total water consumption in the Middle East and North Africa region (MENA) while water is a scarce commodity. Reclaimed wastewater (RW) has been recognized as a valuable non-conventional resource (Angelakis et al.,1999).Yet, the market for RW in the MENA is unbalanced.On the supply side of the mar-ket there is growth,revealed by the increasing number of wastewater treatment plants. On the demand side of the market there is stagnancy, revealed by the substantial proportions of RW being discharged into receiving water bodies without proper utilization.Balancing the market for RW means reducing the gap between supply and demand, which is of major con-cern in the region. Securing a market or users for the RW is the most critical factor to suc-cess of reuse projects; this should be a key task in the planning process (Mills and Asano, 1996; Al-Hamdi,2001). Assessing the potential market for the RW has rarely been recog-nized by planners of the eighties,which may partially explain the low rate of wastewater reuse (Bahri and Brissaud, 1996; Mills and Asano,1996). In general,the receptive market for such water comprises three major elements: (a) availability of agricultural land,(b) availability of infrastructure for conveyance and distribution of the treated effluent,and (c) availability of farmers who are willing to accept and pay for this water. The avail ability of agricultural land and infrastructure for conveyance and distribution of RW do not seem to be an obstacle in the MENA countries experiencing reuse. Mills and Asano (1996) empha-size that only identifying a potential RW market for planning purposes is not enough,but there must be some assurance that particular users (farmers)intend to use and pay for RW before embarking on design and construction of reuse projects.

Across the world water pricing has been a reliable tool to reduce freshwater (FW) con-sumption, and simultaneously raise revenues.In Israel,for example,a gradual 50% drop in FW use was reported after a series of tariff increases. FW use in agriculture declined from 74% to 62% between 1986 and the early 1990s whilst use of RW proportionally increased.

and overall productivity per unit land doubled (Sanz, 1999; Ahmad, 2000). The objective of this study is to elicit the willingness of farmers to pay for RW and to understand the financial stimuli that might influence farmers' willingness to pay (WTP).

Methodology

Field survey

In 2001, four-months of fieldwork was conducted in Jordan and Tunisia within the framework of a longer-term research. One month was specified for surveying various irrigation schemes using a questionnaire that was prepared prior to the fieldwork and pilot tested on 15 farms in Jordan. The survey was limited to 104 farms. Roughly a quarter of this sample would each use primarily either groundwater, surface water, blended water + wastewater, or treated wastewater. The reasons for this limited sample size were: (a) absence of the right persons who could provide reliable information – in many cases either workers or farmers' kin were available; (b) some farmers were suspicious and hesitant to cooperate; and (c) logistical and budget limitations. Still, this sample provided sufficiently consistent information to be used to achieve the objective of the study.

In order to ensure collection of reliable information, the following measures were applied.

(a) Knowledgeable respondents. Interviewing only knowledgeable persons who could provide detailed information increased the chances for getting reliable feedback.

(b) Mitigation of farmers' suspicions. Observing few issues that would please the farmer and using them as a starter discussion prior to interviews, considerably helped in gaining farmers' trust and getting more reliable information. In some instances admiring a kid that sticks to his father, in other cases flattering a farmer for a nice farm or talking about the healthy atmosphere in the area. However, it is worth mentioning that excess flattering and showing sympathy with farmers were avoided to prevent influenced responses.

(c) Data crosscheck. Three different levels of crosscheck were applied. The first deals with structure of the questionnaire by having questions that have direct and indirect answers. The second was having side talks with the field workers either before or after interviewing the eligible person. The third was confirming parts of the quantitative data from staff of the agricultural departments within the area and representatives of the farmers' unions, if any. As a result, eight out of the 104 cases were rejected because farmer's responses were contradictory and misleading.

Willingness to pay

In this study, the contingent valuation (CV) method is used to test some hypotheses concerning farmers' WTP for RW. These hypotheses are: (a) WTP is expected to decrease as the price of RW increases, (b) WTP is expected to increase as farmers' income or profit increases, (c) WTP is expected to increase as the price of current irrigation water (competitive water source) increases, and (d) WTP is expected to increase as the availability or accessibility to FW decreases (Bahri and Brissaud, 1996; Al-Hamdi, 2001).

The CV method is criticized by some as unreliable because it depends on what respondents say rather than what they do (Snell, 1997; Al-Hamdi, 2001). Nevertheless, CV has gained increased acceptance amongst academics and policy makers as a versatile and powerful methodology for estimating respondents' WTP (Hanneman and Kanninen, 1996; Whittington, 1998; Vaughan *et al.*, 1999; Hanely, 2001). According to Johansson (1999), elicitation of respondents' WTP could be done in several different ways: (a) in an open-ended question, (b) in a single referendum question, or (c) in the form of bidding game. In an open-ended question, the respondent is asked to state the maximum amount that he/she

is willing to pay, while in the referendum format, the respondent is presented with a posted price that he/she is asked to accept or reject. The bidding game is a repeated process, which tries to bracket the respondent's maximum WTP by presenting higher and higher values (bids). A lower value for the WTP can be bracketed in a similar manner (Johansson, 1999). Most CV studies that have compared estimates of WTP obtained have found that dichotomous (Yes/No) choice yields higher estimates than open-ended format (Snell, 1997; Hanely, 2001; Emre *et al.*, 2002). Therefore, bidding technique and dichotomous choice are used in this study.

Prior to presenting the WTP questions respondent farmers were informed that as a consequence of water scarcity tougher laws would lead to higher prices of FW for irrigation, meanwhile reliable RW of high quality would be provided. Subsequently, farmers were asked to respond to sequential dichotomous questions; if they would vote in favor of paying the proposed price (bid) for RW. Literature recommends that extreme bids should be avoided, since they can lead to efficiency losses, and that the number of bids used should be six at a maximum (Cooper, 1993; Alberdin, 1995; Hanemann, and Kanninen, 1996). Therefore, six bid values (0, 0.05, 0.10, 0.15, 0.20, and 0.25 $/m^3$) were pre-selected based upon the pilot testing of questionnaire in Jordan to ensure a bid range that approximately covered: (a) current prices of RW, (b) the operational costs for conveyance and distribution of the treated effluents to the irrigation sites, (c) the total costs (including investment) for conveyance and distribution, and (d) operational costs for treatment. An additional independent question was if farmers would accept to pay any price if FW would not be available anymore and RW would be the only source of water available.

Responses to the CV question provide only qualitative information about WTP. Thus, from the raw responses alone, one cannot obtain a quantitative measure of WTP. Therefore, in this study, we employ two methodologies for analysis of the filed survey. The first is descriptive that presents farmers' WTP as frequencies (count and percentile). The second embeds the data in a model in an attempt to link the qualitative responses to monetary and other stimuli that induced them (Hanemann and Kanninen, 1996).

Descriptive approach for assessing farmers' acceptance and WTP. It presents WTP as frequencies (count and percentile) of the accept responses for each of the presented bid values compared with the four types of water that are currently used for irrigation.

Regression analysis for assessing WTP. Farmers' responses have been analyzed using models for discrete (qualitative) dependent variables, where we may relate the probability of making a certain choice ("pay" or "not pay") to some explanatory variables (independents). The discrete structure of WTP surveys implies the adoption of logistic regression (*logit analysis*) procedures (Maddala, 1983; Hanemann and Kanninen, 1996; Ardila *et al.*, 1998; Creel, 1998; Emre *et al.*, 2002). The goal of logistic regression is to correctly predict the category of outcome for individual cases using the most parsimonious model. In this way, logistic regression estimates the probability of a certain event occurring. To accomplish this goal, a model is created that includes all predictor variables that are useful in predicting the response variable. Several methods are available for selecting independent variables. One is the forced entry method where any variable in the variable list is entered into the model. The other is the stepwise method where logistic regression can test the fit of the model after each coefficient is added or deleted. Stepwise regression is used in the exploratory phase of research or for purposes of pure prediction, not theory testing (Menard, 1995). Exploratory testing makes no *a priori* assumptions regarding the relationships between the variables, thus the goal is to discover relationships. Theory testing is the testing of priori theories or hypotheses where selection of the variables is based on theory,

not on a computer algorithm. Menard (1995) writes, "there appears to be general agreement that the use of computer-controlled stepwise procedures to select variables is inappropriate for theory testing because it capitalizes on random variations in the data and produces results that tend to be idiosyncratic and difficult to replicate in any sample other than the sample in which they were originally obtained". Therefore, the entry method is applied in this study to test the aforementioned hypotheses.

