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FOREWORD

On April 2009, the World Bank published a report entitled: "West Bank and Gaza Assessment of Restrictions on water Sector Development". The Institute of Environmental and Water Studies (IEWS) welcomes this study by the World Bank that highlights some major problems faced daily by Palestinians living under Israel's 42 year military rule. The study highlights the following points:

1. Water withdrawals per head of the Palestinian population have been declining, and there are real water shortages.
2. There has been little progress on wastewater collection and treatment, with negative environmental results.
3. Network coverage rates at Gaza are high and supply and availability had improved but border closures and conflict have now led to severe deterioration of water supply reliability.
4. Sanitation services in Gaza are in crisis. Gaza's wastewater collection and treatment infrastructure is inadequate.
5. The Palestinian Water Authority is unable to conduct integrated management of the resources in the West Bank within the current governance framework.
6. Joint Water Council (JWC) has not fulfilled its role of providing an effective collaborative governance framework for joint resource management and investment. JWC does not function as a "joint" water resource governance institution because of fundamental asymmetries- of power, of capacity, of information, of interests- that prevent the development of a consensual approach to resolving water management conflicts.

Israel has further exacerbated the decades-long water crisis faced by Palestinians through its role as an occupying force on domination and controlling rather than facilitating and sharing the responsibility over the shared management of the transboundary water resources in accordance with international water law.

In the occupied Gaza Strip, Israel has for decades effected policies that promoted, directly or indirectly, de-development of the water infrastructure. It is therefore of little surprise that a mere 10 percent of the water there is of drinkable quality. Moreover, with impunity, Israel has attacked Palestinian wastewater infrastructure and, through its continued siege on the occupied Gaza Strip has prevented its reconstruction. The humanitarian crisis in the Gaza Strip pre-dated Israel's latest war on Gaza at the end of 2008, but was of course made even more critical thereafter.

As an occupying power under international humanitarian and human rights law, Israel is responsible for the welfare of the civilian population and must ensure that Palestinians are provided with or allowed to secure the basics for survival including food, water, medical supplies and shelter.

This issue of Birzeit Water Drops includes five articles that were published in refereed journals in different areas in water and environmental subjects. In addition, updates on the IEWS's activities and staff news are included.

Ziad Mimi,

Director, Institute of Environmental and Water Studies

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THE RIVER MOVES FROM LAND TO WATER TO LAND IN AND OUT OF ORGANISMS, REMINDING US WHAT NATIVE PEOPLE HAVE NEVER FORGOTTEN THAT YOU CANNOT SEPERATE THE LAND FROM THE WATER OR THE PEOPLE FROM THE LAND...

Lynn Noel,
Voyages: Canada's Heritage Rivers
Water Wisdom Book, 2006

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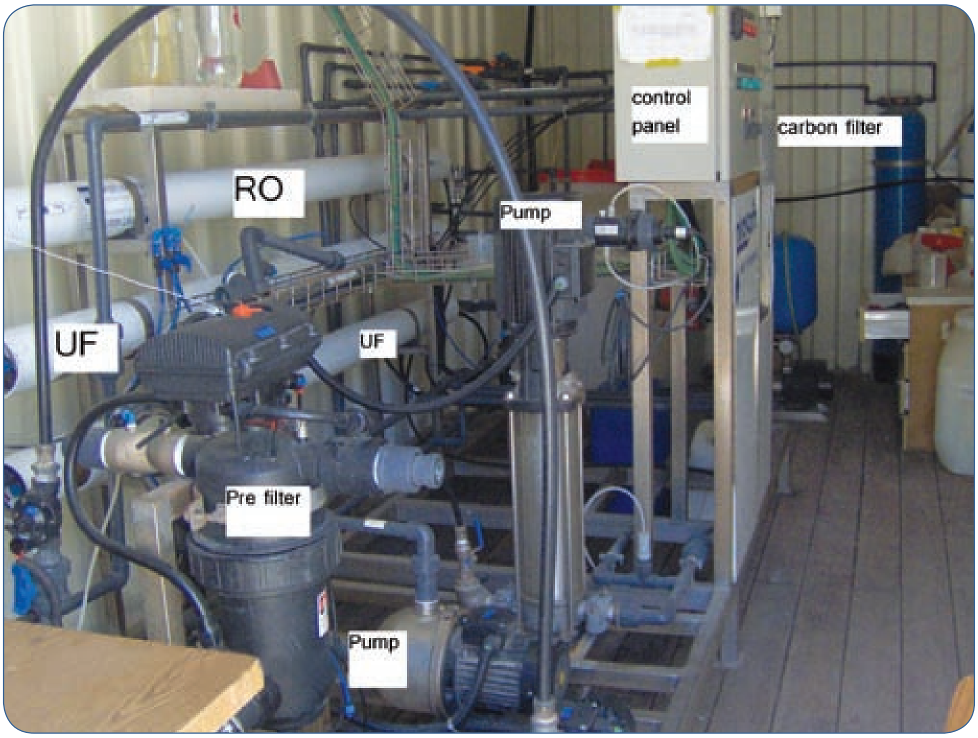
Advancing Membrane Technologies for Wastewater Treatment and Reclamation in Selected Arab MENA Countries

Rashed Al-Sa'ed, Sami Sayadi, Adnan Ghata, Hussein Abdel-Shafi, Gerhard Schories, Marisol Oropeza, Antonia Lorenzo and Enrico Drioli



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Advancing membrane technologies for wastewater treatment and reclamation in selected Arab MENA countries

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ABSTRACT

Membrane technology (MT) is advancing rapidly as a powerful tool to abate the looming water crisis and reduce quality degradation of water resources in the Mediterranean zone. Despite several national membrane research activities, the general trend in promotion of MT is not satisfying and requires further analysis. This article compiles and critically analyzes the current research efforts in the field of membrane technology in selected Mediterranean and North African countries (MENA). A total of 114 research papers published in peer-reviewed literature from 1980 to 2007 and 22 laboratory- and full-scale membrane-based treatment plants in the MENA countries were used as the database for the analysis introduced in this paper. Results revealed few published scientific works (20% of total articles compiled) and pilot-scale studies on membrane bioreactors where further research and development pertinent to MT cost effectiveness and sustainability are needed. Advancing MT research has particular relevance to the decision makers in facilitating investment allocations and choosing sustainable treatment processes and demonstration projects for both effluent reclamation and reuse.

Keywords: Membrane processes; Wastewater treatment; Membrane bioreactor; MENA countries; Reclamation

1. Introduction

The complex dimensions of the Mediterranean freshwater resources, their fragility and their scarcity have been highlighted and received considerable attention as a primary priority issue politically, technically and scientifically. Membrane technology (MT), with its different applications in water treatment (desalination, drinking water treatment, wastewater treatment and reuse) has proven to be a reliable technique to abate the water crisis, worldwide in general, and in the Mediterranean region in particular [1–24]. During the last 5 years, this technology has received much attention by researchers and manufacturers, resulting from an improvement of membrane materials and techniques, which provide higher fluxes, longer lifetime, partly improving the fouling and high

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costs. However, in spite of several national and international membrane research activities, the general progress is not satisfying. Lack of cooperation, limited know-how exchange and an uncoordinated use of resources lead to ineffective research and development (R&D) activities [1–3].

PROMEMBRANE is a Specific Support Action, funded by the EU INCO Mediterranean Partner Countries. Its consortium involves four partners from Mediterranean countries as well as three institutes from the EU that specializ in water and wastewater treatment using various membrane technologies. The project started on 15 August 2006 and was completed by 14 August 2008. The primary objective of PROMEMBRANE (http://www.promembrane.info) was to support the current R&D activities in MT focused on water treatment in the Mediterranean area in order to promote international cooperation among research organizations and universities devoted to the development of membrane technologies in the following areas: municipal and industrial wastewater treatment, brackish and sea water treatment as well as surface water purification for drinking purpose. The first stage of the project covered the identification, mapping and evaluation of the on-going research, with the objective of proposing future research strategies which will help to overcome the current technical barriers of application. The second stage was the diffusion and dissemination of the successful experiences and research activities, through the organization of local seminars in targeted countries and an international conference, in order to encourage the further research activities in membrane technologies.

Increased population growth, rapid urbanization and industrialization associated with living standards improvement in most Mediterranean and North Africa countries (MENA) has aggravated the water balance gap between the available water supplies and the water demands. In MENA countries, especially those with limited water resources, there are challenges of satisfying rapid and substantial increases in water demand for industrial, domestic and agricultural purposes. The annual precipitation in MENA countries ranged between 150 and 600 mm, while the available water resources are limited, overexploited, polluted, politically confronted. A recent survey [1] on the present water uses in these regions revealed an average of 22% for municipal use, 3% for industrial use and 75% for agriculture use. Non-conventional resources such as seawater and brackish water desalination, in addition to limited reclaimed effluent, can alleviate the looming water crises in the MENA zone. In the Gulf region and South Mediterranean countries, experts [2,3,13] have already realized the nature of these challenges and recommended several key policies for water stressed countries, including a reduction of water subsidies, an increase reclaimed effluent reuse, aquifer recharge, advancement of local industrial bases and building capacity in sustainable membrane processes for both water and wastewater treatment [14,15,18].

The membrane-based activated sludge technology, referred to as membrane bioreactor (MBR), is the combination of activated sludge process with effective sludge separation using either microfiltration (MF), ultrafiltartion (UF), nanofiltartion (NF) or effluent reclamation utilizing reverse osmosis (RO) stages. In Europe, the application of membrane-based wastewater treatment systems, mostly the MBR type as indicated by Rachwall and Judd [4], is promoted under official legislations to meet the Drinking Water and European Union Bathing Water Directives. Two types of submerged modules are available today on the market: flat-sheet membranes and hollow-fiber membrane modules. An analysis by Lesjean and Luck [5] on the current MBR applications for municipal wastewater treatment revealed that flat-sheet systems are feasible for medium-size WWT plants, while hollow-fiber systems are adequate for large urban sewage works. In Europe, the largest MBR plant equipped with Zenon modules was installed in 2004 to serve the City of Kaarst (Germany) with an 80,000 population equivalent. A quick development and application of MBR technology has been illustrated by the establishment of a Zenon membrane bioreactor in Washington (USA) to treat a daily municipal flow of 144,000 m^3. Within the MENA countries, the available knowledge regarding municipal MBR is extremely limited and often very specific for a particular country's wastewater characteristics [19–29].

In this article, we first discuss major challenges facing the Mediterranean and North African countries behind endorsing membrane technologies for wastewater treatment, focusing on currently available published data. Second, the recent technological and current economic advancements of membrane-based treatment technologies are reviewed as the major drivers for the membrane processes promotion. Finally, recommendations pertinent to future research on membrane technologies are suggested to enhance their implementation as advanced sustainable water treatment processes.

2. Applied methodology

The PROMEMBRANE consortium is composed of a research committee from six countries representing a wide range of expertise in desalination technology, environmental engineering, water resources planning, and public health. The project entailed nine selected MENA countries in two geographical regions. The Middle East (Region A) including Syria, Lebanon, Jordan and Palestine and North Africa (Region B) including Egypt, Tunis, Libya, Algeria, and Morocco. Two database files have been created: one to collect information about the current research activities and another to map professional experts, research centers and universities focussing on MT applications for water and wastewater treatment. The findings of this article are based on the authors' own experience, data collected from 114 articles of 550 peer-reviewed papers found on the application of MT for water and wastewater treatment, and 22 installed laboratory- and full-scale membrane-based treatment systems. The authors claim by no means the exclusivity of the database files created. For MBR installations and published works from the countries under study, the WERF-Database and MBR-Network were accessed (http://www.mbr-network.eu/mbr-database/literature.php).

Feedback and discussions with relevant experts during workshops were also collected; however, due to space limitations, the results are not presented. As national R&D programs for the MBR technology applications in wastewater treatment and reclamation have started in some MENA countries, compiled research efforts made in Tunisia, Morocco and Algeria are presented and discussed. However, due to space limitations, it is not the aim of this paper to compare the MT efforts made within the MENA countries with those R&D efforts on MT applications in industrialized countries [4,5,21–24,30,31].

3. Results and discussion

3.1. Researchers and experts working in the field of membrane technology

In Palestine, a total number of 80 researchers identified their filed of expertise in membrane technology including desalination application in water and sanitation facilities. Fig. 1 illustrates the distribution of the researchers on R&D institutions where about 67% are working in both academic and governmental agencies. The non-governmental organization (NGO) sector is actively working in the field of MT where about 22% of experts are engaged in both local and foreign NGOs. The industrial sector has about 12% of experts employed. Almost half of the Jordanian academic staff (55%) are professionals working in the governmental sector (25%), leading to 80% of the experts are working by the public sector.

Compared to Jordan and Palestine, the situation in Lebanon is totally different where the vast percentage (60%) of membrane professionals is employed by industry. Despite many attempts to collect technical data on academic and governmental experts, only a few were identified. About 24% of MT experts were found working at academic institutions and even less (4 %) are encaged in governmental departments. For Syria, Fig. 1 shows a similar percentage of expert's distribution working in academic departments, however with a smaller share (29%) of industry involved in MT technology planning and marketing. It is worth mentioning that a total percentage of 58% of MT identified themselves as employed within the public sector (academia and government), compared with 80% and 67% in Jordan and Palestine, respectively.

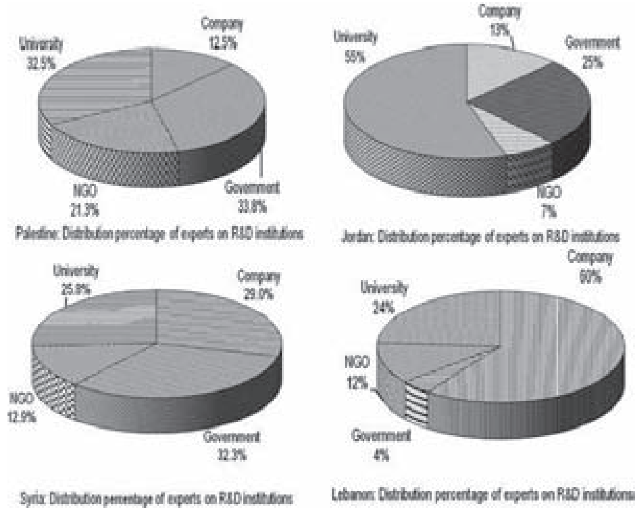

Fig. 1. Distribution of professionals identified as MT experts in region A.

Compared with compiled published works (data not shown) from North Africa (Area B: total 70 articles), the total publications of 44 mapped in Area A were grouped into the following application areas: (1) drinking water treatment; (2) wastewater treatment (domestic, grey wastewater, industrial, municipal, leachate and effluent reclamation). The grouping was performed according to the main objective of the PROMEMBRANE project. As the number of professionals specialized in MT is limited in Area A, and the region is characterized as a water scarce zone, the main focus of publications was on use of MT applications for drinking water treatment (Fig. 2). Among the drivers for MT professionals to focus on drinking water treatment rather than wastewater purification are water demands increase, groundwater overexploitation, surface water pollution increment, ineffective service delivery and aging of water infrastructures [4–7,32,33]. During the 5 years 1996–2000, only six papers tackled MT for water and wastewater treatment.

A rapid increase of published articles is identified during the five years 2001–2005 where about 52% of the papers were on the use of MT for both water desalination of brackish water and marine water sources for drinking water purposes. Also a marked increase of 25% of published scientific work is made on use of MT in wastewater treatment and effluent reclamation. This definitively shows the importance of membrane processes as a part of water scarcity and production of reclaimed effluent suitable for agricultural irrigation. This might be induced by annual drought periods, limited quantity and degraded quality of available freshwater resources due to over-

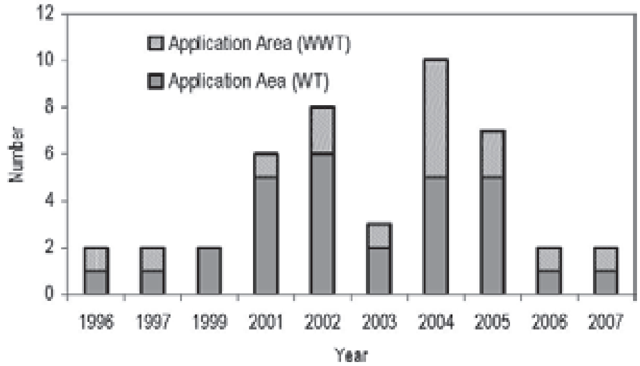

Fig. 2. Research publications on application areas of MT technology in region A.

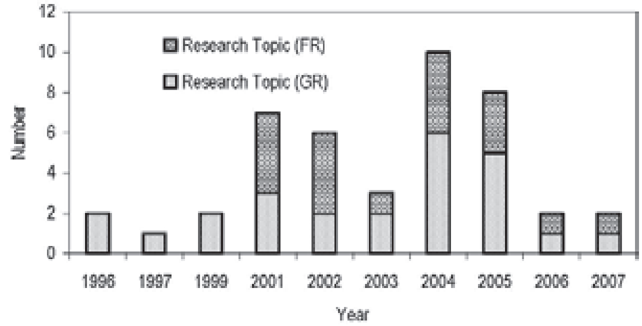

Fig. 3. Research publications on application areas of MT technology in region A.

exploitation, additions of allocthonus pollution loads and salt intrusions, stringent local and regional standards on treated effluent destined to agricultural irrigation.