The sequential nature of the dichotomous questions entails considering the sample size separately for each bid being studied as shown in Table 1. The sequential models are easy to handle provided we make the probability of choice at each stage independent of the choice at previous stage. In other words, different models are needed to explain farmers' responses to each presented bid value (Maddala, 1983).

The SPSS software package is employed in this study where the dichotomous responses to each of the seven bids are entered as dependent variables. The current price of irrigation water (\$ cent/m^3) and the gross profit (\$/Donum) including the value of farmers' own labour are entered as independents. Other independent variables that are thought to be influential are not included in the model because each time a new independent is added the model significantly becomes unstable. This is because some independents have majority voting (e.g. availability of FW) and some others cause collinearity problems to the logit model.

Assessing model fit. In assessing model fit, several measures are available (Hair *et al.*, 1998). First, the log likelihood value (–2LL) value; smaller values of the –2LL measure indicate better model fit. The goodness of fit measure compares the predicted probabilities to the observed probabilities, with higher values indicating better fit. There is no upper or lower limit for this measure. Next, three measures comparable to the R^2 measure in multiple regression are available. The Cox and Snell R^2 measure operates in the same manner, with higher values indicating greater model fit. However, this measure is limited to that it cannot reach the maximum value of 1, so Negelkerke proposed a modification that had the range of 0 to 1. The third measure is the "Pseudo" R^2 measure based on the improvement in the –2LL value [The Pseudo $R^2 = [(-2LL_{initial}) - (-2LL_{model})]/(-2LL_{initial})]$. The final measure of model fit is the Hosmer and Lemeshow value, which measures the correspondence of actual and predicted values of the dependent variable. Better model fit is indicated by smaller differences in the observed and predicted classification. A good model fit is indicated by a non-significant chi-square value (Hair *et al.*, 1998).

Results and discussion

Acceptance to irrigate with reclaimed wastewater

The percentages of farmers that accept to use RW for restricted and unrestricted irrigation are 56.3% and 75.0%, respectively (Table 2). The percentages of unsure farmers are 28.1%

Table 1 Distribution of sample size for the sequential responses of farmers

Bid value (\$/m^3)	0	0.05	0.10	0.15	0.20	0.25	Any price
Total responses	3 No 93 Yes	12 No 81 Yes	36 No 45 Yes	21 No 24 Yes	16 No 8 Yes	5 No 3 Yes	60 No 36 Yes
Sample size	96	93	81	45	24	8	96

Table 2 Farmers' acceptance to use reclaimed wastewater for irrigation ($n = 96$)

Type	Accept		Unsure		Reject	
	Count	%	Count	%	Count	%
Restricted irrigation	54	56.3	27	28.1	15	15.6
Unrestricted irrigation	72	75.0	17	17.7	7	7.3

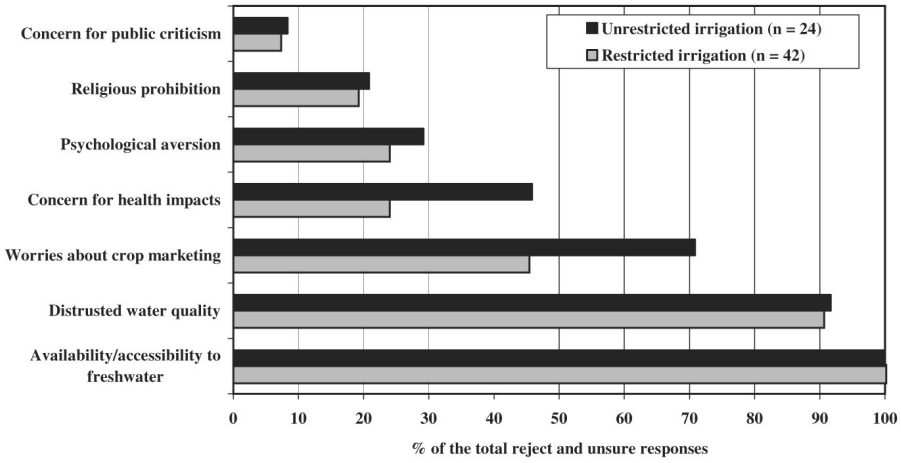

Figure 1 Comparison of factors that make farmers reject or be unsure about using reclaimed water

and 17.7%, respectively. Farmers prefer to use RW for unrestricted irrigation rather than for restricted irrigation. These results reflect a promising stage in the era of wastewater reuse for agricultural irrigation. On the other hand, only 15.6% and 7.3% refuse to use RW for restricted and unrestricted irrigation, respectively. Therefore, more efforts are needed in order to improve the farmers' acceptance by mitigating the factors that might make farmers reject or hesitant to use RW.

The major obstacles for farmers to accept RE are shown in Figure 1. Accessibility to FW at low price is the most critical one. In other words, in order to make farmers use RW their access to FW must be restricted. However, this issue should be carefully dealt with, especially where the supplies of RW cannot offset the agricultural water demand.

Willingness to pay for reclaimed wastewater

Results of three models (WTP_0, $WTP_{0.05}$, and $WTP_{0.25}$) are non-significant (Table 3), thus unrepresentative and cannot be interpreted. This is mainly because of super-majority voting, which according to Hanemann and Kanninen (1996), interrupts model fit; but it still may be considered ethically superior. This is the case in our study for bid values 0 and 0.05, where majority of the interviewed farmers accept to pay up to 0.05 \$/m^3 of treated wastewater. Whereas results of the model for bid value 0.25 are non-significant and thus rejected mainly because the sample size is too small ($n = 8$) as a consequence of sequential questioning and majority reject responses.

Results of the other models ($WTP_{0.10}$, $WTP_{0.15}$, $WTP_{0.20}$, and $WTP_{\text{any price}}$) are significant at 95% and 90% confidence. Thus, accepting the hypotheses that water price and profit significantly influence farmers' WTP; the positive sign indicates that higher prices of FW as well as higher profit increase the WTP. The logit model for each bid value can be written as:

$$P = \frac{e^{(K+\beta_1 X_1+\beta_2 X_2)}}{1+e^{(K+\beta_1 X_1+\beta_2 X_2)}} = \frac{1}{1+e^{[-(K+\beta_1 X_1+\beta_2 X_2)]}} \quad (1)$$

where,

P = Probability that a farmer is willing to pay the presented bid value

K = Model constant

β = Logistic coefficient

X_1 = Prices currently paid for irrigation water (\$ cent/m^3).

X_2 = Net profit including the value of farmers' own labor (\$/Donum) or (\$/1,000 m^2).

The survey results show that farmers in general have a high WTP for RW if the unit price is low, the quality is high, and if access to FW is restricted or its price is high. This means that

Table 3 Regression results for analysis of WTP

Model	β	S.E	Wald	Sig.	R	Exp(β)	Goodness of fit measures
P_0 = Probability that a farmer responds yes to Bid = 0							–2LL = 24.045
X_1 PRICE	–0.043	0.026	2.664	0.103	–0.158	0.958	Cox and Snell R^2 = 0.027
X_2 PROFIT	–0.002	0.002	0.747	0.387	0.000	0.998	Negelkerke R^2 = 0.112
K CONSTANT	4.213	0.916	21.173	0.000	–	–	Pseudo R^2 = 0.099
							Hosmer and Lemeshow = 9.729
							8 df 0.786 sig.
$P_{0.05}$ = Probability that a farmer responds yes to Bid = 0.05							–2LL = 59.396
X_1 PRICE	0.031	0.041	0.597	0.440	0.000	1.032	Cox and Snell R^2 = 0.122
X_2 PROFIT	0.004	0.002	9.035	0.003	0.314	1.004	Negelkerke R^2 = 0.228
K CONSTANT	1.912	0.410	21.775	0.000	–	–	Pseudo R^2 = 0.171
							Hosmer and Lemeshow = 13.072
							8 df 0.109 sig.
$P_{0.10}$ = Probability that a farmer responds yes to Bid = 0.10							–2LL = 88.858
X_1 PRICE	0.206	0.073	7.916	0.005	0.231	1.229	Cox and Snell R^2 = 0.242
X_2 PROFIT	0.003	0.001	5.802	0.016	0.185	1.003	Negelkerke R^2 = 0.324
K CONSTANT	–0.909	0.372	5.965	0.015	–	–	Pseudo R^2 = 0.202
							Hosmer and Lemeshow = 23.059
							8 df 0.003 sig.
$P_{0.15}$ = Probability that a farmer responds yes to Bid = 0.15							–2LL = 35.801
X_1 PRICE	0.444	0.151	8.654	0.003	0.327	1.559	Cox and Snell R^2 = 0.444
X_2 PROFIT	0.004	0.002	6.649	0.010	0.273	1.004	Negelkerke R^2 = 0.592
K CONSTANT	–3.059	1.002	9.330	0.002	–	–	Pseudo R^2 = 0.424
							Hosmer and Lemeshow = 2.161
							7 df 0.950 sig.
$P_{0.20}$ = Probability that a farmer responds yes to Bid = 0.20							–2LL = 12.056
X_1 PRICE	0.169	0.090	3.511	0.061	0.222	1.184	Cox and Snell R^2 = 0.537
X_2 PROFIT	0.004	0.003	2.307	0.128	0.100	1.004	Negelkerke R^2 = 0.746
K CONSTANT	–4.610	1.859	6.151	0.013	–	–	Pseudo R^2 = 0.605
							Hosmer and Lemeshow = 14.522
							8 df 0.069 sig.
$P_{0.25}$ = Probability that a farmer responds yes to Bid = 0.25							–2LL = 6.415
X_1 PRICE	0.163	0.279	0.340	0.559	0.000	1.177	Cox and Snell R^2 = 0.406
X_2 PROFIT	–0.006	0.006	1.067	0.302	0.000	0.994	Negelkerke R^2 = 0.554
K CONSTANT	–8.259	14.909	0.307	0.580	–	–	Pseudo R^2 = 0.394
							Hosmer and Lemeshow = 5.137
							6 df 0.526 sig.
P_{Any} = Probability that a farmer responds yes to Bid = Any price							–2LL = 111.371
X_1 PRICE	0.039	0.018	4.752	0.029	0.147	1.040	Cox and Snell R^2 = 0.150
X_2 PROFIT	0.003	0.001	9.151	0.003	0.237	1.003	Negelkerke R^2 = 0.205
K CONSTANT	–1.048	0.287	13.348	0.000	–	–	Pseudo R^2 = 0.123
							Hosmer and Lemeshow = 8.351
							8 df 0.399 sig.

[a] Wald statistic is a test used in logistic regression for the significance of the coefficient (β). Its interpretation is like the F or t values used for testing the significance of linear regression coefficient

X_1 *Price* = Prices currently paid for irrigation water (\$ cent/m^3)

X_2 *Profit* = Net profit including the value of farmers' own labor (\$/Donum); One Donum = 1,000 m^2 = 0.1 ha

β = Logistic coefficient; S.E. = standard error; Wald = Wald statistic; Sig. = significance level; R = correlation; Exp(β) = exponentiated coefficient; –2LL = –2log likelihood; df = degrees of freedom

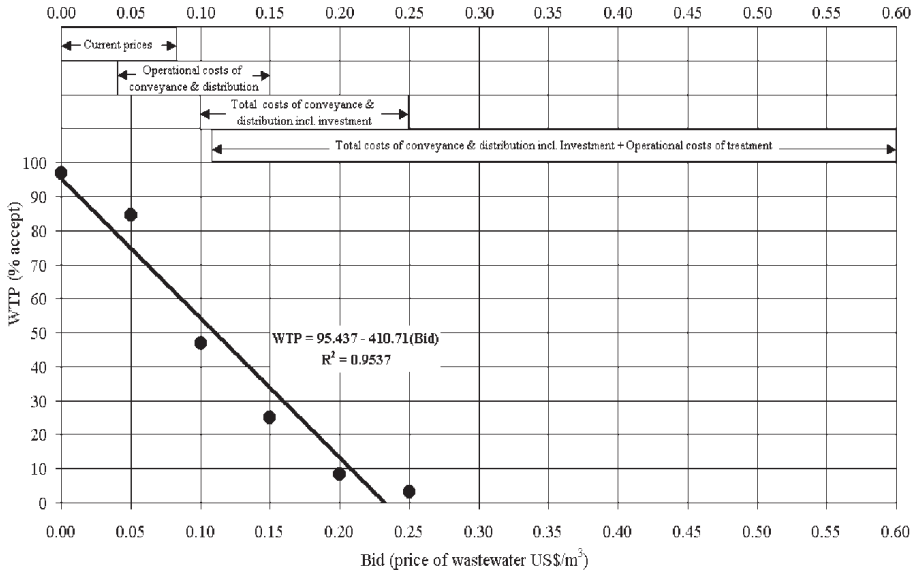

Figure 2 Willingness of farmers to pay for different prices of reclaimed wastewater

the current prices are highly perceived by farmers as suitable having the quality of service improved. Increasing the water prices to cover the operational costs of conveyance and distribution is inversely reflected on the farmers WTP. Ambitious attempts might fail to recover the full cost, not only for treatment, but also for conveyance and distribution (Figure 2).

Conclusions

In Jordan and Tunisia, in principle, farmers are willing to apply RW for agricultural irrigation with preference for unrestricted irrigation. Availability or accessibility to FW and concern for water quality and crop marketing are the major factors that make farmers reluctant or hesitant to irrigate with RW. Farming profitability as well as the prices of FW and RW significantly influence farmers' WTP. Farmers prove to be unwilling to pay more than 0.05 $/m^3$ of RW primarily because of comparatively easy access to FW at low price. The water price that farmers are willing to pay hardly covers the operation and maintenance costs for conveyance and distribution of the RW. Ambitious attempts to recover the full cost of treatment and conveyance and distribution might not succeed. Contingent valuation and logistic regression analysis prove to be reliable for elicitation of farmers' WTP.

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References

Ahmad, M. (2000). Water pricing and markets in the Near East: Policy issues and options. *Wat. Policy*, **2**, 229–242.

Alberdini, A. (1995). Efficiency vs. bias of willingness-to-pay estimates: Bivariate and interval-data models. *J. Env. Econ. and Manag.*, **29**, 169–180.

Al-Hamdi, M. (2001). *Competition for Scarce Groundwater in Sana'a Plain, Yemen: A Study on the Incentives System for Urban and Agricultural Water Use*. Ph.D. Thesis, IHE-Delft, The Netherlands.

Angelakis, A., Marecos, M., Bontoux, L. and Asano, T. (1999). The status of wastewater reuse practice in the Mediterranean basin: Need for guidelines. *Wat. Res.*, **33**(10), 2201–2217.

Ardila, S., Ricardo, Q. and Vaughan, W. (1998). A review of the use of contingent valuation methods in project analysis. *Env. Division, Working Paper No. ENV-126*. Inter-American Development Bank. Washington DC., USA.

Bahri, A. and Brissaud, F. (1996). Wastewater reuse in Tunisia: assessing a national policy. *Wat. Sci. Tech.*, **33**(10–11), 87–94.

Cooper, J. (1993). Optimal bid selection for dichotomous choice contingent valuation surveys. *J. Env. Econ. and Manag.*, **24**, 25–40.

Creel, M. (1998). A note on estimation of mean WTP using a misspecified logit contingent valuation model. *J. Env. Econ. and Manag.*, **35**(3), 277–284.

Emre, A., David, C., Charles, M. and Vladimir, N. (2002). Application of benefit transfer with contingent valuation method to the root river watershed. *Technical Report No 12*. May 2002. Milwaukee, Wisconsin.

Hair, J., Anderson, R., Tatham, R. and Black, W. (1998). *Multivariate Data Analysis*. 5th edition. Prentice-Hall International, USA.

Hanely, N., Wright, R. and Mourato, S. (2001). Choice modeling approaches: A superior alternative for environmental valuation. *J. Econ. Survey*, **15**(3).

Hanemann, M. and Kanninen, B. (1996). *The Statistical Analysis of Discrete-response CV Data*. Working Paper 794, Dept. of Agriculture and Resource Economics, University of California, Berkeley.

Johansson, M. (1999). *Economics without Markets: Four Papers on Contingent Valuation and Stated Preference Methods*. Department of Economics, Umea University, Umea. Borlange.

Maddala, G.S. (1983). *Limited-dependent and Qualitative Variables in Econometrics*. New York, Cambridge University Press, NY, USA.

Menard, S. (1995). *Applied Logistic Regression Analysis*. Sage Publications. Series: Quantitative applications in the social sciences, No. 106.

Mills, R. and Asano, T. (1996). A retrospective assessment of water reclamation projects. *Wat. Sci. Tech.*, **33**(10–11), 59–70.

Sanz, L. (1999). Irrigated agriculture in the Guadian river high basin (Castilla-La Mancha, Spain): Environmental and socioeconomic impacts. *Agric. Wat. Manag.*, **40**,171–181.

Snell, M. (1997). *Cost-benefit Analysis for Engineers and Planners*. Thomas Telford Publications, London, UK.