As indicated earlier, few NGOs and companies working in the field of MT in the area can have a positive impact on enhancing MT applications in various fields. However, the link between experts in research institutions and the private sector (industry) is still very weak, thus few efforts are being made from industry to invest in R&D of membrane technology. Also, the current professional batch within this region come directly from either M.Sc. or Ph.D. programs with little practical experience in engineering offices or MT companies working at the international level.

3.2. MT research topics within area A

In a similar way, the 44 total publications found in region A were classified and grouped into the following main research fields: (1) general research (GR) papers on review and theoretical aspects of MT use in water treatment and wastewater treatment; (2) fundamental research aspects, which include operation and design parameters, fouling, cost, modeling, membrane-aided treatment systems, hybrid modules, pre- and post-treatment. As the number of research papers is few, the papers were grouped in only two application areas without differentiation on the type of water or wastewater. Fig. 3 illustrates chronologically the distribution of published papers within the two research topics of MT applications: GR issues and specialized applied research themes (FR).

It is obvious that only GR papers on MT applications were written during the 1990s (1996–1999); this is clearly due to the limited human and financial resources available in the region. However, FR has been published from conducted research on MT applications in both water and wastewater treatment since 2000. There are sharp variations in the number of published works among the individual countries in Area A. For example, only four papers were found published by the experts in both Lebanon and Syria, while Palestine and Jordan have published 10 and 29 respectively. GR papers constitute about 57% while applied FR entailed only 41% of the total published articles in this region. This is a good sign that MT has gained interest from the research community and policy makers for the provision of drinking water and improving effluent quality.

3.3. Technical advancements of membrane technologies in region B

Compared to MT applications in water treatment (desalination), the introduction of wastewater membrane and reclamation facilities in the MENA region has been, if any, more regionally based. While in the Mediterranean zone (region A) a larger number of research studies were conducted in the area of potable water desalination than for wastewater treatment, the situation was reversed in North Africa (region B). This could be attributed to the existence of well established research groups, availability of funds, and enforcement of national laws pertinent to protection of tourist coastal areas. This enabled MBR research and applications to flourish at laboratory, pilot- and full-scale installations for high strength industrial flows, municipal sewage treatment and tourist sites [6–18,34–50].

It is assumed that the caution of North African municipalities to consider advanced treatment systems as MBRs to the well established conventional treatment options might have delayed the application of MBRs into the municipal arena. However, the promotion of MBR in industrial applications, particularly for high strength, difficult to treat waste streams, allowed for alternative technologies such as MBRs. This has been reflected in more than 70 published articles from research groups in Tunis, Algeria, and Morocco only (data for Egypt and Libya ongoing) the installation of three full-scale installations for industrial wastewater treatment in Tunis, and Algeria (e.g. [8–12,46]). As of May 2007, the total number of installed membrane-based wastewater treatment plants

Table 1
Number of membrane-based WWTPs in the Mediterranean and North Africa zone

Number	Full scale	Country	Number	Laboratory scale	Country
3	Domestic	Egypt	0	Domestic	None
3	Municipal	Palestine, Israel	4	Municipal	Tunis
3	Industrial	Tunis, Algeria	9	Industrial	Tunis, Morocco, Algeria
9	Total		13	Total	

(immersed and external MBRs, UF/RO) in laboratory- and full-scale applications (domestic, industrial and municipal) has reached 22 (Table 1).

More than half of the membrane-based WWTPs installed within the MENA countries are installed for R&D activities including membrane development, process performance optimization, and fundamental research. Table 1 shows that all installed membrane-based treatment systems, except two pilot-scale systems (Palestine and Israel) utilizing UF/RO as a post-treatment stage are MBRs. Six out of nine of the full-scale installed MBRs, of which 50% serve the municipal sector, are membranes immersed with a hollow-fiber configuration [6,19–20,48].

Compared to conventional WWT systems, MBRs are advantageous in terms of small footprints, process flexibility and excellent hygienic effluent quality, which is suitable for various purposes including unrestricted agricultural irrigation. However, MBRs show higher energy demand, require a higher level of automation, skilled operational staff and frequent cleaning due to fouling and scaling. To modify colloidal fractions in primary and secondary treated wastewater, which plays a significant role in membrane fouling, coagulation and adsorption were found to increase the efficiency of UF with reduction needs for membrane regeneration [8–11].

To date, much of the research efforts made within the African countries on membrane-based treatment systems have mainly focused on bench- or pilot-scale studies [34–36] and short-term operations in municipal applications. Laboratory-scale studies on industrial applications with particularly high strength and difficult to treat waste streams, however, were conducted as alternative technologies such as MF/UF/NF [8–11,37–42]. However, regardless of the source of wastewater, whether it is municipal or industrial, very few publications involved full-scale studies for long-term operational periods [43,44]. For pathogen removal and municipal wastewater pretreatment, anaerobic MBRs have proven to be a particularly reliable technique [45,46]. Few research studies were made on development of local material to improve membrane structure, control fouling, and improve flux permeate at lab scale experiments using dual-membrane systems (MF/UF) and MBR units [17,18,50–55]. Membrane biofouling is considered a crucial problem in MT application for both water and wastewater treatment with potential impact on annual operating costs and water quality. A review on process design, fouling reduction and proper operation of MBR systems implemented worldwide can be found else where [56–63].

3.4. Future research in membrane technologies

The results of this project identified wide research areas related to the types of scientific and technical advances that are crucial for membrane water treatment technologies to find broad acceptance and application in the countries under study. To achieve sustainable, affordable and adequate wastewater treatment facilities in the MENA zone, allocation of regional research funds to guide membrane processes research in the MENA region are required. In this article, we discussed various aspects of current research efforts within the MENA countries including the challenges of MT for wastewater treatment and reclamation. It was demonstrated that the availability of experts and well-trained practitioners, well-equipped research facilities, availability of funds, affordability and technical feasibility of MT, as well as the official commitment and endorsement of stringent effluent standards on treated effluent for intended uses depend on each other.

Protecting the quality of surface and groundwater requires sustainable management on a watershed basin scale to consider every impact on the water. Of equal importance is public health protection, which calls for safe brine disposal or effluent reuse [64–67]. This implies use of advanced treatment technologies, among which are the membrane-based processes. However, because water quality criteria are dependent on local conditions within the MENA region, it is necessary to define groups of similar rivers by clustering them as eco-regions. As protection of the aquatic environment and public health pertinent to emergent pollutants more often lacks a confirmed scientific, financial and managerial basis, further research and updating of criteria based on large-scale MBRs are needed [68–70].

Forming cooperation between technology developers and leading companies is a crucial approach that dramatically shortens the time required to promote MT and address some of today's key business problems and challenges. The approach provides ready access to professionals best qualified to provide commercial development guidance for new MT-based options [19,20]. It enables development or co-development of new membrane-based systems through collaboration or joint development with trend-setting companies who are expert and leaders in their fields [71–73].

Water scarcity in the MENA region has promoted the use of unconventional water sources, namely seawater, brackish water and treated/reclaimed wastewater, which are actually unlimited. With adequate membrane design, utilizing MF/UF as pre-treatment processes might reveal wastewater desalination costs lower than seawater desalination costs, thus making wastewater desalination as one of the feasible processes to produce water that fits many industrial water quality requirements [6–18,50,51]. In the future, it is likely that direct processing of wastewater in MBRs followed by RO will open up more opportunities for effluent reuse for a wide range of purposes. However, recent studies [30,31,53–55] made on MBRs sustainability revealed an overall sustainability for the MBRs as good; however, the current capital and operational costs of membrane-based treatment technologies may not necessarily satisfy some economic and ecologically sustainability criteria [59,72–77].

The technical feasibility of MT applications in wastewater treatment is very well documented, but the widespread utilization of membrane based processes is constrained by the high capital and operational costs. The price of membranes, their replacement frequency and the electrical energy consumed are the most important factors influencing the costs of the processes [23–30,38–42]. Thus, it is important to select an adequate membrane type as well as to optimize the operational conditions of the preceding treatment stage case by case. However, recent rapid proliferation of MBRs as a result of the technological advances and reduced costs has resulted in many owners, operators and engineers considering them as part of plant upgrades and expansion plans of overloaded sewage works [59,70–77]. Nevertheless, a breakthrough in MT advancement for wastewater treatment and effluent reclamation can be made only if we can prove its cost effectiveness and sustainability for developing counties. A revolution in nanoscience and membrane engineering will have a potential impact on social, environmental and economical development as well as on the political stability in Arab MENA countries in particular.

4. Conclusions and recommendations

Establishing databases on published literature and experts based on a literature survey and distribution of questionnaires to collect reliable data on MT applications from individual MENA countries was a challenge, facing numerous obstacles. These included but were not limited to lack of funding, management commitment, as well as professional experts and practitioner personnel. Other barriers most commonly cited by respondents include:

- absence of competitive industry and less economical motivations
- lack of regulatory motivation at local and regional levels
- un-coordinated training and lack of R&D programs
- limited practical experience by academic and unskilled operating staff
- lack of funds for both investment and operation

These barriers make the implementation of MT for wastewater treatment and reclamation difficult and impede their sustainability and wide-scale promotion in the MENA region. The current membrane-based wastewater treatment systems are almost entirely MBR-based technology at pilot-scale levels for industrial wastewater and are predominantly located in the North African countries. Growth in membrane technologies in the municipal sector is likely to be advanced by a combination of decreasing process costs, increasing stringency of environmental legislation and further process innovation, such as the submerged membrane module. A break-through in the industrial commercialization of membrane-based wastewater treatment technologies in the MENA region will only be possible by converting the MT into a profit-making proposition. This can be enhanced by close cooperation among industries, research communities and decision makers, utilizing committed and reliable multi-disciplinary research groups in various R&D fields. The following recommendations can be made:

1. Building on the current efforts and recent technological advancements, a strategic research program should be developed to enhance the R&D activities pertinent to performance improvement and cost reduction of current membrane-based wastewater treatment technologies in the MENA region.

2. A strategic research investment program including budget estimates requires adequate and shared funding from industries, government and the public and private sectors. The funds needed to implement this program will promote innovative research; enhance capacity building, award research efforts, and advance knowledge transfer and communication.

3. Establishing sustainable networking; initiation public–private–partnerships; creation of national, regional and international industrial alliances; public awareness campaigns; and creation of local and regional R&D incubators are among the crucial efforts needed to enhance the promotion of membrane-based wastewater treatment technologies in the MENA countries and worldwide.

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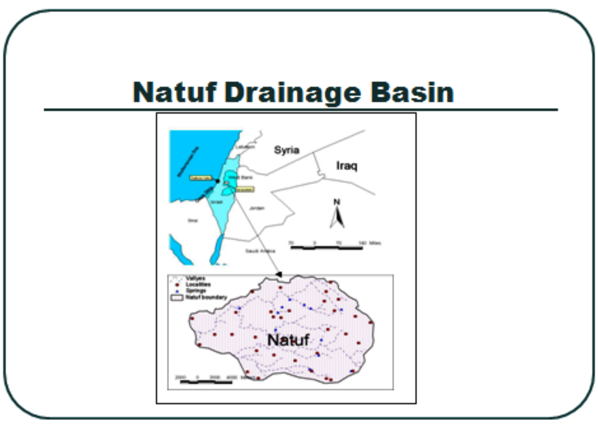
Hydrochemistry of the Natuf Drainage Basin in Ramallah Area/West Bank

Ibrahim Shalash and Marwan Ghanem



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Hydrochemistry of the Natuf drainage basin in Ramallah area/West Bank

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Abstract The Natuf drainage basin in the western hills of Ramallah district is about 200 km^2. Many springs emerge in the area from perched aquifers and outcrop from limestone and dolomite limestone formations. This study aims to add more information about hydrochemical parameters and the chemical changes in spring water between dry and wet seasons and to locate possible sources of pollution and their effect on the water quality of water from the springs for domestic and agricultural uses. The study involved collection and analysis by conventional and available instrumental methods for the hydrochemical parameters from 12 springs before and after recharge. Water samples of runoff from two places in eastern and western parts of the study area were collected and analyzed as well. Most of the springs in the study area are of good water quality for domestic and agricultural uses. Variations in the chemical composition between dry and wet seasons, and from one spring to another, were observed. Springs near densely populated areas and agricultural activities show higher values of EC, SSP, SAR and TH. Also uncountable colonies of faecal- and total coliform were detected. Trace amounts, within World Health Organization (WHO) and the Palestinian standard limits, of cadmium, chromium, cobalt and lead are found in some springs; while concentrations of iron and zinc that were detected in springs near populated areas are higher than other springs. Water types of Ein Musbah, Al Alaq and Ein Arik El Tehta are of earth alkaline with increased portion of alkalis with prevailing bicarbonate and chloride in wet and dry seasons. Other springs show a variation in water type between earth alkaline with prevailing bicarbonate in the wet seasons to earth alkaline with prevailing bicarbonate and chloride in the dry seasons.

Keywords Hydrochemical parameters · Water types · Natuf drainage basin · Western Aquifer Basin

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Introduction

The continuous supply of high quality water is essential for economic growth, quality of life, environmental sustainability and survival. The quantity and quality of potable water varies over time and space, and is influenced by natural and man-made factors, including climate, hydrogeology management practices and pollution. In the West Bank, the demand for potable water for domestic uses has increased in the last few decades because of the rapid increase of population in the West Bank.

Ground water is the major source of fresh water in the West Bank and provides about 70% of drinking and domestic water needs. The sole source of groundwater in the West Bank is in the Mountain Aquifer System, which is divided into three subsurface drainage basins: Northeastern; Western and Eastern.

The Natuf drainage basin, which is part of the Auja-Tamaseeh sub-basin[1] in the Western subsurface drainage basin, like other areas in the West Bank, suffers from the

[1] SUSMAQ [P1]- NAT#48V0.3 (2003) Field Measurement Campaign for Wadi Natuf Recharge Estimation: Background, Design and Workshop. Palestinian Water Authority, Palestine

scarcity of water as well as other parts in the West Bank. The scarcity of water in the study area has limited land use for agriculture.

Heavy exploitation of groundwater, the shortage of sewer systems, the wide distribution of cesspools and septic tanks with inadequate quality control, the common practice of gray water disposal into gardens and road ditches and the uncontrolled disposal of untreated municipal sewage into valleys, may cause rapid contamination of aquifer systems through karstic conduits in the area (Qannam 1997).

Because of the lack of information about water quality in the area, there is a need for investigation of chemical and biological pollutants in water to determine the sources of pollution, which will help authorities to prepare and to implement successful management plans.

Location and geography of Natuf drainage basin

Natuf drainage basin is in the Western part of the West Bank between 34° 98′ W and 35° 26′ E, it is about 204 km^2, and drains from the mountains of Western Jerusalem into the coastal plain of Mediterranean Sea and serves about 80,000 inhabitants that are distributed into 28 villages and some parts of Ramallah city (PCBS 1999).

Natuf drainage basin is one of the main recharge areas in the Western Aquifer Basin (WB). It has a cultural value as one of the oldest world cultures, Natufian culture, 8000 BC, where man began the first domestic agricultural community. The area will be soon listed by UNESCO as one of the world's cultural reserves in Palestine for its historic and cultural heritage (Ministry of Tourism and Antiquities 2005).

Climate

West Bank is in the Mediterranean climate, which is considered to be semi-arid to arid climate, with dry and wet seasons. The wet season starts approximately in early November and extends to late April. The rainfall in the study area ranges between 400 and 900 mm (Meteorological Service 2003). Out of the rainfall, 2–13% returns to the Mediterranean Sea as surface runoff, 20–26% infiltrates to groundwater aquifers, and the rest is lost by evapotranspiration (Rofe and Raffety 1965)

The study area is part of the hilly regions in the West Bank. Temperatures are lower than other places in the West Bank. The temperature in the coldest month (January) is in the range of 6–13°C and the average temperature in the hottest month (August) was 37.5°C during 1994–1995. The mean annual temperature ranges between 18 and 20°C (Applied Research Institute in Jerusalem 1996).

Hydrology of the study area

Water resources in the Natuf drainage basin originates from rainfall in the winter season and from snowmelt which falls occasionally for a few days on the eastern parts of the study area near Ramallah and Birzeit hills.

The Natuf drainage basin is underlain by the Western aquifer; many springs emerge in the study area (Table 1), with an average annual discharge of 0.3–0.6 million cubic meters (mcm) of fresh water, which is used for domestic and agricultural purposes. There is only one groundwater well from the lower aquifer near Shibteen village downstream Natuf valley, which is controlled by the Israeli Water Authority (Mekarot) and supplies about 0.7 mcm/year of

Table 1 Springs in the Natuf drainage basin

No.	Spring code	East	North	Spring name	Location	Formation
1	BA/152	166.775	152.575	Al-Alaq	Abu Shekhedem	Qatana
2	BA/153	164.700	149.900	Harrashah	Al-Mazr'a Al-Quibliya	Qatana
3	BA/157	159.100	155.410	Akari	Beitillu	Bottom upper beit kahel
4	BA/158	161.440	153.700	Al-Balad	Beitillu	Bottom Lower Yatta
5	BA/159	161.400	154.140	Al-Quos	Beitillu	Lower upper Beit kahel
6	BA/163	165.000	148.680	Old JWU well	Ein Qinia	Lower Ein Qinia
7	BA/170	163.600	145.850	Ein Arik Al-Fuqa	Ein Arik	Lower lower Beit kahel
8	BA/171	163.400	146.180	Ein Arik Al-Tehta	Ein Arik	Lower lower Beit kahel
9	NS/007	159.130	150.580	Ein Ayoub	Ras Karkar	Hebron[a]
10	NS/040	159.410	153.440	Al-Tina	Jammalah	Lower Yatta
11	NS/041	159.740	153.600	Al-Shakhariq	Deir Ammar	Lower Yatta
12	NS/MUS	169.380	146.275	Ein Musbah	Ramallah	Lower upper Beit kahel
13	SHW	155.220	153.250	Shibteen Well	Shibteen	Hebron

[a] The formation in this site is more likely alluvial

fresh water. The apparent surface water is the base flow of the springs and the seasonal flow of valleys during heavy storms (Fig. 1).

Geology of the study area

The geological settings in the Natuf drainage basin are composed of thick sequences of layered limestone, dolomite, chalk and marl. The main outcrop formations belong to formations of the Albian to Turonian age (Fig. 2).[1]

Most of the springs are distributed in the middle part of the study area near Beitillu and Deir Ammar, where Yatta formation, which is an Aquitard, is dominant. The flow discharge of these springs is greatly affected by the intensity of precipitation and by the heavy withdrawal (80 m^3/h) of Shibteen productive well down stream of Natuf Wadi. Springs in the study area are an outcrop of perched aquifers distributed over Ramali, Yatta and Abu Dis Aquitard formations (Fig. 2).

Methodology

The hydrochemistry of the springs in the study area has been monitored by many researchers. Collected hydrochemical data from the springs of the study area from 1999 to 2002 were used in this work for comparison.

Sampling

The sampling protocol was carried out in wet and dry seasons, starting from November 2003 to May 2005; a total of 47 samples were collected. Twelve major springs were assigned for sampling campaign (Table 1). During winter 2005, two samples were collected from Shibteen well, one runoff sample near Birzeit University and one sample from Al-Fawarah, Seasonal Base flow from Natuf valley, giving a total of 51 samples.

The water samples were collected in 1-l polyethylene bottles and refrigerated in the laboratory at 2°C. Onsite

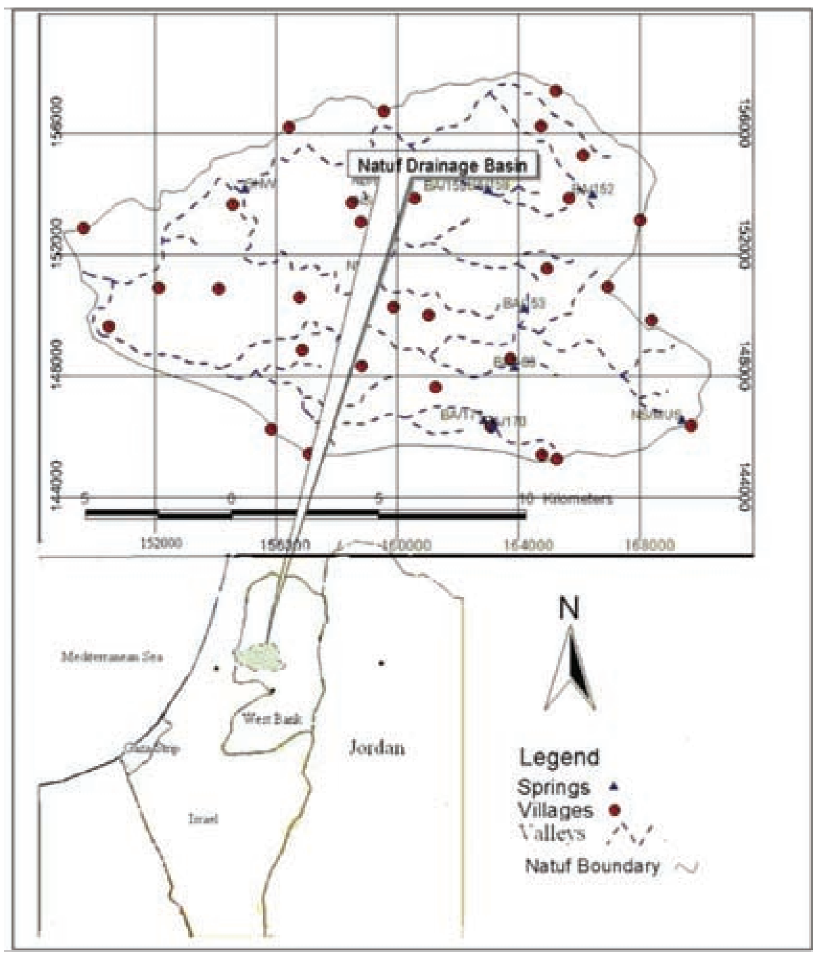
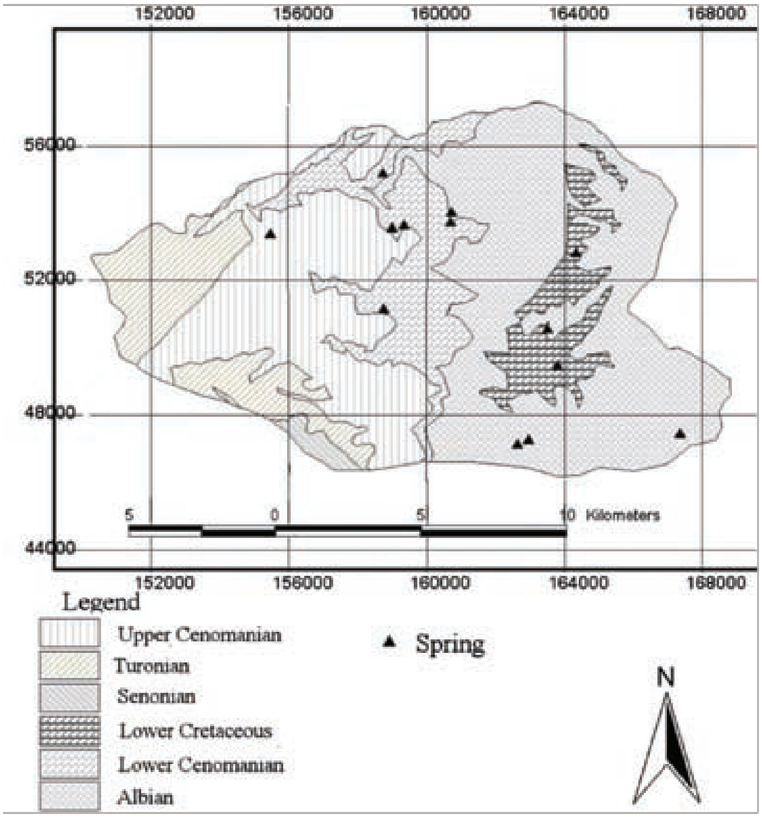


Fig. 1 Location of the Natuf drainage basin

Fig. 2 Geological formations of Natuf area



tests for pH, electrical conductance (EC) and temperature (T) were carried out for each site using Hanna field multimode meter.

Three sites, Ein Musbah, Harrashah and Al Alaq, were chosen for biological tests, to show the possibility of wastewater intrusion from sewer systems and cesspit. Samples from these sites were collected in sterile 100 ml glass bottles, cooled and transferred to the laboratory on the same day for biological tests.

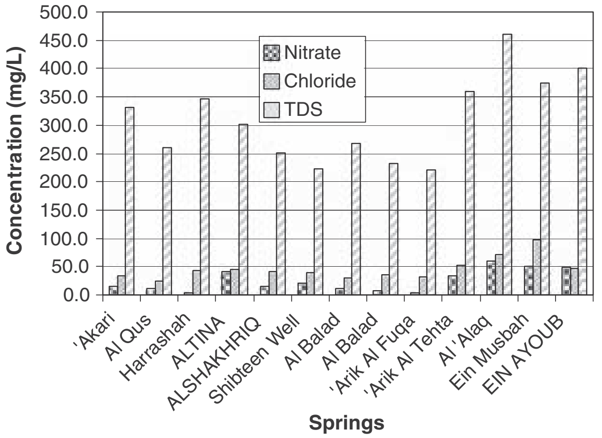


Fig. 3 Average values of nitrate, chloride and TDS in Natuf springs' water 2003–2005

Laboratory tests

All samples were acidified for trace elements analysis, with 69% nitric acid (14.4 M); a Perkin–Elmer ICP Optima 3000 was used to detect iron, copper, zinc, chromium, lead, cadmium, cobalt and magnesium.

A Sharewood 4010 flame photometer was used to determine calcium, sodium and potassium. A HP 8453 Diode Array Spectrophotometer was used to determine nitrate and sulfate concentrations. A Hanna pH multi-meter was used onsite for the determination of pH, TDS, EC temperature. A Metrohm 716 titrator used to determine chloride and bicarbonate concentrations.

Results and discussion

The mean values of major ion concentrations, pH and calculated P_{CO_2} for the 12 springs and Shibteen well for the period from October 2003–May 2005 are listed in Table 2. HCO_3^- is the dominant anion in all springs, and ranges between 174 and 321 mg/l, Cl^- is the second most

Table 2 Average values of hydrochemical parameters from spring water of Natuf drainage basin

Spring ID	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	Cl^{-} (mg/l)	HCO_3^{-} (mg/l)	NO_3^{-} (mg/l)	SO_4^{-2} (mg/l)	EC (µS/cm)	pH (mg/l)	P_{CO_2} (atm.)
BA/152	81.2	40.6	35.4	4.1	71.1	321.2	56.3	30	842	7.2	2.10E–02
BA/153	65.1	24.4	11.8	1.5	38.8	259.8	4.2	22.4	555.3	7.5	5.00E–03
BA/157	57.8	24.2	17.2	2	32.7	210.2	14.8	21	514.8	7.6	3.60E–03
BA/158	47.5	24.7	14	1.8	29.5	226.3	13.2	27	502.3	8	8.10E–04
BA/159	41.9	19.7	11.6	1.3	26.2	205.2	12.1	22.4	472	7.5	7.00E–03
BA/163	54.5	15.9	13.5	1.3	34.8	215.5	7	24	512.3	7.4	4.70E–02
BA/170	48.2	15.1	11.6	1	31.6	202.2	4.2	21.2	403	7.9	1.50E–03
BA/171	71	18.6	29	6.1	49.4	244.6	28.5	29.2	612.3	7.1	4.10E–02
NS/007	72.4	23.2	26.6	2.6	48.3	218.3	49.1	25.9	609.5	7.2	2.00E–02
NS/040	54.5	15.6	24.8	1.4	45.7	174.8	41.4	26.7	526.3	7.6	5.30E–03
NS/041	60.9	15.6	17.2	5.6	42	207.2	15.6	26	479	7.6	3.80E–03
NS/MUS	83.4	42.8	61.3	2.1	97.5	310.4	50.9	28	916.7	7.9	5.50E–04
SHW	58.9	16.4	16.7	2.04	39.1	206.6	19.9	17.3	453	8.1	5.60E–04

abundant anion with ranges between 29.5 and 97.5 mg/l. The concentrations of NO_3^{-} show moderate values below the WHO limits of 45 mg/l (World Health Organization 1996) and Palestinian drinking water standards (Palestinian Standards Institute 2005). Two sites, Al - Alaq and Ein Musbah springs, show average values of nitrate 56.3 and 51.6 mg/l, respectively (Fig. 3). Those two springs are in a densely populated area where cesspits are in the outcrop area of these springs. SO_4^{-2} concentrations are moderate compared to the dominant anions.

The Na^{+}/Cl^{-} ranges between 0.26 and 0.8 in all samples except one sample collected in the dry season of 2003 from Akari spring showed a Na^{+}/Cl^{-} ratio of 1.79. The high levels of sodium and chloride are assumable to be related to contamination processes (Helena 1998). The high concentrations of sodium and chloride found in Al Alaq, Ein Ayoub and Ein Musbah reveal the probable wastewater leakage from sewer systems and cesspits. All samples lie within the pH range of 7.1–8.1. The calculated values of P_{CO_2} are higher than the atmospheric P_{CO_2} ($10^{-3.5}$ bar), which indicates that the water from the spring is saturated with CO_2 during infiltration of rainfall water.

Saturation indices (SI), listed in Table 3, for anhydrite ($CaSO_4$), aragonite ($CaCO_3$), calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) and gypsum ($CaSO_4.2H_2O$) were calculated for 47 samples using PHREEQC.

The SI for anhydrite and gypsum is below zero in all samples, which means that water is undersaturated with respect to anhydrite and gypsum. SI for Aragonite is between –0.7 and 0.9 with 40% of the samples having an SI > 0, which means that they are in saturation and aragonite is precipitated. Around 8.5% of the samples have SI = 0 meaning that water is in equilibrium in these samples with respect to the aragonite.

Table 3 Average values of saturation indices for Natuf drainage basin

Spring ID	Anhydrite	Aragonite	Calcite	Dolomite	Gypsum
BA/152	–2.4	–0.2	0	0	–2.2
BA/157	–2.6	0	0.1	0.2	–2.4
BA/158	–2.5	0.4	0.5	1.1	–2.3
BA/159	–2.7	–0.2	–0.1	0	–2.5
BA/163	–2.5	–0.2	–0.1	0	–2.4
BA/170	–2.7	0.3	0.3	0.5	–2.4
BA/171	–2.4	–0.4	–0.3	–0.9	–2.2
BA153	–2.5	0.1	0.2	–0.2	–2.2
NS/007	–2.4	0	–0.7	–0.4	–2.2
NS/040	–2.4	0	0.1	0.1	–2.1
NS/041	–2.4	0	0.2	0.1	–2.2
NS/MUS	–2.5	0.4	0.5	1.0	–2.2
SHW	–2.8	0.3	0.4	0.5	–2.6

Fifty-one percent of the samples have SI < 0, which means under saturation with respect to the aragonite. SI for calcite ranges between –0.6 and 1.1. Fifty-seven percent of the sample have SI > 0, which means that they are oversaturated for precipitation of calcite. Around 13% of the samples have SI = 0, which means equilibrium and 30% of the samples have SI < 0 which means that they are undersaturated with respect to calcite. For dolomite, SI ranges between –2.2 and 1.9, and 51% of the samples have SI > 0, which means that they are oversaturated and precipitation of dolomite occurs. About 11% of the samples have SI = 0, which means equilibrium conditions and 38% of the samples have SI < 0, which means that they are undersaturated with respect to dolomite.

Statistical analysis

Correlation analysis was performed using SPSS version 11.5, between all parameters. Based on the correlation coefficient value (*R*), the interrelationships between hydrochemical parameters can be classified from poor ($R < 0.7$) to very high significance ($R > 0.9$) (Abed Rabbo et al. 1999). The results show that (EC) is highly dependent on chloride, magnesium, nitrate, sodium, bicarbonate concentrations, which means that field measurement of EC with a suitable instrument, can be used for quick estimation of other related parameters. The values of EC during the study period for water samples from springs of Natuf drainage basin range between 403 and 917 μS/cm. The highest values of EC were recorded in the dry season of 2003 in Ein Musbah (916.7 μS/cm), which is in a densely populated area in the center of Ramallah city and in Alalaq spring (842 μS/cm), which is near an agricultural area. All other springs have values range between 403 and 600 μS/cm, which is considered as good water for agricultural purposes (Bauder et al. 2005).

Chloride and nitrate show the same trend of variation, which supports the supposition that human activity contributes to high pollution rates in this sensitive area (Ghanem 1999).

The significance of interrelationship between TDS and other ions is an indication of salinity-controlling ions (Abed Rabbo et al. 1999). TDS was high correlated with EC ($R = 0.86$), good correlation with NO_3^- ($R = 0.78$), Cl^- ($R = 0.76$), Na^+($R = 0.79$), Mg^{+2} ($R = 0.75$) and acceptable correlation with HCO_3^- ($R = 0.71$) and Ca^{+2} ($R = 0.70$).

Trace elements are in very low concentrations and below toxic limits in all samples. The highest value (27 μg/l) of Pb^{+2} was recorded in Ein Ayoub in the dry season of 2004, and decreases to 16 μg/l in the wet season of 2005 because of dilution. The location of the outcrop is full of old vehicle dumping sites where old galvanic batteries are disposed. Zinc content shows variations between 1 μg/l at Ein Arik El Tehta in wet season of 2005 and 142 μg/l at Al Alaq in the dry season of 2004. Other springs contain values of zinc within this range.

Biological results for faecal (FC) and total coliform (TC)in the three target springs of Harrashah, Ein Musbah and Al Alaq show that Ein Musbah and Al Alaq contain colonies of FC and TC, which reveals contamination from wastewater from sewerage system near Ein Musbah and cesspits near Al Alaq. Harrashah spring also shows TC colonies, which is probably related to sheep herds and animal manure piles near the spring outlet.

Graphical representation of the hydrochemical data

The chemical composition of the springs in the study area is affected by rainfall chemistry, climate, rock type, rock division, human activities and residence time of water (Cruz and Amaral 2004). The hydrochemical characteristics of spring water based on the percentages of anions and cations can be illustrated by Piper trilinear diagram (Fig. 4) (Fetter 1994). Similar waters are clustered in clearly defined areas, indicating water-mixing phenomena, precipitation and dissolution (Helena 1998).