Vaughan, W., Russell, C., Rodriguez, D. and Darling, A. (1999). *Willingness to Pay: Referendum Contingent Valuation and Uncertain Project Benefits*. Inter-American Development Bank. Washington, D. C.

Whittington, D. (1998). Administering contingent valuation surveys in developing countries. Elsevier Science Ltd., UK, *World Development*, **26**(1) 21–30.

5

A Decision Tool for Allocating the Waters of the Jordan River Basin Between all Riparian Parties

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A Decision Tool for Allocating the Waters of the Jordan River Basin Between all Riparian Parties

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Abstract. Shared water resources are strong sources of conflict in the Jordan River basin shared by Israel, Jordan, Palestine, Syria and Lebanon. The control and allocation of water has been explicitly made a part of the ongoing peace negotiations. This 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 negotiators need a decision tool based upon objective criteria or standards to reach equitable entitlements to shared water resources by all parties. This paper introduces a multi-criteria decision tool as a possible approach to the problem of allocating the waters of the Jordan River between all riparian parties. The prime principle of the criteria is equitable allocation factors identified by water law. A general mathematical model was derived in which the proportional entitlements of the Jordan River basin waters were determined to the five riparians. It is hoped that, water negotiators review this approach.

Key words: conflict resolution, equitable allocation, International river basin management, Jordan river basin, middle east, riparian water rights, transboundary waters

1. Introduction

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, including the Nile, Jordan, and Euphrates. Shared water resources are especially strong sources of conflict in the Middle East particularly in the Jordan River basin shared by Israel, Jordan, Palestine (West Bank and Gaza), Syria and Lebanon. In this basin, water has been the roots, means, and causes 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 (Gleick, 1994).

The present problems that are related to water in the Jordan River riparian countries that are generally characterised by aridity and water scarcity are many

and varied and the disparity between water supply and demand is growing with time due to rapid population growth (Mimi and Smith, 2000). Unless all states cooperate and jointly manage their shared water resources they all stand to lose in terms of the long-term viability of their water systems. States can no longer fully satisfy their needs from common resources without adversely affecting (whether in terms of quantity or quality) the supply available to others. Both surface and groundwater resources of the basin suffer from overuse. The Jordan River south of the Lake Taberias becomes almost dry at summer times because of upstream diversion works. Because of this decreased flow the level of the Dead Sea has fallen from 392 to 407 m below sea level over the last years. As a result, groundwater levels have dropped and signs of the salination of the Jordan Valley' soils can be seen (Salameh, 1992). In other words, the only real choice all sides face is between a lose-lose situation if they do not cooperate, and a potential win-win situation if they do.

Over the past 100 years, many management plans and attempts to reach agreements over water resources in the Jordan River basin have been proposed. Al-Kloub and Abu-Taleb (1998) discussed the major formal plans like the Main Plan/Unified Plan (1953), Cotton Plan (1954), Arab Plan (1954), and Johnston Plan (1953). Countries in the region have continued to develop their water resources, often at the expense of other countries. Subsequent to the dissolution of the Johnston Plan, both Israel and Jordan decided to proceed with their water projects situated entirely within their own boundaries. As a result Israel constructed the National Water Carrier, which brings water from Lake Taberias to the south and central regions of Israel. Jordan further developed the East Ghor Canal off the Yarmouk River for irrigation.

In the Jordan River basin, the international water laws that regulate riparian rights are not well observed. No comprehensive agreements between all neighbouring countries exist, except the bilateral Jordanian-Israeli agreement signed in 1994. The agreement guarantees to Jordan about 215 million cubic meters per year (Mcm yr^{-1}), and sets the rules for rehabilitating the Jordan River water and for protecting the quality of shared water resources in both states (Al-Kloub and Abu-Taleb, 1998).

Currently, Arabs and Israelis are trying to break the political cycle of conflict within the framework of the Middle East peace process negotiations. Barring a collapse of the process, they will at some point have to confront the complex problem of water, including the definition of entitlements to shared fresh water resources. The challenge, however, will be to negotiate a fair and reasonable assignment of entitlements based on existing international water law. Therefore, the negotiators need a decision tool based upon objective criteria or standards to reach acceptable entitlements to shared water resources by all parties. This paper introduces one such multi-criteria decision tool and provides one possible approach to the problem of allocating the waters of the Jordan River between all riparian parties.

The approach depends on the discussion of the principles of a comprehensive water-sharing regime drawn from the international law of transboundary waters.

2. The Jordan River Basin System

The Jordan River originates in the southwestern Anti-Lebanon range, on Mount Hermon (Jabel Esh-Sheikh), which is covered with permanent snow. The river flows through Lebanon, Syria, Jordan, Palestine and Israel. The discharge that feeds the upper part of the Jordan River is derived principally from the group of karstic springs located on the Western and southern slopes of Mount Hermon.

The river flows southwards for a distance of 228 km along the bottom of a longitudinal graven known as the Rift Valley before emptying into the Dead Sea. Its principal tributary, the Yarmouk, forms the boarder between Syria and Jordan and divides Israel and Jordan in the Yarmouk triangle. Based on the nature of the hydrology, hydrogeology, and water use, the Jordan river system may be classified into three sections, namely: (1) Upper Jordan River that includes three major head-water streams: (i) the Dan, (ii) the Hasbani and (iii) the Banias; and (iv) the Huleh valley and (v) Lake Tiberias; (2) Yarmouk river which is the largest tributary of the Jordan river system; (3) Lower Jordan river which flows through the deepest portion of the Rift Valley to enter the Dead Sea at 401 m below sea level, the lowest point of the earth. The natural flow of the river in the absence of extraction is estimated from 1250 to 1600 Mcm yr^{-1} at the entrance to the Dead Sea (Soffer, 1994; Lonergan and Brooks, 1994). Figure 1 shows the Jordan River System with the main existing and planned water projects including the National Water Carrier and the East Ghor Canal discussed earlier.

3. International Water Law

International water law and international institutions must play a leading role in solving water conflicts and reducing the associated risks of war and pollution. International water law may be the acceptable basis of an agreement for the ripari-ans of the Jordan River basin. In 1991, the International Law Commission (ILC), an organisation 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. The pertinent aspect of international water law is the following principles spelled out in the above convention and Helsinki Rules that help to reduce tensions and encourage effective and productive negotiations by the parties involved. It should be noted that these principles are not ranked according to priority (Gleick, 1994; UN, 1997):

- equitable allocation;