There is no obvious change in the chemical composition of spring water at Harrashah, Akari, Ein Arik Al Fuqa,

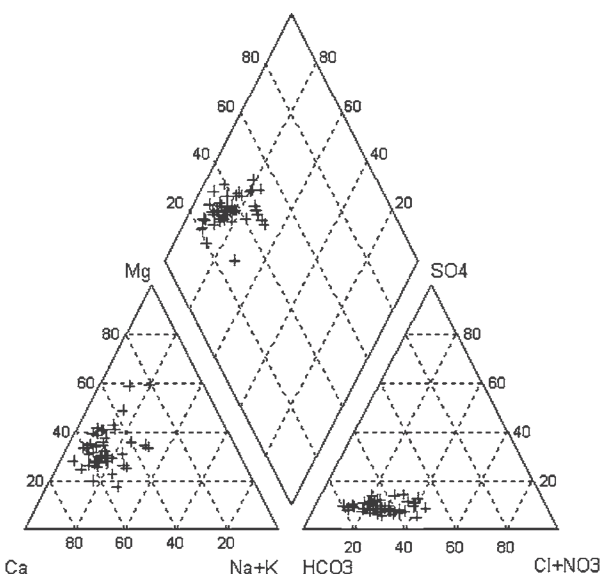


Fig. 4 Piper diagram for hydrochemical parameters of Natuf springs (2003–2005)

Beitillu Al Balad, Alshakhariq and Al Quos springs. The water type remains as normal earth alkaline before and after recharge. The chemical composition also remains as earth alkaline with prevailing bicarbonate and sulfate or chloride for Al Alaq and Al Tina springs. Other springs show different variations in chemical composition before and after recharge. Ein Ayoub and Arik El Tehta show an increase in alkali type with prevailing bicarbonate and chloride after recharge, which indicates human contribution in pollution. Ein Musbah shows an increase in chloride concentrations, which indicates leakage of waste water from a nearby sewerage system.

Ion distribution and chemical composition

The total dissolved ions (TDI) for the major ions in the springs (Table 1) of Natuf drainage basin was calculated as 152 meq/l, in the dry season of 2004 and 144 meq/l, in the wet season of 2005, reveals for the dilution process. The higher content of TDI during dry season confirms the effect of residence time on dissolution process of minerals from rocks.

Water quality parameters and pollution rates are also affected by dry and wet seasons as well as the effect caused by the human activities and agricultural processes. As indicated by Schoeller diagrams (Fig. 5), the concentrations of major cations and anions recorded in dry seasons are higher than those in the wet seasons, which can be explained by the longer residence time of water and lowering of the water table in the dry season. In the wet seasons, the dilution process due to the infiltrated rainfall is the main cause of lowering the concentrations of major cations and anions. Nitrate and chloride concentrations increase in wet season more than dry seasons, which indicates a washing process of pollutants by runoff over agricultural and urban areas.

Water quality parameter

Salinity

Springs in Natuf drainage basin are used mainly for irrigation purposes where many market vegetables are produced such as lettuce, cabbages, bell pepper, beans, parsley and zucchini in addition to many other fruits such as citrus. Many of these crops are sensitive to high water salinity (Todd 1980). Ein Musbah spring in Ramallah city is considered as high saline and cannot be used for unrestricted irrigation in crops sensitive to this parameter. Other springs in the area are of medium salinity and can be used for irrigation purposes in crops of suitable choice.

Total hardness (TH)

Hardness of water is defined as the inhibition of soap action in water because of the precipitation of magnesium and calcium salts such as carbonates, sulfates and chlorides. It can be temporary or permanent hardness. Temporary hardness is mainly due to the presence of calcium carbonate and is removed by boiling water. Permanent hardness is caused by the presence of calcium and magnesium chlorides and sulfates and can be cured only with ion exchange processes.

Hardness of water limits its use for industrial purposes; it causes scaling of pots and boilers, closure to irrigation pipes and may cause health problems to humans, such as kidney failure.

TH is calculated as follows (Todd 1980):

$$\text{TH } (CaCO_3) \text{ mg/l} = 2.497\ Ca^{+2} + 4.115\ Mg^{+2}$$

The concentrations of Ca^{+2} and Mg^{+2} are expressed in mg/l. As a water quality parameter, TH values can be used to classify water for domestic and industrial uses.

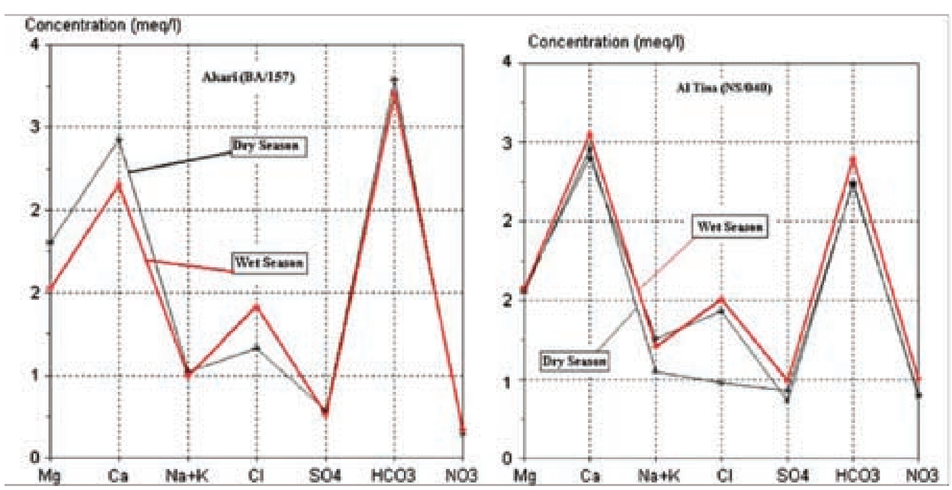


Fig. 5 Schoeller diagrams for some springs in Natuf Area 2003–2005

In the study area, the lowest value of TH recorded was 74.8 mg/l for Wadi Natuf runoff on 6 February 2005, and the highest value was 568.8 mg/l for Ein Musbah spring on 19 October 2004. Water types according to the average TH in the study area range from soft to very hard water with prevailing hard water in 80% of the samples.

Soluble sodium percentage (SSP)

Water quality for agricultural purposes in the Natuf drainage basin shows variation between excellent to good based on Todd' classification of soluble sodium percentage (SSP) values, which is defined as:

$$SSP = \left(\frac{(Na^{+} + K^{+})}{(Na^{+} + K^{+} + Ca^{+2} + Mg^{+2})} \right) \times 100,$$

where all concentrations are in meq/l. SSP values were 16.7 and 13.67 for dry 2004 and wet 2005 seasons, respectively.

Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is used as an index for sodium hazard in water for irrigation purposes in accordance with EC values. SAR is calculated according to the formula:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$$

where all concentrations are in meq/l.

Sodium hazard starts at values of SAR > 1 and EC values >650 uS/cm, respectively (Bauder et al. 2005). The values of SAR are <1 and <650 uS/cm for EC in most the springs, Ein Arik Al Tehta, Ein Ayoub and Ein Musbah show values of SAR > 1 and >650 uS/cm, which means that water from these springs is not recommended for unrestricted irrigation.

Based on EC and SAR ratio, water from Natuf springs can be classified for irrigation purposes according to Wilcox diagram (Fig. 6; Abed Rabbo et al. 1999).

Microbiological analysis

Water is a good media for microorganism. Groundwater and surface water may contain bacteria, viruses, fungus and algae, which makes water objectionable for domestic purposes and health threatening. In this study, water samples from three springs near densely populated areas, were tested for FC and TC. The results obtained from microbiological analysis of Harrashah, Ein Musbah and Al- Alaq show that Ein Musbah and Al Alaq contain uncountable colonies of FC and TC, which indicates contamination from wastewater

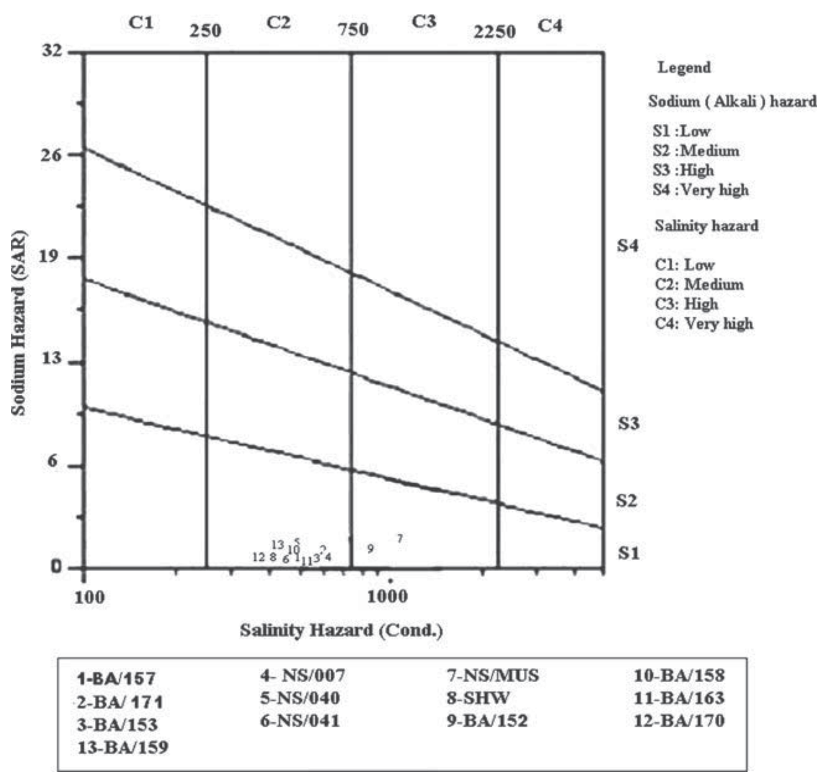


Fig. 6 Classification of Natuf springs according to Wilcox

from sewerage systems near Ein Musbah and cesspits near Al-Alaq. Harrashah spring show uncountable TC, which is referred to sheep herds and manure piles near the spring outlet.

Conclusions

Springs in Natuf drainage basin emerge from perched aquifers and are distributed over Yatta formation in the upper aquifer. The springs are of good water quality, except Ein Musbah, Al Alaq and Ein Ayoub springs which are near populated areas. Samples from these three springs have low water quality for agricultural and domestic uses based on SAR, SSP and EC values. Faecal and Total coliform are found in these springs. The recorded trace elements levels are not harmful according to WHO water quality guidelines.

The recharge areas for the springs in Natuf area are mainly composed of limestone and dolomite. The dominant water types in springs of Natuf drainage basin are earth alkaline with prevailing bicarbonate. Some springs show earth alkaline water type with a little increase in alkalis and prevailing bicarbonate and sulfate or chloride. The change of water types in some springs is related to mixing with wastewater, rainfall and dissolution of minerals.

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Farm-Level Perspectives Regarding Irrigation Water Prices in the Tulkarm District, Palestine

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Farm-level perspectives regarding irrigation water prices in the Tulkarm district, Palestine

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ABSTRACT

Agriculture consumes about 70% of water available in the Occupied Palestinian Territories. Domestic and industrial users utilize 30% of the water supply. Water resource managers are considering the policy of reallocating a portion of the water supply from agriculture to other uses. It is believed that increasing irrigation water prices could influence water consumption and thus make water available for non-agricultural (more economic) uses. This paper examines the impacts of water pricing on agricultural water consumption and farming profitability and provides some guidelines for policy makers regarding water pricing as a tool to manage scarce water resources. We estimate a regression model describing agricultural water consumption as a function of water prices, irrigated land area, farm income, and irrigation frequency, using data collected in a survey of about 150 farmers in the Tulkarm district. We conclude that irrigation water prices are perceived as high and comprise a large portion of total farming expenses. Therefore, attempts to increase irrigation water prices in the Tulkarm district might jeopardize farming feasibility and might have substantial impacts on agricultural water consumption. Nevertheless, many farmers would continue farming even if the water prices were increased beyond their willingness to pay threshold.

1. Introduction

1.1. Global context

Irrigation consumes 50–70% of global water resources (Ahmad, 2000; WRI, 2000; Rosegrant and Cline, 2002; Molle, 2002). Although this share is higher than 89% in the Middle East and North Africa (MENA) region, irrigation water prices are only 10% of domestic and industrial water prices (Abu-Madi et al., 2008a,b). Many authors have examined the effectiveness of water pricing as an instrument for improving water allocation and reducing water consumption (Dinar and Subramanian, 1998; Maestu, 2001; Perry, 2001; Saleth, 2001; Bosworth et al., 2002; FAO, 2002; Johansson et al., 2002; Easter and Liu, 2005; Gong et al., 2005; Hussain et al., 2006; World Bank, 2006; Dudu and Chumi, 2008). The Fourth Principle of the 1992 Dublin Statements defines water as an economic good in order to achieve efficient and equitable use, and encourages conservation and protection of water resources. The Fourth Dublin Principle denoted a landmark shift in emphasis to the economic dimensions of water use in general, and irrigation development in particular (WMO, 2007). By comparison, the first principle of the 1992 Rio Statements, which supplemented the Fourth Dublin Principle, suggests implicitly that water is a social good (Dinar and Saleth, 2005).

Many water experts recognize water pricing as a policy intervention that can mitigate both quantity and quality dimensions of water scarcity and thus enhance efficient water use. Pricing of water plays two main roles: (1) the financial role, which is a mechanism for recovering the investment and operation and maintenance (O&M) costs, and (2) the economic role of signaling the scarcity value and the opportunity cost of water, to guide allocation decisions both within and across water subsectors. In economic terms the full cost of water includes O&M costs, capital costs, opportunity costs, and the costs of economic and environmental externalities (Tsur and Dinar, 1997; Rogers et al., 2002). In most cases, only supply costs are considered in water pricing structures. However, the other cost components can be larger than the supply cost (Rogers et al., 1998; Johansson et al., 2002). Limiting water prices to reflect only supply costs is due partly to the difficulty of measuring other cost components and partly due to political considerations.

A study of the Mula Canal in India found that farmers respond to price-induced water scarcity, but water price policy and/or a system of tradable water rights is not the most effective way to increase irrigation efficiencies (Ray, 2002). A field study in Nepal regarding the possibility of introducing cost recovery irrigation

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charges concluded that farmers are in a position to pay the operation and maintenance costs, while charging capital costs was found to be difficult to justify (Maskey and Weber, 1998).

Dinar and Subramanian (1998) revealed that water prices across countries are not related to relative water availability, suggesting either that the current objective for charging is not to manage scarcity, or that other factors are pertinent. Those countries with greater scarcity are not necessarily more aggressive in reforming their pricing schemes. Water pricing policies have failed to perform well in many countries, due mostly to faulty approaches and inappropriate institutions that have their roots in complicated political and economic environments (Dinar and Mody, 2004; Dinar and Saleth, 2005). According to Cornish et al. (2004), the response in demand to volumetric water pricing is widely shown to be minimal as current prices are well below the range where water saving is a significant financial consideration for the farmer. Volumetric prices may need to be 10–20 times the price needed for full supply cost recovery to affect demand. This was confirmed by a review of the 67 irrigation projects funded by the World Bank, which revealed that water pricing mechanisms had not been planned as incentive tools in any of the projects (Tiwari and Dinar, 2001).

The low or negligible elasticity of demand for irrigation water is a major obstacle to effective conservation pricing, especially at current charges (Moore, 1989; Sampath, 1992; Rosegrant and Cline, 2002). Bos and Wolters (1990) found that in almost all of the projects studied, a price that was less than 10% of net farm income was too low to have significant impact. Latinopoulos (2005) found no relationship between prices and water use in a sample of 21 irrigation districts in Greece. A study of nine Spanish schemes attributed differences in water use to other factors (e.g. soil, nature and abundance of the source, history, etc.), and concluded that inelastic demand reflected the relatively low share of water in production costs and the lack of a substitute for water (Berbel and Gomez-Limón, 2000). Some studies carried out in the United States indicate a similar lack of demand responsiveness to water prices (Hoyt, 1984; Moore et al., 1994).

1.2. Local context

Ensuring sufficient water is one of the most fundamental challenges to sustainable development, economic growth, and political stability in the MENA region in general and in the Occupied Palestinian Territories (OPT) in particular. Water security is especially critical to the viability of the anticipated Palestinian State where the long-term challenge for water resource managers is to sustainably increase water supply while managing water demands. Water management decisions have strong links to the agricultural sector, which consumes 65–70% of the water supply in the OPT (RAND, 2007).

The political conflict between Palestinians and Israelis exacerbates the water and agricultural problems. Palestinians do not have full control over their groundwater resources, as these are shared with Israelis. Groundwater aquifers are the major sources of water for Palestinians and Israeli settlements in the West Bank. Groundwater is pumped from deep aquifers through agricultural and domestic wells that were constructed during the Jordanian mandate (before 1967). Israel imposes restrictions on construction of new wells by Palestinians and limits the annual abstraction rates from existing wells. Most of the wells are owned by individual farmers or farmers' cooperatives and are intended for agricultural irrigation. The owners of wells use part of the produced water for irrigation of their own lands and sell excess water to neighboring farmers. Many owners of wells have begun supplying drinking water to towns and villages from their agricultural wells because it is more profitable than selling irrigation water to farmers in difficult economic conditions.

Irrigation water prices are determined by owners of wells, based on their recurring costs and their understanding of the hardships facing Palestinian farmers, with limited interference from the Palestinian government. The irrigation water prices are much lower than those for domestic and industrial uses. Palestinian water experts often argue that such low water prices encourage farmers to use excessive water for irrigation (Abdo, 2008; Abu-Madi et al., 2008a,b).

A current policy question is what role irrigation water pricing might have in water demand management in the OPT. Most Palestinian water (about 70%) is consumed by agriculture, which is the least economic productive sector; its contribution to local GNP is between 6% and 7% (PCBS, 2007; RAND, 2007). Agriculture is the major source of income to about 6.1% of the Palestinian population; most of them are poor and lack opportunities for other sources of income. About 25% of the Palestinians depend on agriculture as a main source of household income and about 70% of them are poor (PCBS, 2007). However, poverty problems cannot be solved only by improving access to water (Hussain, 2007). Improved access must be accompanied by a proper water price strategy and a sound crop marketing system. This research provides information regarding the potential reform of irrigation water prices in the OPT by examining farm-level perspectives regarding irrigation water prices in the Tulkarm district as a case study.

2. Materials and methods

2.1. Study area

The Tulkarm district is 1 of 11 main Palestinian districts and is located in the northwestern part of the West Bank (Fig. 1). The district lies between 40 and 500 m above mean sea level. Based on records of the Palestinian Central Bureau of Statistics (PCBS, 2007), about 175,320 residents live in 42 communities. The Tulkarm district has a moderate climate characterized by a rainy winter (October–May) and dry summer (June–September). Average annual precipitation varies between 530 and 630 mm, which is the main water source for the western groundwater aquifer (PWA, 2005; MOA, 2007).

According to PCBS (2005), about 182,000 hectares (ha) of farmland are cultivated in the OPT, of which 91% are in the West Bank and 9% are in the Gaza Strip. Fruit trees constitute 63% of the cultivated area, while vegetables and field crops comprise 10% and 27% of the cultivated areas, respectively. About 69% of the cultivated area in the Gaza Strip relies on irrigation, compared with about 8% for the West Bank. The Tulkarm district covers about 246 km^2 or 4.35% of the total West Bank area (PCBS, 2005). The cultivated land is about 38% of the total area of the district. Rainfed farming constitutes 92% of the cultivated area in the district, whereas irrigated farming constitutes 8%. Much of the land (53.4%) is unused or partly used as pasture. The land use patterns in this district are influenced by topography, climate, and the political conflict over land and water resources. Most of the irrigated land is used for vegetables (e.g. cucumbers and tomatoes) under greenhouse agriculture and fruit trees (e.g. olives and citrus).

The Tulkarm district, as elsewhere in Palestine, suffers from water shortages. The average water consumption for municipal purposes ranges between 50 and 70 l per capita per day (l/c/d) (PWA, 2005). Most residents depend on groundwater wells for domestic water supply. Twelve of the 42 communities in the Tulkarm district do not have a domestic water supply network.

Agricultural activities in the district consume about 65% of the water supply (Table 1). Most water consumed in the district is pumped from the western aquifer, which is the largest formation of the mountain aquifer system in the West Bank. Of the 287 Palestinian groundwater wells in the West Bank, 63 wells are

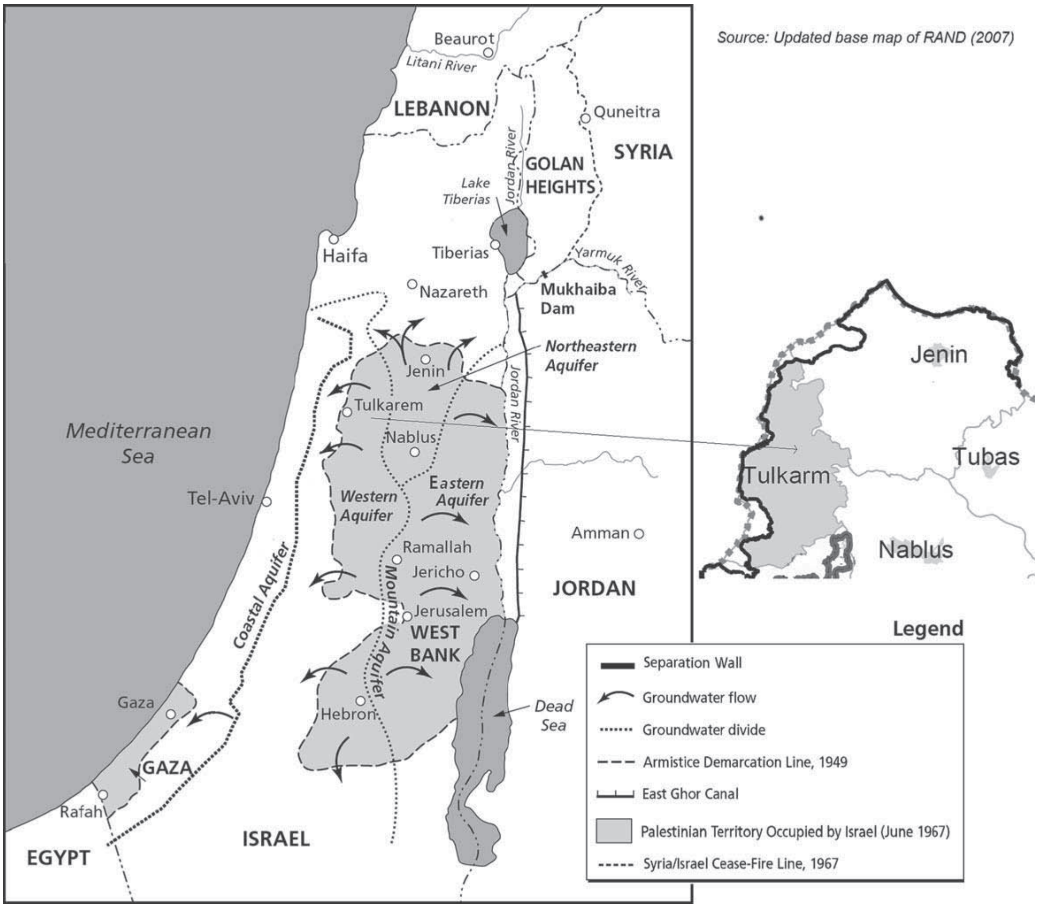

Fig. 1. Location of the Tulkarm district.

located in the Tulkarm district. Eleven of these wells are restricted for municipal water supply, and 52 wells are used primarily for agricultural water supply (PWA, 2005). The total volume of groundwater pumped from the 63 wells in the district is about 12.3 million m^3 per year (Table 1) (PCBS, 2005).

The Palestinian Water Authority (PWA) is responsible for water sector management, supervision, and improving the water situation in the OPT. There is discrepancy in the water price system in the West Bank and Gaza Strip even within each of the districts, due to social, physical, institutional, and political sensitivity. Current irrigation water prices in the Tulkarm range between \$0.25 and \$0.37 per cubic meter (US\$/m^3), and are based on the O&M costs of abstracting groundwater (MOA, 2006). The water prices are influenced by the variety of energy sources used in abstracting and pumping water, performance of the distribution network, and differences in pumping cost efficiency (Table 2).

2.2. *Methods and analysis*

We organized a national workshop in 2006 to discuss irrigation water pricing. We invited farmers, owners of wells, and stakeholders from the policy-making. During that workshop, we drafted the main questions and key sections of the questionnaire that was used in this research. We finalized the questionnaire after testing it on 20 irrigated farms in the Tulkarm district.

We employed a specialized survey team to interview the farmers. The sample size selected for the survey was limited to 157 farms (about 10% of all farms in the district) due to time and budget constraints. The sample was distributed randomly among irrigated farms to cover the major agricultural villages in the district: Attil, Deir Al-Ghosoun, Zeita, Allar, Saida, Baqa Sharqeyah, Qafin, Nazlah Sharqyeh, and Nazlah Wustah.

The survey team interviewed 157 farmers in the Tulkarm district during the last quarter of 2006. During data analysis, we

Table 1
Number of water wells and annual pumping volumes in the Tulkarm district.

Region	Use	No. of wells	Annual Pumping (1000 m^3/year)
West Bank	Domestic	39	24,911
	Agricultural	248	30,074
Tulkarm	Domestic	11	4,356
	Agricultural	52	8,037

Source: Palestinian Central Bureau of Statistics (2005).

Table 2
Average irrigation water prices (\$/m^3) in the Palestinian Territories, 2006.

Jordan Valley	0.03–0.19
Jenin	0.15–0.21
Tulkarm	0.25–0.34
Gaza Strip	0.12–0.14

Source: Ministry of Agriculture (2006), personal communication.

reduced this number to 147 after reviewing and cross-checking the completed questionnaires. Ten questionnaires were eliminated due to illogical or incomplete answers.

We used the Statistical Package for Social Sciences (SPSS) to analyze the data in an attempt to build statistical models that link decisions regarding agricultural water consumption with explanatory variables.

3. Results and discussion

3.1. Labor force and agriculture

Most of the surveyed farmers were younger than age 60, while 10 were older (Table 3). Only one of the interviewed farmers was a female, as male farmers dominate Palestinian rural society and thus are responsible for farm management. However, farmers' wives and children accomplish most of the farming work. Farmers rely on internal (unpaid) labor, such that 82% and 11.6% of the farmers have 1–3 and 4–8 persons from their families working in the farm, respectively. The results also show that 68% of the framers have at least one child below age 11 and one child between age 11 and age 18 working in the farm.

Palestinian farmers' society is characterized by large family size. In the study area, 31% of farmers have families of 4–6 persons, while 49% have 7–10 persons, and 19% have more than 10 persons (Table 3). This might be attributed to low living expenses in the rural areas and most importantly, the need for family labor to help in the farming business. Nevertheless, 20% of the farmers rely fully on unpaid labor while 52% hire 1–3 external persons (paid labor). A few farmers hire between 4 and 7 persons. About 84% of the farmers have completed elementary and secondary school, while 6.8% have a Diploma and Bachelors degrees.

Most Palestinian farms are small. The land area of the surveyed farms ranges between 0.2 and 11.0 ha (Table 4). The major crops in our sample are vegetables – primarily cucumbers, tomatoes, eggplants, cauliflower, potatoes, beans, and others – and fruits – primarily citrus and others. Ownership varies between self owned, leased, and shared. About 39% of the farms are owned by the farmers, 39% are leased, and 12% are shared. Sharing involves compensation in the form of a percentage (30–50%) of net farm output.

Most Palestinian farmers are located in rural areas and earn low to middle income. In the study area, the family income of 26.5% of surveyed farmers is less than $250 per month (Table 3). Most (63.5%) have a family income of $250–500 per month. Only 9.5% of framers report family income greater than $500 per month. For 81% of the respondents, agriculture contributes more than 75% to family income (Table 3).

Table 3
Summary statistics pertaining to a survey of 147 farmers in the Tulkarm district, 2006.

	Number	Proportion (%)
Age group (years)		
20–40	83	56.5
40–60	49	33.3
Above 60	15	10.2
Family size (persons per family)		
1–3	1	0.7
4–6	46	31.3
7–10	72	49.0
More than 10	28	19.0
Average monthly income ($)		
Less than 250	39	26.5
250–500	94	63.9
500–750	11	7.5
More than 750	3	2.0
Contribution of agriculture to total family income		
More than 75%	119	81.0
50–75%	21	14.3
20–50%	5	3.4
Less than 20%	2	1.4
Ownership of the wells		
Privately owned	131	89.1
Water association	15	10.2
Local council	1	0.7

3.2. Agricultural water consumption

Groundwater is the only accessible water source for farmers in the study area. They also rely partly on rainwater harvesting during winter. The surveyed farmers indicated that private persons own 89% of the wells, 10.2% are owned by farmers' cooperatives, and only one well is owned by a local council (municipality) (Table 3). The mean agricultural water consumption in the study area varies between 1200 and 36,000 m^3/ha with an average of 12,608 m^3/ha (Table 4). Agricultural water consumption varies between farms depending on: (i) water availability, (ii) water price, (iii) land area, (iv) types of irrigated crops, (v) farmer experience, (vi) method of measuring water consumption, (vii) technical performance of the irrigation system, and (viii) type of irrigation system.

We used the multiple regression component of SPSS to generate a mathematical model that explains agricultural water consumption as a function of several explanatory variables. The regression analysis results in Table 5 show the most statistically significant variables that determine agricultural water consumption in the Tulkarm district. The linear Eq. (1) is the best fit generated by the regression model. We did not observe significant correlations between agricultural water consumption and farmer's age or level of education, or the type of irrigation system or cultivated crops. Therefore, these variables were excluded from the final regression model:

q = farm water consumption (m^3/ha);
X_1 = water price ($/$m^3$);
X_2 = irrigated land area (ha);
X_3 = annual income of farm ($/ha);
X_4 = frequency of irrigation (times/week).

$$q = 6294.3 - 5703.8X_1 - 486.2X_2 + 0.302X_3 + 1021.39X_4 \quad (1)$$

The estimated regression coefficients are shown in column B of Table 5. The two-tailed significance levels for water price, annual farm income, and frequency of irrigation are less than 0.05, while the significance level for area of irrigated land is about 0.08. Negative signs indicate that agricultural water consumption decreases with the increase in values of these variables, and vice versa. The F value and the R^2 value suggest that the model fits the data reasonably well. An estimated 57.7% of the observed variation in agricultural water consumption is explained by the independent variables in Eq. (1).

The regression results suggest that irrigation water prices and the size of irrigated lands are inversely correlated with agricultural water consumption in the Tulkarm district. Irrigation frequency and farm annual income are positively correlated with agricultural water consumption. Small-scale farmers tend to consume more irrigation water than others and thus they are more economically sensitive to increases in water prices.

Farmers determine irrigation requirements based on their experience, with minimum input from governmental and non-governmental organizations in the area. Water meters are used to measure irrigation water on 21% of the surveyed farms (Table 6).

Table 4
Agricultural data and water costs of surveyed farms in the Tulkarm district, 2006.

	Number	Min.	Max.	Mean	S.D.
Irrigated land area (ha)	135	0.17	11.00	1.19	1.2546
Annual farm water consumption (m^3)	130	2000	70,000	11,977	10,366
Water consumption (m^3/ha)	125	1200	36,000	12,608	5,558
Annual water cost ($/year)	140	120	21,875	3,717	3,159
Annual cost of the farm ($/ha/year)	134	475	48,250	14,060	9,021
Water price ($/$m^3$)	130	0.025	1.56	0.33	0.14
Water price ($/ha)	135	138.9	12,000	3,992	2,112
Annual cost of the farm ($/year)	138	950	71,650	12,789	10,026
Annual income of the farm ($/year)	129	1750	277,500	19,643	26,222
Water share to total farm costs (%)	138	2.14	65.79	32.2	12.10
Annual income of the farm ($/ha)	125	1225	67,000	19,997	12,212
Annual profit of the farm ($/ha)	124	750	28,411	5,901	4,823
Annual profit of the farm ($/person/year)	124	138.9	4,460	773	650
Farming profit per person per day ($)	124	0.38	12.20	2.10	1.78

Table 5
Regression model of the relationship between agricultural water consumption and major explanatory variables[a].

	Explanatory variables	*B*	SE. *B*	Beta	*t*	Sig.
	(Constant)	6294.3	1670.7		3.767	0.000
X_1	Water price ($/$m^3$)	−5703.8	2255.9	−0.159	−2.528	0.013
X_2	Irrigated land area (ha)	−486.2	278.3	−0.118	−1.747	0.083
X_3	Annual income ($/ha)	0.302	0.030	0.691	10.184	0.000
X_4	Frequency of irrigation	1021.39	453.4	0.140	2.253	0.026

[a]Dependent variable (q): agricultural water consumption (m^3/ha). $N = 115$; $F = 37.857$; Sig. = 0.000; $R = 0.760$; $R^2 = 0.577$; adjusted $R^2 = 0.562$; Standard Error of the Estimate = 3579.3.

The water meters are read and maintained by operational staff of the groundwater wells. In most cases (79% of the surveyed framers), irrigation water is measured by supply hours (60–110 m^3/h). This system is common in the district, as the wells' owners tend to reduce their operational costs associated with water meter installation, repair, and reading. Moreover, this system requires that the farmers pay for the unaccounted water that is lost through leakage or illegal connections.

3.3. Water prices and agricultural profitability

Farmers do not play a direct role in determining irrigation water prices. Rather, the wells' owners (private and cooperatives) determine prices that will recover their operational costs and generate a limited profit margin. Operational costs depend largely on the energy (electricity and diesel) prices that fluctuate with changes in the global oil market. However, the process of determining irrigation water prices in the district does not fully respond to changing operational costs of the wells. The competition among well owners often leads to a close range of water prices. This functions as an incentive to well owners and managers to increase profitability by improving technical performance and reducing the pumping costs.