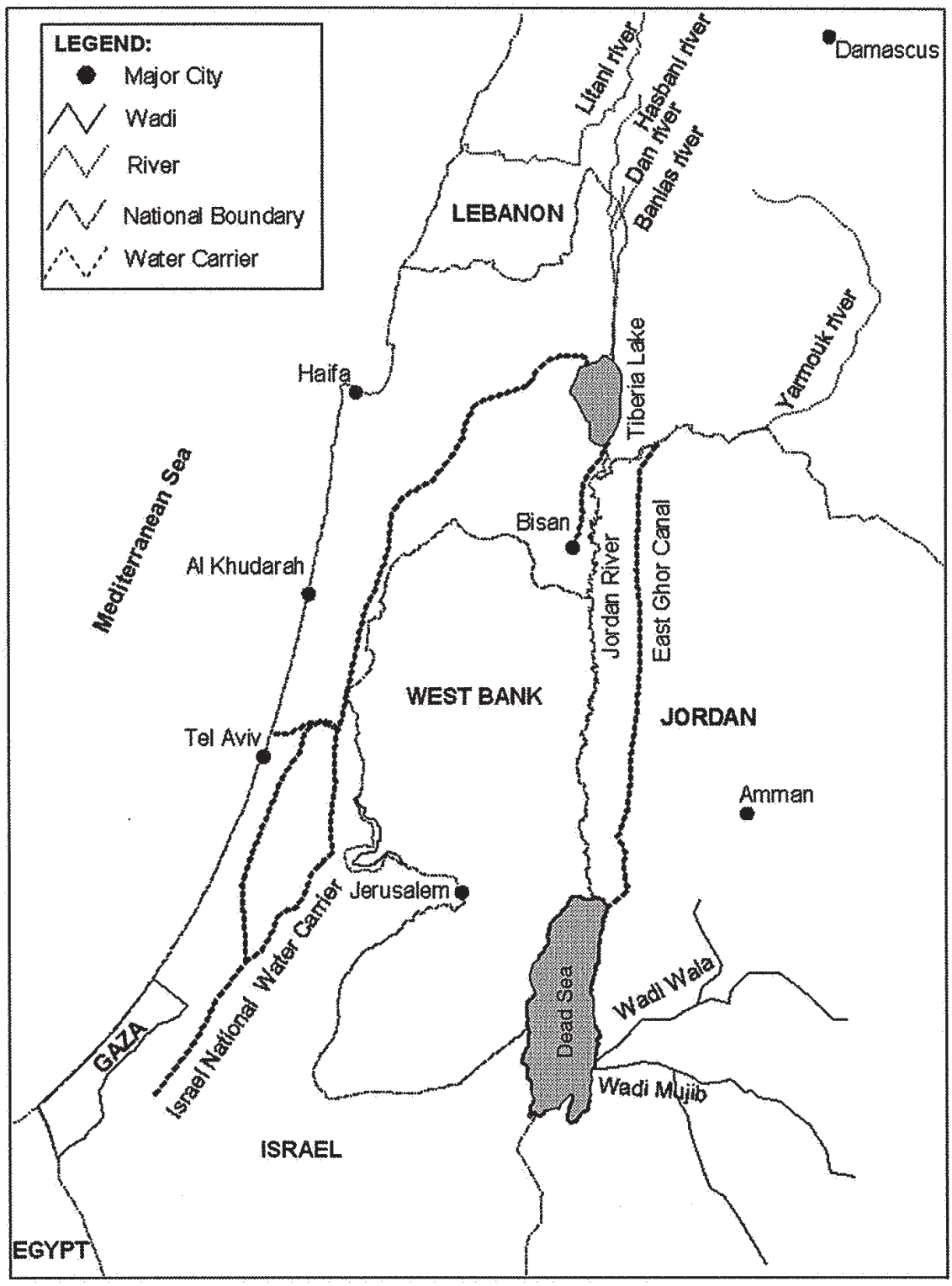


Figure 1. The Jordan River system.

Table I. 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 utilisation of the waters of the basin, including in particular existing utilisation.
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.

- obligation to resolve water related disputes peacefully;
- obligation not to cause harm to other riparian states;
- obligation to exchange hydrologic and other relevant data and information on a regular basis.

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 principles and means of enforcement (Caponera, 1994; Elmusa, 1994). In some ways, the more challenging task for negotiators is to translate those principles into operating rules and procedures to determine the equitable apportionment of waters from shared water resources. One assumes that Arab and Israelis would wish to abide by international water law.

The principle of equitable allocation is one of the most important developed by ILC 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 (Gleick, 1994). 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 I lists the diverse factors that the International Law Association associated with equitable water use (Eaton and Eaton, 1994; UN, 1997).

Table II. Alternative equity standards (share in percent)

Equity standard No.	F1	F2	F3	F4	F5	F6	F7	F8	F9
Israel share	9	12	10	60	8.4	16.4	6.7	19	8.4
Jordan share	39	38	12	25	5.3	14.5	26.7	21	5.3
Lebanon share	3	8	29	1	11.6	11.2	20	9	11.6
Syria share	37	31	29	12	70.8	47.1	13.3	8	70.8
Palestine share	12	11	20	2	3.9	10.8	33.3	43	3.9
Total	100	100	100	100	100	100	100	100	100

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 (Caponera, 1994).

4. An Approach for Allocating the Waters of the Jordan River Basin

There has been much written in recent years about the application of water law in the Jordan River basin, as well as the development of different allocation schemes based on the interpretation of these 'laws' or using other criteria. These publications include Assaf *et al.* (1993), Shuval (1994), Moore (1994), Gleick (1994), Caponera (1994), Elmusa (1994), Al-Kloub and Abu-Taleb (1998), and Haddadin (2000).

The approach presented here will provide one possible approach to the problem of allocating the waters of the Jordan River between all riparian parties. The approach translates the principle of equitable utilisation into a set of procedures to determine the riparians' entitlements to the shared waters.

The nine equity factors (Table I) were applied yielding alternative nine equity standards (Table II). 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 II 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 III. Catchment area and riparian contributions in the Jordan River Basin (km^2)

	Israel share	Jordan share	Lebanon share	Syria share	Palestine share	Total
Catchment area (km^2)	1867	7663	664	7301	2344	19839
F1 equity standard (%)	9	39	3	37	12	100

Source: Elmusa (1997).

Table IV. Riparians' contribution to the flow of the Jordan River Basin

	Israel share	Jordan share	Lebanon share	Syria share	Palestine share	Total
Discharge (Mcm yr^{-1})	155	506	115	416	148	1340
F2 equity standard (%)	12	38	8	31	11	100

Source: GTZ (1996).

4.1. FACTOR F1 – GEOGRAPHY

The geography of the basin determines the amount of rainfall caught and, consequently, the total volume of surface and ground water run-off into the mainstream courses (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 laying within each watercourse state represents only one measure of the inflow to the basin coming from these states. Table III presents one estimate of each riparians' share of the Jordan River catchment area and the equity standard derived from this factor.

4.2. FACTOR F2 – HYDROLOGY

The hydrology of the Jordan River basin affect the discharge of the stream that can be defined as the total volume of water flowing past a given point in a known unit of time. Table IV offers one estimate of the average annual riparians' contribution to the discharge of the Jordan River basin and the equity standard derived from this factor.

4.3. 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

Table V. Average annual rainfall over the Jordan River Basin

	Israel share	Jordan share	Lebanon share	Syria share	Palestine share	Total
Rainfall (mm)	184	222	508	508	361	1783
F3 Equity standard (%)	10	12	29	29	20	100

Source: GTZ (1996).

Table VI. Existing utilisation of the Jordan River Basin

	Israel share	Jordan share	Lebanon share	Syria share	Palestine share	Total
Quantity (Mcm yr^{-1})	810	340	5	165	20	1340
F4 Equity standard (%)	60	25	1	12	2	100

Source: GTZ (1996).

this research precipitation was considered for the Jordan River basin as shown in Table V (other factors could be considered as well).

4.4. FACTOR F4 – UTILIZATION

Israel is currently the dominant user of the waters of the Jordan River basin. With the capture of the Golan Heights during the Six-Day War and the extension of the security zone into southern Lebanon, Israel became the major user of the Jordan River. Table VI presents the existing utilization of the Jordan River basin and the equity standard derived from this factor.

4.5. FACTOR F5 – ECONOMIC AND SOCIAL NEEDS

The economic and social needs of each basin state can be quantified by estimating the projected water demands form all sources for domestic, industrial and agricultural sectors for the five riparian states as summarised in Table VII.

Table VII. Projected water demands (million m^3)[1]

	Israel	Jordan	Lebanon	Syria	Palestine	Total
Water demand for the year 2025 (million m^3)	2800	1760	3850	23555	1290	33255
F5 equity standard (%)	8.4	5.3	11.6	70.8	3.9	100

Source: ESCWA (2002) except the figures for Israel, which were compiled by the authors from GTZ (1996).

Table VIII. Projected population for the year 2015 (millions)

	Israel share	Jordan share	Lebanon share	Syria share	Palestine share	Total
Population 1998	6.0	4.6	4.2	15.3	2.7	32.8
Population 2015	7.6	6.7	5.2	21.8	5	46.3
F6 equity standard (%)	16.4	14.5	11.2	47.1	10.8	100

Source: World Bank (2000).

Table IX. GDP for the Jordan River Basin riparians (millions U.S.$)

	Israel share	Jordan share	Lebanon share	Syria share	Palestine share	Total
GDP (1998)	100525	7393	17229	17412	3589	146148
Rank	1	4	3	2	5	
F7 equity standard (%)	6.7	26.7	20	13.3	33.3	100

Source: World Bank (2000).

4.6. FACTOR F6 – POPULATION

The countries of the Jordan River Basin 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 VIII presents the projected population for the countries of the Jordan River basin and the equity standard derived from this factor.

4.7. FACTOR F7 – COMPARATIVE COSTS OF ALTERNATIVES

Alternative water resources refer specifically to potential 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 (Elmusa, 1994). 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 or canals from the 'water rich' countries in the Middle East like Turkey, to poorly endowed countries (Murakami and Musiake, 1994).

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,

Table X. Renewable water resources and water demands in the countries of the Jordan River Basin

	Israel	Jordan	Lebanon	Syria	Palestine
Total renewable water resources (million m^3)	1104	627	3100	21475	215
Water demand for the year 2025 (million m^3)	2800	1760	3850	23555	1290
WSI (for the year 2025)	254	281	124	110	600
F8 equity standard (%)	19	21	9	8	43

Source: ESCWA (2002) except the figures for Israel, which were compiled by the authors from GTZ (1996).

GDP was taken as measure of comparison to reach the equity standard as shown in Table IX.

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 economical for agriculture, while desalinated seawater is affordable for domestic use and may be economical for some crops. Palestinian, Syrian, Lebanese, and Jordanian consumers, conversely, would be heavily burdened by the costs of desalinated water (Kally, 1994).

4.8. FACTOR F8 – AVAILABILITY OF OTHER RESOURCES

Renewable water resources, water demands and Water Stress Index (WSI) in the countries of the Jordan River basin are presented in Table X. 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 X was compiled to obtain the equity standard.

4.9. FACTOR F9 – APPRECIABLE HARM

The words 'appreciable harm' have created definitional problems to all riparian states (Elmusa, 1994). Goldberg (1992) 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 (1992) 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*

Table XI. Weight of alternative equity standards[a]

Equity factor	F1	F2	F3	F4	F5	F6	F7	F8	F9
Average weight (%)	8	15	14	20	12	10	8	8	5
Range	7–12	12–16	12–15	17–22	10–13	8–11	7–9	7–11	2–7

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

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.

5. Optimal Allocation Outcome to the Shared Surface Water Resources

It could be argued that some of 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 ninety water experts all over the world including experts from the five riparian countries. The water experts who work in water institutions, universities and non-governmental organizations involve professional economists, irrigation engineers, water resources engineers 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). Table XI presents the average weight for each equity factor obtained from the collected answered questionnaires.

Returning to the nine alternative equity standards (Table II), 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 necessarily 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 II can be written as $F_i = (X_{i1}, X_{i2}, X_{i3}, X_{i4}, X_{i5})$ that specify the proportional shares of the Jordan River basin waters allocated to the riparians, where i refers to the equity standard, X_{i1} represents the Israeli, X_{i2} the Jordanian, X_{i3} the Lebanese, X_{i4} the Syrian, and X_{i5} the Palestinian shares. The sum of the five shares equals 100%. To illustrate, the first and second alternative

equity standards can be written, respectively, as F_1 (9, 39, 3, 37, 12) and F_2 (12, 38, 8, 31, 11).

Any allocation outcome can be written as $X_j = (X_1, X_2, X_3, X_4, X_5)$ that specify the proportional entitlements of the Jordan River basin waters allocated to the five riparians, where X_1 represents the Israeli, X_2 the Jordanian, X_3 the Lebanese, X_4 the Syrian, and X_5 the Palestinian entitlements. The sum of the five entitlements equals 100%.

The optimal allocation outcome can be written as $X_j^* = (X_1^*, X_2^*, X_3^*, X_4^*, X_5^*)$ and can be defined as the one that minimises the square of the summation of the distances (d) measured outward from itself to all equity standards. The objective function 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.

$$\text{Minimize } d = \sum_{i=1}^{9} W_i \sum_{j=1}^{5} \left(X_{ij} - X_j^*\right)^2 , \tag{1}$$

where

i = 1, . . ., 9, refers to the equity standards.

j = 1, . . ., 5, 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 (%).

W_i = the weight of the ith equity factor (%).

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

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 equalled to zero ($\frac{\partial d}{\partial X_j^*} = 0$). This leads to Equation (2), which is the optimal solution of Equation (1).

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

Applying Equation (2) to the Jordan River basin and based on Tables II and XI, the optimal allocation outcome specifies the proportional entitlements of the Jordan River basin waters allocated to the five riparians. The equation yields the following

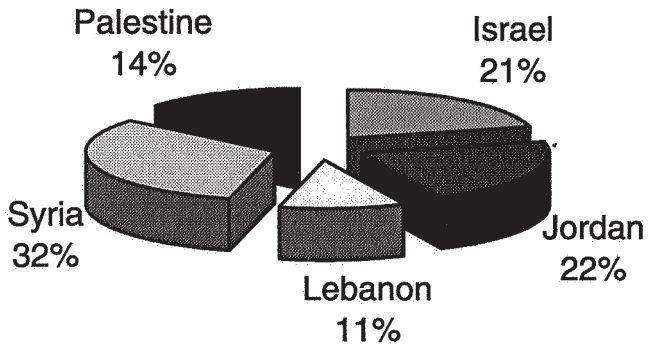


Figure 2. Optimal allocation for the river basin.

results (21, 22, 11, 32, and 14%), where 21 represents the Israeli, 22 the Jordanian, 11 the Lebanese, 32 the Syrian, and 14 the Palestinian entitlements as presented in Figure 2.

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.

6. 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 law 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 Jordan River basin 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 Jordan River basin and 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.

Sharing water resources data is considered a basic tenet of water international law, yet accurate long-term data on shared and disputed water resources in the Jordan River basin are often restricted. This restriction must stop if any progress is to be made in resolving water disputes, and all water resources data should be immediately and fully released to all parties.

References

Al-Kloub, B. and Abu-Taleb M.: 1998, 'Application of multi-criteria decision aid to rank the Jordan-Yarmouk Basin co-riparians according to the Helsinki and ILC rules', *Water International* IWRA **23**(3), 164–173.

Assaf, K., Alkatib, N., Kally, E. and Shuval, H.: 1993, *A Proposal for the Development of a Regional Water Master Plan*, Israel-Palestine Centre for Research and Information, IPCRI Publishers, Jerusalem, p. 192.

Caponera, D.: 1994, 'The Legal Institutional Issues Involved in the Solution of Water Conflicts in the Middle East: The Jordan', in J. Issac and H. Shuval (eds), *Water and Peace in the Middle East*, Elsevier Publishers, Amsterdam, pp. 163–179.

Eaton, J. and Eaton, D.: 1994, 'Water Utilisation in the Yarmouk-Jordan, 1192–1992', in J. Issac and H. Shuval (eds), *Water and Peace in the Middle East*, Elsevier Publishers, Amsterdam, pp. 93–106.

Elmusa, S.: 1994, 'Towards an Equitable Distribution of the Common Palestinian-Israeli Waters: An International Water Law Framework', in J. Issac and H. Shuval (eds), *Water and Peace in the Middle East*, Elsevier Publishers, Amsterdam, pp. 450–468.

Elmusa, S.: 1997, *Water Conflict: Economics, Politics, Law and Palestinian-Israeli Water Resources*, Institute for Palestine Studies, Washington, DC, p. 408.

ESCWA: 2002, *Assessment of Legal Aspects of the Management of Shared Water Resources in the ESCWA Region*, United Nations, New York, p. 142.

Gleick, P.: 1994, 'Reducing the Risks of Conflict over Fresh Water Resources in the Middle East', in J. Issac and H. Shuval (eds), *Water and Peace in the Middle East*, Elsevier Publishers, Amsterdam, pp. 41–54.

Goldberg, D.: 1992, *Projects on International Waterways: Legal Aspects of the Bank's Policy*, World Bank, Washington, DC, p. 230.

GTZ: 1996, *Middle East Regional Study on Water Supply and Demand Development*, Al-Najah University Press, Nablus, p. 350.

Haddadin, M. J.: 2000, 'Negotiated resolution of the Jordan–Israel water conflict', *Internat. Negot.* **5**(2), 263–288.

Kally, E.: 1994, 'Costs of International Conveyance of Water and Costs of Sea Water Desalination', in J. Issac and H. Shuval (eds), *Water and Peace in the Middle East*, Elsevier Publishers, Amsterdam, pp. 289–300.

Lonergan, C. and Brooks, D.: 1994, *Watershed: The Role of Fresh Water in the Israeli–Palestinian Conflict*, International Development Research Centre, IDRC Publishers Ottawa, p. 310.

Mimi, Z. and Smith, M.: 2000, 'Statistical domestic water demand model for the West Bank', *Water International*, IWRA **25**(3), 464–468.

Moore, J.: 1994, 'Partining the waters: Calculating Israeli and Palestinian entitlements to West Bank aquifers and the Jordan River Basin', *Middle East Policy* **3**(2), 91–108.

Murakami, M. and Musiake, K.: 1994, 'The Jordan River and the Litani', in A. Biswas (ed.), *International Waters of the Middle East from Euphrates-Tigers to Nile*, Oxford University Press, Oxford, pp. 117–155.

Shuval, H.: 1994, 'Proposals for the integrated management of the shared transboundary water resources of the Jordan River Basin', *Water Science and Technology*, IAWQ **30**(5), 187–193.

Salameh, E.: 1992, 'The Jordan River System', *Proc. of a Symposium on Jordan's Water Resources and Their Future Potential*, University of Jordan Press, Amman, p. 570.