The annual farming costs in the Tulkarm district range between $475 and $48,250/ha with an average of $14,060/ha (Table 4). The large range in costs per hectare is attributed to the different farming inputs that are based on crops and local conditions, the different amounts of water consumed, different land sizes, and different water prices. The survey results reveal that the actual water prices range between $0.025 and $1.56/$m^3$ with an average price of $0.33/$m^3$. The large range in water prices can be explained by several observations: (i) some of the well owners assign very low prices when irrigating their own farms, and (ii) some farmers pay additional pumping costs when they store water in reservoirs for later use. However, the mean value of survey results ($0.33/$m^3$) is within the range reported by the Ministry of Agriculture (Table 2).

The annual expenditure on irrigation water represents from 2.1% to 65.8% of the total farming cost, with an average of 32.2%. The large range is a natural consequence of the large range of water prices and consumed water quantities. About 90% of the surveyed farmers responded that their annual expenditure on water represents 25–50% of their total farming costs (Table 7). Comparing farmers' responses to the calculations shows that farmers' expenditures on irrigation water dominate their farming expenses. Thus, the farmers are currently burdened with high expenses and low farming profitability, which must be considered when developing new policies that might modify the price of irrigation water.

Farmers' profitability – excluding unpaid labor – can range from $138 to $4460 per person per year with an average of $773 per person per year. Including the economic value of the unpaid labor will make farming unfeasible. However, farmers do not include the value of unpaid labor when assessing the economic feasibility of their farming business. This may be attributed to the socio-cultural value of farming, which outweighs the opportunity cost of family labor, particularly when farmers' wives and children have limited chances of obtaining non-farm jobs.

The results also show that the farmers' income from agriculture ranges between $0.38 and $12.20 per person per day, with an

Table 6
Irrigation frequency and water measurement in the Tulkarm district, 2006 ($N = 147$).

	Number	Proportion (%)
Irrigation frequency		
Once per week	3	2.0
Twice per week	57	38.8
Three times per week	74	50.3
More than three times per week	7	4.8
No schedule	6	4.1
Irrigation water measurement		
Water meter	31	21.1
Pumping hours estimated	116	78.9

Table 7
Farmers' perceptions and willingness to pay for increased water prices in the Tulkarm district, 2006 (N = 147).

	Number	Proportion (%)
Proportion of water cost in total farming expenses (%)		
More than 50%	8	5.4
25–50%	132	89.8
10–25%	7	4.8
Farmers' rating of current water prices		
Low	1	0.7
Good	3	2.0
High	143	97.3
Willingness to pay for water prices ($/m^3)		
Less than 0.125	135	91.8
0.188	5	3.4
0.250	4	2.7
More than 0.375	3	2.0

Table 8
Farmers' coping strategies if water prices are increased in the Tulkarm district, 2006 (N = 147).

Coping action	Number	Proportion (%)
Continue farming as usual	60	40.8
Reduce irrigated land area	50	34.0
Change crops	6	4.1
Look for more efficient irrigation techniques	6	4.1
Look for other source of income	16	10.9
Other	9	6.1

average of $2.10 per person per day. Thus many farmers in the Tulkarm district operate below the poverty line of $2.00 per person per day (World Bank, 2003).

The Palestinian Territories have considered increasing irrigation water prices as an efficient water demand management tool. Although current irrigation water prices are much lower than domestic water prices, almost all surveyed farmers consider the current irrigation water prices to be high (Table 7) and they show limited willingness to pay (WTP) for higher water prices. About 92% of the farmers are willing to pay a maximum price of $0.125/m^3 (Table 7), although they already pay higher prices. The results of our study reveal that if water prices were increased, 41% of the farmers would continue farming, 34% would reduce their land area, and 11% of the farmers – normally the poorest farmers with limited farm sizes – would stop farming and search for another source of income (Table 8).

4. Conclusions

Most of the farmers in the Tulkarm district of Palestine are poor, and they rely on agriculture for their subsistence. Agriculture represents the major source of income for most of the farmers, who depend on unpaid labor from their wives and children to reduce the high farming expenses. Although current irrigation water prices are much lower than domestic prices, most farmers consider the irrigation water prices to be quite high. Annual expenditures for water are large portions of the total annual farming costs, even without considering the economic value of unpaid labor. The farmers' net revenue – excluding unpaid labor – ranges from $138 to $4,460 per person per year.

Despite a low willingness to pay for increased water prices, many farmers would continue farming even with increased water prices and reduced profitability. Hence, attempts to raise irrigation water prices in the Tulkarm district will jeopardize farming feasibility and even sustainability of the farming system, especially for those farmers operating below the poverty line of $2.00 per person per day.

Palestinian policy makers should consider empowering farmers by providing appropriate marketing strategies for agricultural crops. This might include programs to stimulate exports to neighboring countries. The Palestinian Authority needs to consider providing subsidies on farming expenses such as machinery and equipment, seeds and nursery materials, and other inputs. Moreover, the agricultural sector needs substantial restructuring and organization to optimize agricultural production in accordance with needs of the local market. This will improve the economic feasibility of farming and encourage wiser use of irrigation water.

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4

Interaction Between Digestion Conditions and Sludge Physical Characteristics and Behaviour for Anaerobically Digested Primary Sludge

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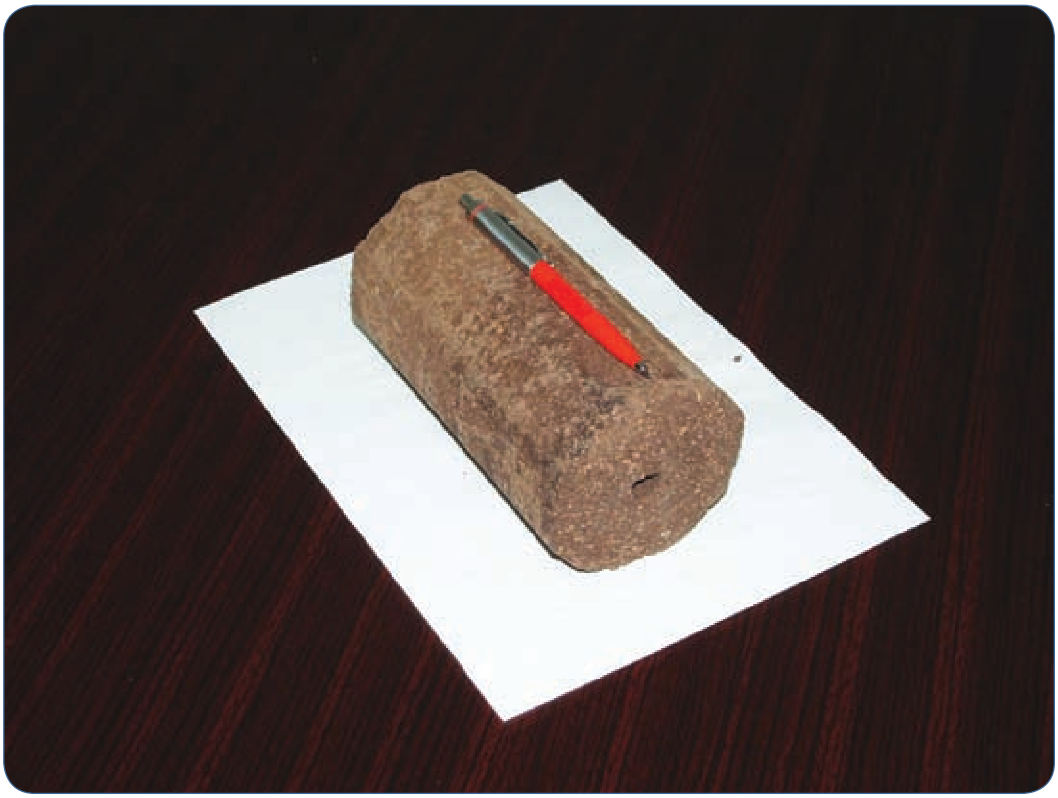

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Interaction between digestion conditions and sludge physical characteristics and behaviour for anaerobically digested primary sludge

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Abstract

The interaction between digestion conditions and the sludge physical characteristics and behaviour was investigated for anaerobically digested primary sludge in completely stirred tank reactors (CSTRs). The CSTRs were operated to maintain sludge retention times (SRTs) of 10, 15, 20 and 30 days and temperatures of 25 and 35 °C. The change of the floc size as a result of digestion was examined using wet sieve analysis (0.100, 0.125, 0.200, 0.500 and 1.000 mm). The results reveal a substantial reduction in all floc sizes with improving digestion conditions. Digestion leads to the transfer of bigger flocs into smaller ones, which has a remarkable effect on the sludge physical behaviour. The majority of the raw and digested flocs are smaller than 0.100 mm. The dewatering results showed the existence of an optimal SRT for dewaterability at 20 and 15 days for the reactors operated at 25 and 35 °C, respectively. The dewaterability of sludge digested at less favourable conditions, viz. 10 days at 25 °C deteriorates due to increase of small flocs generated from destruction of larger flocs. The digested sludge settling results showed a slight worsening but insignificant trend with increasing the SRT.

Keywords: Anaerobic processes; Dewaterability; Floc size distribution; Mixing; Optimisation; Waste treatment

1. Introduction

The operational conditions of anaerobic digesters are expected to largely influence the physical–chemical characteristics and consequently the physical behaviour of the sludge through influencing the organic matter degradation and biomass growth. However, the relation between the digestion conditions, i.e. temperature and sludge retention time (SRT), and sludge characteristics, e.g. floc size distribution (FSD) and behaviour, e.g. dewaterability and settleability, has been scarcely reported in literature [1].

Anaerobic digestion changes the sludge floc size distribution, which is influenced by the operating conditions. Lawler et al. [2] showed that FSD highly influences the sludge dewaterability, e.g. dewaterability worsens with decreasing floc size which took place in high loaded reactors. Nevertheless, no significant data have so far been available on the sludge dewatering behaviour once the reactor is operated at low loading rate, viz. long SRT.

The sludge loading rate and substrate composition are likely to influence floc charge and the quantity and composition of the extracellular polymeric substances (EPS) content [3–5], which in turn affect the sludge dewaterability [6], and settleability [7]. When the substrates are utilised or the organic loading rate is low, the bacteria metabolise the EPS for energy and/or carbon [5]. The EPS degradation under anaerobic conditions forming CO_2 and CH_4 was also reported [8].

EPS are thought to influence the dewatering characteristics of sludge by forming a charged surface layer on sludge flocs [9]. The interactions of these polymers between cells allow adjacent bacteria to aggregate by bridging cell surfaces electrostatically and physically and therefore, initiate floc formation which allows the sludge settlement [10,11].

The objective of this research was to investigate the relation between digestion conditions, viz. temperature and SRT, and sludge physical characteristics, viz. FSD, and sludge physical behaviour, viz. dewaterability and settleability for anaerobically digested primary sludge in completely stirred tank reactors

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(CSTRs) operated at 25 and 35 °C. The temperature of 25 °C is the average sewage temperature in Palestine/the Middle East during summer time so the CSTRs can be operated during summer time without any external heating/or with minimal heating and 35 °C is the optimum temperature under mesophilic conditions.

2. Materials and methods

2.1. Continuous experiments

Two sets of eight CSTRs, with a 15-l working volume, were operated in order to maintain SRTs of 10, 15, 20 and 30 days at process temperatures of 25 and 35 ± 1 °C. The temperatures were controlled by re-circulating water of pre-controlled temperature through the reactors double walls. The reactors were inoculated with primary sludge digested at 34 °C and 20 days from the wastewater treatment plant (WWTP) of Ede, The Netherlands. The feeding stock primary sludge was collected once from the aforementioned WWTP and stored at 4 °C. Around 20 l of the stock was diluted weekly to 20 g TS/l and stored at 4 °C from which the reactors were fed once daily. The reactors were intermittently mixed at 30 rpm for 10 s/min. Biogas was continuously collected in 10 or 5 l gas bags and was measured daily. The pH was measured daily and the VFAs were measured at least once every two weeks and digesters temperatures were checked from time to time. After a period of at least three SRTs of continuous operation, the monitoring parameters were stable and the reactors were considered to be at steady-state conditions. Afterwards, within three weeks, four samples in duplicate were analysed for total solids (TS) and volatile solids (VS), volatile fatty acids (VFA), capillary suction time (CST), floc size distribution, sludge volume index (SVI) and sludge settling inside the reactor was measured once at the end of the CSTRs operational periods. The quantity of methane produced was measured daily.

2.2. Analytical methods

TS and VS of sludge were determined according to standard methods [12]. The VFA were measured as previously described by Mahmoud et al. [13]. Sludge volume index was measured according to the *Dutch Standard Normalized Methods* [14]. Dewaterability of the sludge was detected by the capillary suction time (s) and expressed as filterability constant, which is calculated based on the CST [15]. The dimensionless constant, ϕ, of the CST apparatus is 0.794.

2.3. Determination of FSD by sieving

1. A 250 ml sludge sample was collected and diluted 20 times with centrifuged (15 min at 1000 rpm) and filtered (4.4 μm paper filter) effluent of a two-step anaerobic system treating domestic sewage [16].
2. The diluted slurry was poured through each sieve (1.000, 0.500, 0.200, 0.125 and 0.100 mm) starting with the largest size.
3. The sieve was soaked in the filtrate for 40 times, in a systematic downward–upward slow motion.
4. The retained solids were conveyed from the sieve to porcelain crucibles. The conveyance process was carried out using a gentle jet of tap water to collect all scattered flocs over the sieve surface to one edge of the sieve. Then a jet of demi-water was used to push the collected flocs into the porcelain crucibles with the help of a small spoon.
5. The collected solids were examined for total solids and volatile solids.

The reproducibility of the method was validated by testing several anaerobic primary digested sludge samples, brought from the WWTP of Ede, which showed that the results are reproducible.

2.4. Settleability of sludge

The sludge settleability was measured by two ways, by measuring: (1) SVI parameter and (2) the sludge settling in the CSTRs. The latter measurement was carried out according to the following procedure:

1. Mixing inside the CSTR was stopped.
2. The height of the developed ‘clear’ supernatant was followed with time by measuring the distance between the top of the water phase and the top of the sludge phase.

2.5. Statistical data analysis

Statistical comparison of means was followed by “paired samples *t*-test” for the measured parameters of the two reactors using the SPSS program for windows—release 11.0.0, SPSS® Inc. (2001), with p-value < 0.05 considered significantly different.

3. Results and discussion

3.1. Flocs size distribution

The results presented in Table 1 reveal a substantial reduction in all flocs (on mass basis) within the set size intervals (0.1–1.0 mm) due to digestion. The mass of the flocs of the digested sludge was always lower than that of the flocs of identical size of the raw sludge. Nevertheless, the results of the FSD of the sludge digested at 10 days and 25 °C clearly show the transfer of larger flocs into smaller flocs as is clear from flocs accumulation in the size range smaller than 0.10 mm. The conversion of larger into smaller flocs is also clear as the mass of the flocs in the range 0.10 mm ≤ diameter < 0.125 mm, of the sludge digested at sub-optimal conditions (SRT: 10 days, 25 °C), is less than those digested at more optimal temperature conditions (35 °C). Moreover, the results clarify that the main achievement in large flocs (diameter ≥ 0.1) reduction could be attained by digestion at even sub-optimal conditions (SRT: 10 days, 25 °C), while the main reduction of small flocs (diameter < 0.1) could be achieved at improving the digestion conditions to (SRT: 10 days, 35 °C).

Table 1
Floc size distribution (FSD) and percentage flocs reduction (R%) of raw and anaerobic digested primary sludge in CSTRs operated at different conditions (SRT and temperature)

Size (mm)	Sludge type					
	Raw	10, 25	10, 35	15, 35	20, 35	30, 35
$1.000 \leq$ diameter	426 (17.0)	169 (14.8)	141 (15.3)	144 (6.9)	140 (23.2)	94 (7.1)
$0.500 \leq$ diameter < 1.000	418 (17.4)	166 (23.5)	137 (4.6)	129 (5.1)	106 (7.8)	93 (8.1)
$0.200 \leq$ diameter < 0.500	404 (5.2)	204 (5.2)	203 (5.0)	183 (4.7)	164 (3.4)	156 (2.5)
$0.125 \leq$ diameter < 0.200	143 (8.3)	106 (7.2)	104 (4.7)	103 (1.6)	89 (2.5)	88 (1.8)
$0.100 \leq$ diameter < 0.125	98 (4.1)	53 (4.8)	70 (2.7)	64 (5.2)	61 (3.0)	65 (1.4)
Sum diameter ≥ 0.100	1489 (35)	698 (1.2)	655 (7)	623 (10)	560 (9)	496 (0.35)
R% diameter ≥ 0.100	0	53	56	58	62	67
Diameter < 0.100	2191 (36)	2503 (0.5)	1737 (7.2)	1628 (13.43)	1562 (23.76)	1451 (1.06)
R% diameter < 0.100	0	−14	21	26	29	34

For all sludges, sample size of 250 ml was used. The FSD is expressed as sludge mass (VS, mg) accumulated over sieves of different mesh sizes. Standard deviations are presented between brackets.

Table 2
VS/TS ratio of raw and digested primary sludge accumulated over sieves of different mesh sizes

Size (mm)	Sludge type					
	Raw	10, 25	10, 35	15, 35	20, 35	30, 35
$1.000 \leq$ diameter	0.92 (0.003)	0.91 (0.007)	0.90 (0.037)	0.89 (0.009)	0.91 (0.025)	0.89 (0.012)
$0.500 \leq$ diameter < 1.000	0.92 (0.003)	0.89 (0.003)	0.87 (0.030)	0.86 (0.004)	0.86 (0.006)	0.85 (0.007)
$0.200 \leq$ diameter < 0.500	0.82 (0.004)	0.85 (0.003)	0.78 (0.010)	0.79 (0.004)	0.79 (0.006)	0.79 (0.012)
$0.125 \leq$ diameter < 0.200	0.61 (0.009)	0.83 (0.006)	0.68 (0.022)	0.72 (0.007)	0.71 (0.017)	0.68 (0.028)
$0.100 \leq$ diameter < 0.125	0.50 (0.009)	0.77 (0.015)	0.60 (0.013)	0.65 (0.013)	0.66 (0.009)	0.60 (0.024)

For all sludges, sample size of 250 ml was used. The sludge was digested in CSTRs operated at different conditions (SRT and temperature). Standard deviations are presented between brackets.

The flocs with a diameter in the range of 0.200–0.500 mm were dominant in all examined digested sludge samples. The same trend was shown for the inoculum primary digested sludge brought from the WWTP of Ede, The Netherlands, which was used for examining the reproducibility of the method. The VS/TS ratio illustrated in Table 2 indicates an increase of the inorganic content with a decreasing floc size, independent of the type of sludge. Moreover, the table clearly shows that the VS/TS ratio of the larger flocs (diameter ≥ 0.2 mm) is either not or just slightly affected negatively by improving sludge digestion conditions. However, the VS/TS ratio of the smaller flocs (diameter < 0.2 mm) is always significantly higher than that of the raw sludge ($p < 0.05$). The latter indicates that the small flocs from the influent are for a substantial part hydrolysed to dissolved products and replaced by new small flocs produced by hydrolysis and breakdown of the larger flocs. This finding demonstrates the shift in FSD of big flocs to flocs of <0.100 mm where the main biodegradation took place. The results presented in Table 3 show that the majority of the flocs in the raw as well as the digested sewage sludge are smaller than 0.100 mm.

3.2. *Dewaterability*

The results presented in Fig. 1 reveal a large influence of the digestion conditions on the sludge dewatering characteristics. The dewaterability results of the digested sludge in both sets of reactors, operated at 25 and 35 °C, reveal the existence of an optimal SRT for dewaterability. The optima at 25 and 35 °C are shown at an SRT of 20 and 15 days, respectively ($p < 0.05$). The dewaterability of the digested sludge in the digester operated at

Table 3
Percentage pass of flocs (measured as VS) through different mesh sizes for raw and digested sludge in CSTRs operated at different digestion conditions (SRT and temperature)

Size (mm)	Sludge type					
	Raw	10, 25	10, 35	15, 35	20, 35	30, 35
Diameter < 1.000	88 (0.46)	95 (0.46)	94 (0.45)	94 (0.31)	93 (1.10)	95 (0.37)
Diameter < 0.500	77 (0.94)	90 (0.27)	88 (0.30)	88 (0.53)	88 (0.70)	90 (0.05)
Diameter < 0.200	66 (1.08)	83 (0.11)	80 (0.29)	80 (0.42)	81 (0.49)	82 (0.18)
Diameter < 0.125	62 (0.85)	80 (0.10)	76 (0.23)	75 (0.61)	76 (0.36)	78 (0.09)
Diameter < 0.100	60 (0.96)	78 (0.04)	73 (0.29)	72 (0.44)	73 (0.56)	74 (0.02)

For all sludges, sample size of 250 ml was used. Standard deviations are presented between brackets.

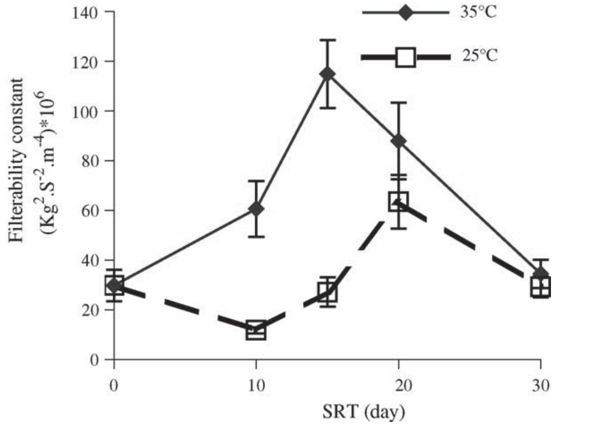

Fig. 1. Dependency of primary sludge dewaterability expressed as filterability constant according to Vesilind [15], on anaerobic digestion conditions (SRT: 0, 10, 15, 20 and 30 days; temperature 25 and 35 °C) in CSTRs. SRT = 0 stands for the raw influent.

10 days SRT and 25 °C deteriorated in comparison with the raw influent ($p < 0.05$), which is in agreement with results presented by Miron et al. [17]. This digester was under stress as it is clear from the digestion results, whereas the reactors operated at 15 and 30 days and 25 °C operational temperature were not different from the raw sludge ($p > 0.05$). At an SRT of 30 days at both process temperatures, 25 and 35 °C, the dewaterability of digested sludge did neither differ from each other nor from the raw sludge ($p > 0.05$).

3.3. Settling characteristics

The results presented in Fig. 2 show that the SVI was insignificantly affected by the digestion conditions ($p > 0.05$). The results however show a slightly worsening trend of sludge settling characteristics with digestion. The results of sludge settling obtained by following the sludge settling inside the CSTR (Fig. 3) confirm that digestion does not affect the sludge settling characteristics.

3.4. Discussion

The results of this research reveal that sludge digestion conditions highly influence the sludge physical characteristics and behaviour. The raw sludge was not submitted to the same mixing conditions as the reactors, and accordingly a strictly true comparison between FSD in raw and digested sludges is not valid.

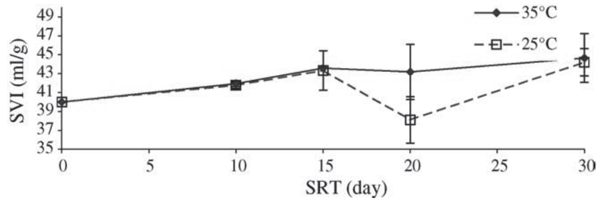

Fig. 2. Dependency of primary sludge settleability expressed as SVI, on anaerobic digestion conditions (SRT: 0, 10, 15, 20 and 30 days; temperature 25 and 35 °C) in CSTRs. SRT = 0 stands for the raw influent.

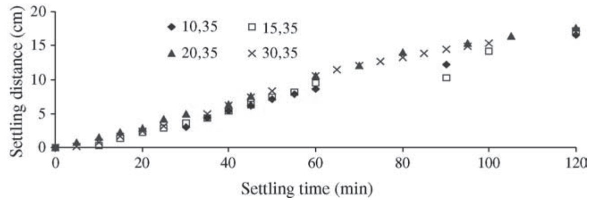

Fig. 3. Dependency of digested anaerobically primary sludge settleability measured as the developed clear distance inside the CSTR reactors after switching off the mixer, the CSTRs were operated at different conditions (SRT: 0, 10, 15, 20 and 30 days; temperature 35 °C). The working height of the CSTR is 35 cm. SRT = 0 stands for the raw influent.

However, the operated reactors are CSTRs which entail a must mixing, and so mixing is an inherent parameter of digestion in this type of reactors.

The worsening of the dewaterability of the sludge digested at 10 days SRT and 25 °C is probably due to the coupled effect of larger flocs transfer to the pool of small flocs and poor digestion conditions. The results indicate that the main improvement of organic matter conversion upon improving the digestion conditions from (10 days, 25 °C) to (10 days, 35 °C) takes place in the flocs smaller than 0.100 mm. Therefore, the improvement of dewaterability with improving digestion conditions, up to optima, can be explained by biodegradation of the small flocs and consequently the reduction of the specific surface area. Karr and Keinath [18] found that flocs in the range of 0.001–0.100 mm had the most significant effect on dewaterability.

The here proved phenomenon of the existence of optimal conditions for sludge dewaterability and the afterwards decline has also been pointed out in literature. Lawler et al. [2] found during anaerobic digestion of mixed primary sludge and secondary sludge (weight of activated sludge is 20% of total solids) in CSTRs operated at 35 °C, a worsening trend of dewaterability with increasing SRT from 7 to 21 days, but this trend was not statistically significant at a 0.05 level. Similarly, Nellenschulte and Kayser [19] showed during anaerobic digestion of primary sludge in CSTRs operated at 35 °C that after 15 days, the degradation of organic substances has advanced to such an extent that an optimal dewatering result was achieved. Further extension of the SRT did not result in any significant change of the dewatering result.

The decline of the dewaterability after the optimum might be due to increase of very small flocs, which are normally referred to as fines due to biomass decay, and accumulation of inorganic material after long SRT [2,19]. Unfortunately, in this research the influence of the sludge charges on the digestion conditions was not assessed, as the sludge charges are reported to influence the dewatering characteristics of sludge [9] due to alteration of the electrostatic forces between the water molecules and the sludge flocs.

Nellenschulte and Kayser [19] found that increasing the fines (1.9–3.9 nm) content in the sludge by means of mechanical disintegration resulted in a significant increase of the total negative charge of sludge flocs, expressed by zeta-potential, viz. after agitating the sludge for 15 min, the zeta-potential changed from −4.5 to −13.9 mV. Moreover, they showed that, the longer the digestion period, the higher becomes the fine flocs content in the digested sludge. After a digestion period of 15 days at 35 °C, the fines content of primary sludge increased from 2031 to 2080 flocs and to 2511 flocs/g solids after a digestion period of 25 days, which might suggest that solids become more negatively charged with digestion. Differently, Elmitwalli et al. [20] reported during anaerobic batch sewage digestion at 35 °C for a period of 135 days, only a slight decrease in the negative zeta-potential, viz. from −22.6 to −19.5 mV. The latter might explain that hardly any effect of digestion was shown on the sludge settling characteristics in the present research.

4. Conclusions

- Anaerobic digestion conditions have a substantial influence on the sludge physical characteristics and behaviour.
- Floc size plays an important role in sludge physical behaviour, i.e. dewaterability.
- Majority of flocs in both raw and digested sludge are smaller than 0.100 mm.
- Anaerobic digestion at full methanogenic conditions improves dewaterability up to an optimum value.
- Primary sludge settling characteristics are slightly affected due to digestion. In practice, this effect is expected to be negligible.
- More research is recommended into the interaction between sludge physical–chemical characteristics and the digestion conditions with special emphasis on EPS and electrical charges.

Acknowledgments

This research was supported by grants from the Dutch government (SAIL-IOP/SPP project). The technical support provided by R. Roersma and B. Willemsen is highly acknowledged. The first author wishes to thank Jules van Lier/Lettinga associates foundation and Wa'el Hashlamoun/Birzeit University (BZU) for managerial support.

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5

Water Footprints of the Palestinians in the West Bank

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WATER FOOTPRINT OF THE PALESTINIANS IN THE WEST BANK[1]

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ABSTRACT: Water in the West Bank of Palestine is a key issue due to its limited availability. Water is used from own sources for domestic, industrial, and agricultural purposes. Moreover, water is consumed in its virtual form through consumption of imported goods, such as crops and livestock, the production of which used water in the country of production. In addition, wastewater in many parts of the West Bank is disposed off without treatment into the *wadis*, deteriorating the quality of the water resources in the area and, therefore, further reducing the quantity of good quality water available. This paper calculates the water footprint for the West Bank. The consumption component of the water footprint of the West Bank was found to be 2,791 million m^3/year. Approximately 52% of this is virtual water consumed through imported goods. The West Bank per capita consumption component of the water footprint was found to be 1,116 m^3/cap/year, while the global average is 1,243 m^3/cap/-year. Out of this number 50 m^3/cap/year was withdrawn from water resources available in the area. Only 16 m^3/cap/year (1.4%) was used for domestic purposes. This number is extremely low and only 28% of the global average and 21% of the Israeli domestic water use. The contamination component of the water footprint was not quantified but was believed to be many times larger than the consumption component. According to the official definition of water scarcity, the West Bank is suffering from a severe water scarcity. Therefore, there is a need for a completely new approach towards water management in the West Bank, whereby return flows are viewed as a resource and that is geared towards a conservation oriented approach of "use, treat, and reuse."

(KEY TERMS: West Bank; water use; virtual water; water footprint; water scarcity.)

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INTRODUCTION

The water resources in the West Bank in Palestine are limited. There is water shortage in the area and this is expected to be more serious in the near future as both the population and the per capita consumption are increasing (MOPIC, 1998a). Moreover, the water resources are threatened by water pollution due to the inadequate wastewater disposal which further decreases water quality and, therefore, availability.

Adequate management of water resources is important, specifically when resources are limited.

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A starting point for the adequate management of water is knowledge about the availability of water for the population and its economic activity. One way of expressing water use is through the concept of water footprint. The objective of this paper is to determine the water footprint for the West Bank.

BACKGROUND

Study Area

Historical Palestine is the area situated in the western part of Asia between the Mediterranean Sea in the west and the River Jordan and the Dead Sea in the east. It is bordered by Lebanon in the north, Syria and Jordan in the east, the Mediterranean Sea in the west and Egypt, and the Gulf of Aqaba in the south (Figure 1). This study focuses on the West Bank in Palestine. The West Bank is situated on the central highlands of Palestine; the area is bordered by the Jordan River and the Dead Sea in the east and the 1948 cease-fire line in the north, west, and south. The total area of the West Bank is 5,788 km^2 including the area of the Dead Sea that falls within the West Bank boundaries (WRAP, 1994) (Figure 1). CIA fact book (CIA, 2005) estimated the population of the West Bank at 2.4 million in 2004 with a growth rate of 3.13%. According to PCBS (1999), in 1997 the total Palestinian population living in the West Bank was 1.8 million. Table 1 presents the projected population of the West Bank during the period 1997 to 2025.

FIGURE 1. The West Bank Regional Location.

TABLE 1. Projected Population in the West Bank During the Period 1997-2025 (PCBS, 1999).

Year	1997	2000	2005	2010	2015	2020	2025
Population*	1.8	2.0	2.5	3.0	3.5	3.9	4.4

*Population in millions.

Water Resources

Ground water is the main source of freshwater in Palestine. Ground water in the aquifer system flows in three main directions, according to which three main ground-water drainage basins can be, identified: the Western, the Northeastern, and the Eastern basins. The first two basins are shared between the West Bank and Israel, the eastern basin falls entirely within the West Bank (WRAP, 1994; MOPIC, 1998a; SUSMAQ and PWA, 2001).

Surface water is considered to be of minor importance in the West Bank. The only source of surface water in the area is the Jordan River; Palestinian access to fresh surface water from the Jordan River is zero because the Israelis control the flow of the river (WRAP, 1994; MOPIC, 1998a; ARIJ, 1998).

Rainwater harvesting forms an additional source of water for domestic consumption in the West Bank. People collect rainwater falling on roofs or rock catchments and store it in cisterns, to meet part of their household needs (WRAP 1994; MOPIC, 1998a). MOPIC (1998b) estimated the quantity of harvested water in the West Bank at 6.6 million m^3/year.

Virtual Water and Water Footprint

A good can be produced locally or can be imported. In the first case, the production of the good requires the use of local water, and in the second case, the water is used in the country from where the good is imported. By consuming imported goods, water is consumed in its virtual form. Virtual water is the water embodied in a good, not only in the real, physical sense, but mostly in the virtual sense. It refers to the water required for the production of a certain good (Allan, 1997).

To assess the water use in a country, we usually add up the water withdrawal for the different sectors of the economy. This does not give the real picture about the water actually needed by the people of that country, as many goods consumed by the people of the country are produced in other countries using water from that country (Hoekstra and Chapagain, 2007).

In order to have a consumption-based indicator of water use, the water footprint concept was developed by Hoekstra and Hung (2002) in analogy to the ecological footprint concept. The "ecological footprint" of a population represents the area of productive land and aquatic ecosystems required to produce the resources used, and to assimilate the wastes produced by a certain population at a specified material standard of living, wherever on earth that land may be located (Wackernagel and Rees, 1996; Wackernagel *et al.*, 1997; Wackernagel and Jonathan, 2001 cited in Chapagain and Hoekstra, 2004). The water footprint of an individual, business or nation then was the total annual volume of freshwater that is used to produce the goods consumed by the individual, business or nation (Chapagain and Hoekstra, 2004; Chapagain, 2006). However, in Hoekstra and Chapagain (2007) the authors agree that there is a contamination component in the definition of the water footprint. Therefore, in this study it is suggested to complete the definition of the water footprint by including a contamination component. So, the water footprint (Q_{FP}) will be the total volume of freshwater used to produce goods consumed by the individual, business, or nation (consumption component, $Q_{FP}*$) plus the volume of freshwater needed to somehow assimilate the waste produced by that individual, business or nation (contamination component, $Q_{FP}**$).