Soffer, A.: 1994, 'The Relevance of Johnston Plan to the Reality of 1993 and Beyond', in J. Issac and H. Shuval (eds), *Water and Peace in the Middle East*, Elsevier Publishers, Amsterdam, pp. 107–122.

UN: 1997, *Convention on the Law of the Non-navigational Uses of International Watercourses*, <http://www.thewaterpage.com/UN_Convention_97.html> (July 12, 2001).

World Bank: 2000, *2000 World Development Indicators*, The International Bank for Reconstruction and Development, Washington, DC, p. 389.

6

List of Successfully Defended Thesis at the Water Studies Institute in the Last Four Years

"Discipline is the Bridge between Goals and Accomplishment"

Jim Rohn

The following table lists the thesis studies which had been successfully defended at the Water Studies Institute in the last four years.Abstracts are available on the institute's website:http://home.birzeit.edu/iws.Hard copies of the thesis are available at the main library at Birzeit University.

NO.	THESIS TOPIC	Author
1	Optimization of Specific Methanogenic Activity (SMA) Assay	Abdul-Fattah Hasan
2	Development of Two Stage Biofilter as a Post Treatment Option for UASB pre Treated Domestic Wastewater.	Abdul-Halim Fuqaha'
3	Hydrology of Uja-Tamsah Catchment with Emphasis on the Analysis of Rainfall Data	Adel Yasin
4	Enhanced Pretreatment of Black Wastewater from Birzeit University Using UASB Technology	Ahmad Juaidi
5	Investigation of Bilogical Nitrogen Removal in Natural Treatment Systems	Arqam Hijawi
6	Evaluation of the Municipal Water Supply Systems in the West Bank.Statistical Analysis and Identification of the Influencing Factors	Ayesh Salahat
7	Multi Criteria Decision Model of the Quantification of the Shared Water Resources Based on the International Water Law	Bassam Sawalhi
8	Rainfall Runoff Analysis and the Synthetic Unit Hydrograph for The Wadi Faraa Catchment	Basema Bashir
9	Development of a modified Method for Reducing the Environmental Impact and Economics of the Unhairing- Liming Process in the Leather Industry	Dima Nazer
10	Ammonia Volatilization in Duckweed Based and Algae Based Stabilization Containers.	Iyad Yacoub
11	Development of an Integrated Water Management Strategy for Ramallah Rural Areas	Hani Ayed
12	Performance of Solar Powered Reverse Osmosis Sea	Husam Farah
13	Assessment of Treated Wastewater Reuse for Irrigation in Hebron City	Imad Zeer
14	Performance Evaluation and Process Optimization of Talitha Kumi Waste Stabilization Ponds	Johnny Theodory

15	Assessment of UASB Technology as a pre treatment stage for Domestic Wastewater	Manal Ali
16	Hydraulic Differences Between Duckweed Based and Algae Based Wastewater Treatment Ponds	Mazen Al-Ahmad
17	The Role of Wastewater Characteristics on the Selection of Anaerobic Treatment Technology	Mohamad Amarneh
18	Community Onsite Anaerobic Sewage Treatment in UASB Septic Tank	Mohammad Shayyah
19	Domestic Wastewater Treatment in an Integrated UASB/ Algae and Duckweed Pond Based System	Muheeb Jabari
20	Evaluation of Wastewater Treatment Alternatives for Hebron City	Musbah Tahboub
21	Groundwater Pollution Model for Wadi Zeimar	Nancy Rumman
22	Modeling of Domestic Water Use for the Service Area of Nablus Municipality	Nida Qzeh
23	Quantification of Nitrification and gentrification Rates In Algae Based and Duckweed Based Waste Stabilization Ponds	Nuha Ghneim
24	Optimization of Water Use in Agriculture:Tubas Area as a Case Study	Qabas Bisharat
25	The Effectiveness of Water Education in Water Conservation	Rana Qemari
26	On the Sustainability of Wastewater Management in the Rural Areas of Ramallah-Al-Bireh District	Sana Mubarak
27	Monthly Recharge Estimation for the Western Basin Aquifers System-Al-Aoja Tamsah Catchment ,Palestine	Sawsan Asbah
28	Domestic Wastewater Treatment Using Integrated UASB Pond System :Comparison of Pathogen Removal Efficiency	Subhi Samhan
29	Improvements on the Performance of Locally Constructed Pumps.	Suhad Taweel
30	Septage Characterization and Impact Assessment on the Treatment Efficiency of AlBireh Sewage Treatment	Taghreed Hithnawi
31	Margimal Cost Opprtunity for Municipal Wastwater Treatment In the West Bank	Naser Abu Sharbak

7

WSI Updates

WSI Staff Meeting

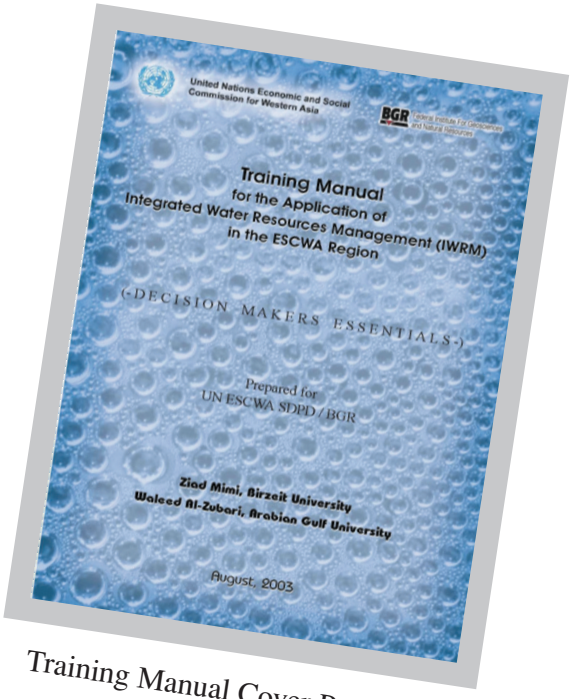
Staff News:

On 1st of July 2004, Dr.Maher Abu-Madi joined the permanent staff of WSI after successful defense of his PhD thesis on 22 June 2004 at the Technical University of Delft and UNESCO-IHE Institute for Water Education, The Netherlands.The title of his PhD thesis was “Incentive Systems for Wastewater Treatment and Reuse in the MENA Region:Evidence from Jordan and Tunisia”. His PhD managed to address and link several aspects of wastewater treatment and reuse, especially technical, financial,and socioeconomics.

PhD defence of Dr.Maher Abu-Madi 22 June 2004 at Delft Technical University,the Netherlands.

***Dr. Ziad Mimi** has been nominated as a member of the graduate and professional training group for the GTZ-PWA Project "Coordination of Training Activities in the Palestinian Water Sector". Dr. Mimi has been selected to work as a representative of Engineering Association and Birzeit University.

Granduate and Proffessional Training Group Meeting



Training Manual Cover Page

***Dr. Mimi** together with Dr Waleed Al-Zubari from Arabian Gulf University has finished the draft Training Manual for the Application of Integrated Water Resources Management (IWRM)in the ESCWA Region. The UN-ESCWA will start implementing the manual in different ESCWA countries in the year 2005.

* Among the main efforts of the WSI is fostering the international networking via memberships of its staff in national and international associations working in the fields of water, sanitation and environment. Arab Healthy Water Association (AHWA) is one of the leading Arab Associations reviewing the international standards of drinking water and disseminating the proper information on the recommended minerals in the drinking water for a healthy life. Dr. Rashed Al-Sa'ed is a member in the AHWA Advisory Panel and also a "Coordinator" nominee in the Arab Union of Scientists and Researchers (AUSR). For more information about the two associations and free memberships you can pay a visit to the AHWA website http://www.mgwater.com/index.shtml and AUSR homepage http://www.ausr.org.

***Dr.Omar Zimmo** has been nominated as a chairman of the Wastewater Technician Training Working Group for the GTZ-PWA Project "Coordination of Training Activities in the Palestinian Water Sector". Dr. Zimmo has been selected to work as a representative of Birzeit University from the service providers/operators in this working group.

***Dr. Zimmo** has been nominated as a member of the Technical Network Commission (TNC) for the UNESCO-FLANDER FIT and Al-Azhar University in Gaza. Dr.Zimmo is presenting Birzeit University in this network commission which is formed from another eight experts from the Palestinian Institutions and Universities.

*During the Anaerobic Digestion World Congress in Montreal, Canada (August 30 –September 2, 2004) the winning project of the second Lettinga Award was made public.Before doing so, the jury judged about 30 project proposals on quality, innovative character, and applicability in practice. The project submitted by Dr. Nidal Mahmoud from the Water Studies Institute entitled "Application of a UASB-digester system for treatment of domestic sewage under Mediterranean temperature conditions" finished second in a very close race with the winning project of Madalena Alves from Portugal.

Ongoing projects

1) "Efficient Management of Wastewater: its Treatment and Reuse in the Mediterranean Countries". The project is funded by European Commission under the EU-MEDA "Regional Program for Local Water Management"and co-funding from the German Ministry for Economic Co-operation and Development (BMZ). Counterpart Organization are: InWEnt Capacity Building International, Germany; Al al Bayt University, Al-Mafraq, Jordan; University of Balamand, Tripoli, Lebanon; Yildiz; Technical University, Istanbul,Turkey; Hamburg University of Technology, Germany;Adelphi Research Consult, Berlin, Germany ENEA, National Agency for New Techn,Energy &Environment,Italy.Project Period:5 January 2003 -30 April 2007.

2) "Compact Onsite Wastewater Treatment Plant Using Biofilters Preceded by An Anaerobic Upflow Sludge Blanket (UASB)Reactor to enhance the effluent quality for agricultural irrigation".The project is funded by USAID via AED through the Ministry of Education and Higher Education. The major aim of the project is to reduce the pathogens content and the nitrogen pollution load in the UASB treated effluent if used for irrigation or discharged into receiving water bodies.

Al-Bireh Demonstration Research

3) "The reuse of reclaimed wastewater for irrigation of agricultural crops in the Palestinian highlands".The project is funded by UNESCO-Flanders Fund-In-Trust."Project Period:November 2003-October 2005.

Flower irrigated by reclaimed wastewater at the research station

4) "Capacity Building in Environmental Sector at Water Studies Institute."The project is funded by European Commission under Tempus projects. The project will be implemented with the help of the Royal Institute of Technology (KTH) at Sweden and UNESCO-IHE at Netherlands. The objective of this project is to develop the curricula of the existing two Master programs (Water Engineering and Water Science and Technology)to include environmental subjects. Starting from academic year 2005/2006, The two academic programs will be offered are (i)Water and Environmental Engineering, and (ii)Water and Environmental Sciences and Technology.

PARTNERSHIPS

PoWER:

Among the international partnerships of the Water Studies Institute is its membership in the Partnership for Water Education and Research (PoWER) lead by the UNESCO-IHE Institute for Water Education. PoWER is an international partnership of knowledge centers dedicated to building capacity for the sustainable management of water and environmental resources in order to improve the quality of human life and the environment in developing countries and countries in transition.Joined by this common vision, the WSI along with seventeen partner organizations from around the world met in Delft,The Netherlands in November 2002 to co-found PoWER.

In combining the strength of all partners through collaborative research and information exchange, PoWER aims to enhance the capacity of each partner in delivering capable professional in the water and environment sectors, in finding innovative solutions for water and environmental challenges, and in building up the capacity of institutions and communities.

AWARENET:

Water Studies Institute is one of the founders and a member in AWARENET (Arab Integrated Water Resources Management Network). AWARENET is a network of institutes collaborating on improving and disseminating knowledge on concepts of Integrated Water Resources Management in the ESCWA region (The Economic and Social Commission for Western Asia con sists of the following 13 member countries:
Bahrain, Egypt, Iraq, Jordan Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Palestine and Yemen).

The members of represent institutions operating at national, regional and international levels. AWARENET aims to improve awareness among professionals working in water and water-related institutions (water ministries, municipalities, universities, training and research institutions, NGOs and other stakeholders) on the need to develop and adapt Integrated Water Resources Management (IWRM) concepts and applications in the context of the Arab region. It is geared towards building -up the technical, institutional and managerial capacity of water stakeholders in implementing IWRM, in view of achieving sustainable water resources development (social equity,economic efficiency,and ecological sustainability)in the Arab countries.

AWARENET Meeting at Bahrain (Feb. 2004)

WATER networks:

WSI is a member of the following three steering committees:(1)The Steering Committee of the Wadi Hydrology Network in the Arab region;(2)The Steering Committee of the Groundwater Protection Network in the Arab region;and (3)The Steering Committee of the Digital Water Map of the Arab world.The main activities of the networks included organizing training courses to train the Arab cadres in the fields of the exploitation of the rain water and the protection of the groundwater resources from pollution and depletion;and supporting the exchange of experience and knowledge among the Arab experts through the use of the information techniques and the Internet.

Water Supply And Sanitation Collaborative Council (WSSCC)

WSI Fought for the Open Seat within the new WSSCC Steering Committee. As a regional WSSCC Steering Committee candidate in the open seat category, Dr.Rashed Al-Sa'ed reached a tied place (Palestine and South Africa 70 votes each; Ivory Coast 102; Israel 58 votes) for the second 'open'seat. The open seat category comprised two seats (any region of the world) and only two candidates can be elected for these seats.

The elections have been very exciting with a great success, where forty-seven candidates have been nominated and more than 20%of the WSSCC members voted electronically.The final decision was met through a secret ballot made by the current Steering Committee during its last meeting held on the 28th of November 2004 at the Global WASH Forum in Dakar. Despite the huge efforts (website battle)made to win the open seat,unfortunately,Dr.Al-Sa'ed was not able to attend the meeting and probably because of that he won only 9 votes against 10 votes in favor of the African candidature.In particular, any water professional, if interested,can apply for a free membership and profit from the information and services provided by the WSSCC **website:http://www.wsscc.org/home.cfm.**

New Funded Projects:

1) The UNESCO-Flanders Fund-In-Trust Project on "Capacity Building and Training on Environmental Planning and Management,Phase-II" will fund two new research proposals. The first research entitled "Application of a UASB-digester system for domestic sewage treatment in Palestine". The second research entitled "Development and valuation of local fixed film materials to reclaim the effluent of septic tank-natural treatment systems for irrigated agriculture".

2)PoWER and UNESCO-IHE will support financially and technically the establishment of "Distance Learning Centre"at Birzeit University.This centre will enable the WSI to extend its academic and training services to beneficiaries all over the world through internet and video conferencing.

3) PoWER and UNESCO-IHE will fund a research project on water and wastewater tariffs. WSI is leading nine institutions in differents countries (Argentina, Mexico, Colombia, Ghana, Zimbabwe, China, Taiwan, Egypt, and Netherlands) in this research project.

Workshops and training:

1) Within the framework of MED-REUNET project, a workshop on Hygienic assessment of Albireh reclaimed wastewater for processed crops irrigation: guidelines development was conducted at the WSI. About 20 local professionals in water and environment representing 12 national, local and foreign NGOs, and university departments showed interest and attended the workshop program.

2)Within the framework of the EMWater project, InWEnt-Capacity Building International Germany and the Water Studies Institute (WSI) at Birzeit University implemented a series of training courses for the Palestinian engineers and professionals working in the water/wastewater management and in the environmental sector. The courses were held at Birzeit University from 19 June till 03 August 2004.

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World Water Day

World Water Day

The Water Studies Institute at Birzeit University will celebrate the World Water Day and the twelve year partnership with the IHE Institute in 13-14 April 2005. The celebration will include presenting scientific papers with the participation of various local and international guests who contributed to the development of the water sector in Palestine in general and the Water Studies Institute in particular.

The international observance of World Water Day is an initiative that grew out of the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro. The United Nations General Assembly designated 22 March of each year as the World Day for Water by adopting resolution (A/res/47/193 of 22 February 1993). This world day for water was to be observed starting in 1993, in conformity with the recommendations of the United Nations Conference on Environment and Development contained in chapter 18 (Fresh Water Resources)of Agenda 21.

States were invited to devote the Day to implement the UN recommendations and set up concrete activities as deemed appropriate in the national context.

Objectives

World Water Day is pivotal to focusing attention on the need, among others,to: address the problems relating to drinking water supply; increase public awareness on the importance of conservation, preservation, and protection of water resources and drinking water supply increase governments, international agencies,non-governmental organizations, and private sector partici pation and cooperation in the organization of WWD celebrations. 22 March is therefore a unique occasion to remind everybody of the extreme importance of water for maintaining the environ ment and increasing development in human societies. Practical efforts can help us to increase worldwide awareness of both problems and solutions. To make a difference our tasks consist in turning words into commitment and action, in the framework of a general theme.

World Water Day 2005

World Water Day (WWD) 2005 will be guided by the upcoming water decade's "Water for Life". It will be the starting day for this International Decade for Action, "Water for Life" 2005-2015, proclaimed by the United Nations General Assembly in its resolution **A/RES/58/217**.