Chapagain and Hoekstra (2004) and Hoekstra and Chapagain (2007) further state that the consumption component of the water footprint, $Q_{FP}*$, consists of two parts. The first part is the *internal water footprint* (Q_{IFP}). This is the sum of the total annual water volume used from the domestic water resources in the national economy *minus* the annual virtual water flow to other countries related to export of domestically produced products (Q_{VWEdom}). The second part is the *external water footprint* (Q_{EFP}) of a country defined as the annual volume of water resources used in other countries to produce goods and services consumed by the inhabitants of the country concerned (Chapagain and Hoekstra, 2004; Hoekstra and Chapagain, 2007).

MATERIALS AND METHODS

Calculation of the Water Footprint

According to the definition suggested in this paper, the water footprint is

$$Q_{FP} = Q_{FP}^{*} + Q_{FP}^{**}, \tag{1}$$

where Q_{FP} is the water footprint [m^3/year]; $Q_{FP}*$ is the consumption component of the water footprint [m^3/year]; and $Q_{FP}**$ is the contamination component of the water footprint [m^3/year].

As it is difficult to calculate the contamination component of the water footprint, only the consumption component was calculated in this study using Equations from (2) to (6) (Chapagain and Hoekstra, 2004).

$$Q_{FP*} = Q_{IFP} + Q_{EFP}, \tag{2}$$

where Q_{IFP} is the internal water footprint [m^3/year] and Q_{EFP} is the external water footprint [m^3/year].

Internal Water Footprint.

$$Q_{IFP} = Q_{AWU} + Q_{IWW} + Q_{DWW} - Q_{VWEdom}, \tag{3}$$

where Q_{AWU} is the agricultural water use [m^3/year]; Q_{IWW} is the industrial water withdrawal [m^3/year]; Q_{DWW} is the domestic water withdrawal [m^3/year]; and Q_{VWEdom} is the virtual water content of exported products produced domestically (m^3/year).

In this study, the Q_{DWW} was calculated from PWAs database (PWA, 2004); it includes the industrial water withdrawal Q_{IWW}. The *agricultural water use* Q_{AWU}, defined as the total volume of water used in the agricultural sector was calculated according to the methodology described in Chapagain and Hoekstra (2004). It includes both effective rainfall, the portion of the total precipitation retained by the soil so that it is available for crop production (FAO, 2000) and the part of irrigation water used effectively for crop production.

External Water Footprint. The Q_{EFP} was calculated according to Equation (4) (Chapagain and Hoekstra, 2004).

$$Q_{EFP} = Q_{VWI} - Q_{VWEre-export}, \tag{4}$$

where Q_{VWI} is the virtual water content of imported agricultural and industrial products [m^3/year] and $Q_{VWEre\text{-}export}$ is the virtual water content of re-exported products [m^3/year].

The virtual water of imported crop products has been calculated according to the methodology described in Chapagain and Hoekstra (2004).

To calculate the virtual water content of imported industrial products, Q_{VWII}, the net value in US$/year of imports (NVI) was calculated for the years 1998-2002 (Chapagain and Hoekstra, 2004).

$$Q_{\mathrm{VWII}} = \mathrm{NVI} \times \mathrm{WUV}, \tag{5}$$

where Q_{VWII} is the virtual water content of the industrial imports [m^3/year]; NVI is the Net value of imports in [US$/year]; and WUV is the global average water withdrawal per unit value of imports [m^3/US$].

The per capita consumption component of the water footprint $Q_{\mathrm{FPc}}*$ [m^3/cap/year] was calculated according to Equation (6) (Chapagain and Hoekstra, 2004)

$$Q_{\mathrm{FPc}}* = \frac{Q_{\mathrm{FP}}*}{\text{Total population}} \tag{6}$$

Appendixes 1 and 2 contain example calculation.

Data Sources

Raw data about the water quantity from wells and springs and annual rainfall was collected for the period 1988-2003 from the Palestinian Water Authority (PWA, 2004). The Palestinian abstraction was calculated from the PWAs database (PWA, 2004), while the Israeli abstraction was taken from (SUSMAQ and PWA, 2001). The domestic and agricultural water abstraction from wells and discharge from springs were calculated by taking the sum of the abstraction from all wells and the discharge from all springs for each year and calculating the average abstraction or discharge and the standard deviation thereof for the years 1988 to 2003. Wells with zero abstraction and springs with zero discharge for the last three years were excluded from the calculations in this study. There is a slight decrease in the trend of the rainfall in the West Bank during the period of 1988 to 2003, so the average of the rainfall was used to estimate the total amount of precipitation entering the West Bank.

The FAO food balance sheet for the years 1998-2003 were used as the basis for the food consumption in order to calculate the virtual water in the crops and livestock consumed by Palestinians. The food balance sheet indicates the consumption for the West Bank and Gaza Strip together. To calculate the consumption for the West Bank, all numbers were multiplied by 0.64, the ratio of the population in the West Bank to the total population (West Bank and Gaza Strip) for the years 1998-2003. Data about industrial imports were taken from the PCBS (2004).

RESULTS AND DISCUSSION

Water Balance

The West Bank receives 540 mm of precipitation annually (PWA, 2004), This equals a total incoming flow from precipitation (Q_{p}) of 2,970 million m^3/year of which 679 million m^3/year infiltrates to the ground-water aquifers (Q_{i}) (Oslo II Agreement, 1995). The runoff (Q_{R}) is about 77 million m^3/year and about 7 million m^3/year are harvested in rain water harvesting systems (Q_{Rh}). Therefore, the total evapotranspiration (Q_{ET}) is 2,207 million m^3/year (Figure 2).

Abed and Wishahi (1999) indicated that the West Bank receives annually a total quantity of rain between 2,700 and 2,900 million m^3/year. According to the Oslo II agreement (1995), the estimated quantity of water that infiltrates into the ground-water aquifers (Q_{I}) is 679 million m^3/year (22.9%). Rofe and

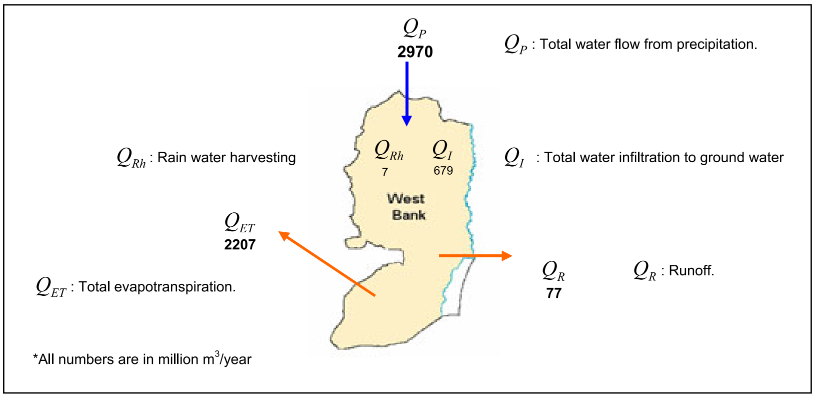

FIGURE 2. Water Balance for the West Bank.

Raffety (1963) cited in Abed and Wishahi (1999) estimated this quantity as 24.6% for the year 1964/1965. In this study, the Oslo II agreement (1995) estimates were used to establish the water balance for the West Bank. According to Abed and Wishahi (1999), Rofe and Raffety (1963) estimated the average runoff (Q_R) in the West Bank at 2% of the rainfall while GTZ (1996) estimated it at 3.2%. In this study, the runoff flow was taken as 2.6%, the average of the GTZ (1996) and Rofe and Raffety (1963) estimates. Based on this estimation the runoff in the West Bank was found to be about 77million m^3/year. The population of the West Bank is harvesting (Q_{Rh}) about 7 million m^3/year from rainwater for domestic purposes (MOPIC, 1998b). Therefore the total evapotranspiration (Q_{ET}) can be estimated to be 2,207 million m^3/year (74.3%). This figure is close to that given by Rofe and Raffety (1963) cited in Abed and Wishahi (1999), who estimated the evapotranspiration as 69.1% of the total precipitation for the year 1963/1964.

Water is abstracted from the ground-water basins by Palestinians and Israelis. Table 2 presents the annual Palestinian and Israeli abstraction rates from the three basins through wells and springs.

From this information, it can be seen that the total water abstraction (fresh and brackish) by both Palestinians and Israelis amounts to 778 million m^3/year while the recharge is only 679million m^3/year which result in an overuse of the ground water.

Water Footprint

The consumption component of the water footprint, Q_{FP}*,of the West Bank was found to be 2,791 million m^3/year. The internal water footprint, Q_{IFP}, is 1,346 million m^3/year and the external water footprint, Q_{EFP}, is 1,445 million m^3/year (Figure 3).

Consumption Component of the Water Footprint. *Internal Water Footprint:* The Palestinians in the West Bank are consuming ground water for domestic, agricultural, and industrial purposes. As can be seen in Figure 3, the total water abstracted from local resources by the Palestinians in the West Bank (Q_{PalAb}) from wells and springs is 117 million m^3/year of which 83 million m^3/year is used for agricultural purposes (Q_{AWW}) (irrigating crops and livestock); 34 million m^3/year is used for domestic and industrial purposes ($Q_{DWW} + Q_{IWW}$). Moreover, the Palestinians in the West Bank are using some 7 million m^3/year rain water harvested in cisterns (Q_{Rh}) for domestic purposes (MOPIC, 1998b). The Palestinians of the West Bank also produce rain fed crops using the rain water stored in the unsaturated soil. The agricultural water use, Q_{AWC}, was found to be 1,371 million m^3/year of which 66 million m^3/year was exported through exporting crops (Figure 3 and Table 3). The term Q_{AWU} represents part of the evapotranspiration term of the water balance, it includes both effective rainfall (the portion of rainfall which is available for crop production) and the part of irrigation water used effectively for crop production, and it excludes the irrigation losses. The major amount of Q_{IFP} (1,137 million m^3/year) is used for producing oil crops and vegetable oils, which is mainly olives and olive oil.

External Water Footprint: The external water footprint, Q_{EFP}, of the West Bank was found to be 1,445 million m^3/year. This figure is the sum of the virtual water imported through the imports of products (crop products, *QVWIc*, animal products, Q_{VWIa}, and industrial imports, Q_{VWII}) minus the virtual water exported in exported products (Figure 3 and Table 3).

The per Capita Consumption Component of the Water Footprint: The results of the study indicate that the per capita consumption component of the water footprint in the West Bank is 1,116 m^3/cap/year. The figure is less than the global average and less than Israeli and Jordanian figures (Chapagain and Hoekstra, 2004) (see Table 4). It can be noted that the domestic part of this figure is far less than that of the

TABLE 2. Annual Recharge and Abstraction by Palestinians' and Israelis' From the Three Basins in the West Bank.

	Recharge Estimates (million m^3/year)			Palestinian Abstraction (million m^3/year)				Israeli Abstraction* (million m^3/year)		
Basin	**Ref. 1**	**Ref. 2**	**Ref. 3**	**This study**	**Ref. 1**	**Ref. 2**	**Ref. 4**	**Ref. 1**	**Ref. 2**	**Ref. 5**
Eastern	172	172	213	62	54	69	61	40	40	32
Northeastern	145	145	124	31	42	30	31	103	103	99
Western	362	362	376	24	22	22	24	340	344	348
Total	679	683	713	117	118	121	116	483	487	479

Notes: Ref 1: Numbers based on Oslo II Agreement (1995); Ref 2: Numbers based on Eckstein and Eckstein (2003); Mimi and Aliewi (2005); Ref 3: Numbers based on Rofe & Raffety (1963); Ref 4: Numbers based on PWA, USAID, and CDM/Morganti (1997); Ref 5: Numbers based on SUSMAQ (2001).

*Numbers exclude some 170 million m^3/year brackish water abstracted or discharged from the aquifers.

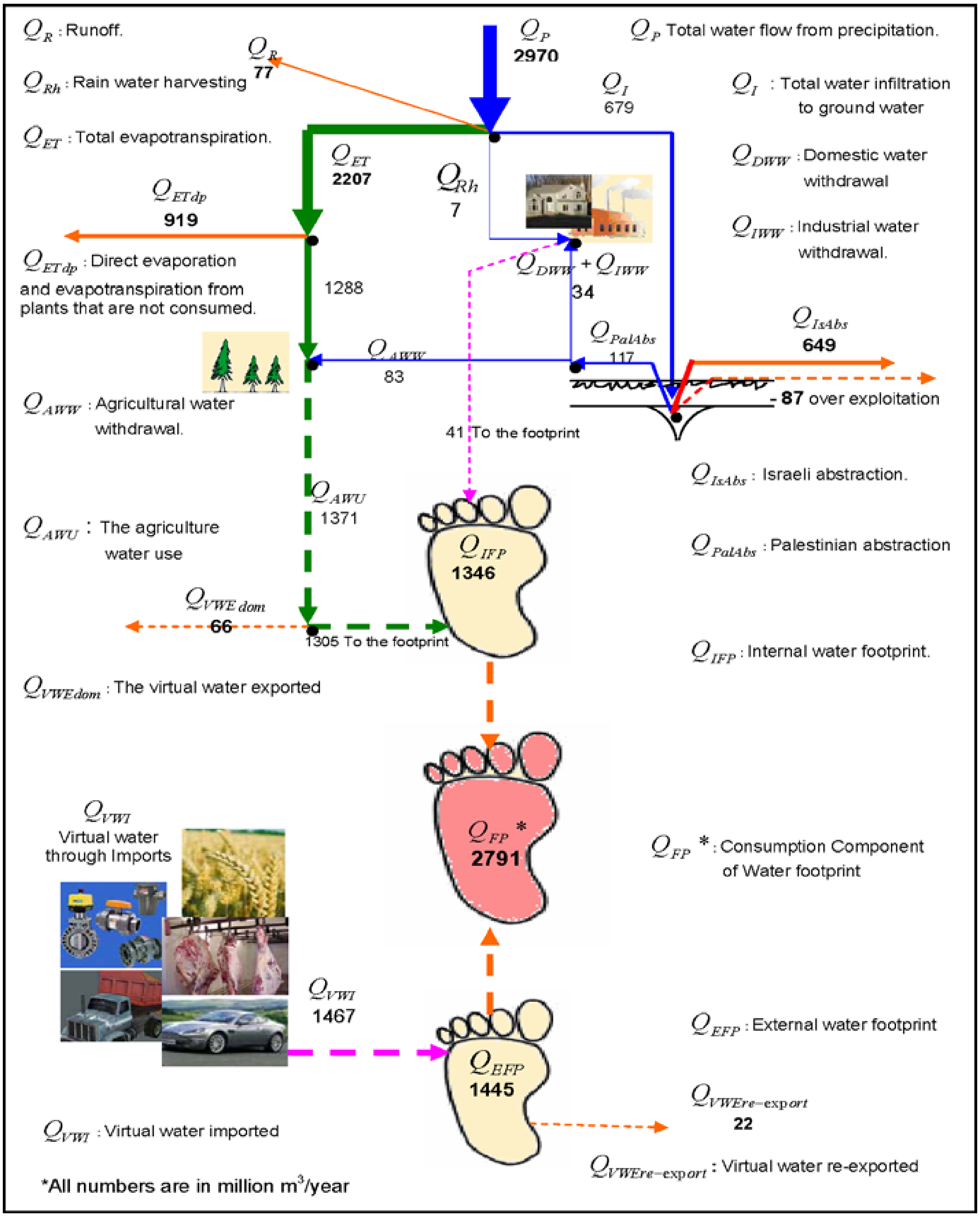

FIGURE 3. Water Footprint of the West Bank.

neighboring countries: only 36% of that of Jordanian and 21% of the Israeli figure.

The Contamination Component of the Water Footprint. As was stated before while defining the water footprint, Chapagain and Hoekstra (2004) did not include the volume of water needed to assimilate the waste produced by the individual, business, or nation, thus ignoring the second component of the ecological footprint. However, Hoekstra and Chapagain (2007) addressed the effect of pollution on the water footprint and stated that one cubic meter of wastewater should not count for one, because it generally pollutes much more cubic meters of water after disposal, various authors have suggested a factor of 10 to 50 they stated.

TABLE 3. The Internal Agricultural Water Use of Crops and Animals and the Net Virtual Water From Agricultural and Industrial Imports.

Group	Internal Agricultural Water Use (10^6 m^3/year)	Internal Virtual Water Exported 10^6 m^3/year)	Net Agriculture Water Use (10^6 m^3/year	Net Virtual Water Imports (10^6 m^3/year)
Crops and crops' products				
Cereals	1,11.4	18.9	92.5	986.9
Starchy roots	10.7	0.7	10.0	0.7
Sugar and sweeteners	0.0	0.0	0.0	106.1
Oil crops	557.4	0.0	557.4	14.9
Vegetable oils	579.4	39.3	540.1	92.1
Vegetables	14.8	1.3	13.5	2.4
Fruits	93.6	5.5	88.1	38.9
Stimulants	0.0	0.0	0.0	98.8
Subtotal	1,367.3	65.7	1,301.6	1,340.8
Animal products				
Meat	2.2	0.0	2.2	58.4
Milk	0.8	0.0	0.8	16.5
Eggs	0.4	0.0	0.4	1.7
Subtotal	3.4	0.0	3.4	76.6
Industrial products				27.6
Total	1,370.7	65.7	1,305	1,445.0

Notes: Crops included in the calculations were the crops listed in the FAO food balance sheet excluding the items with zero consumption. Cereals list: wheat, rice, barley, maize, rye, oats, millet, and sorghum; Starchy roots list: cassava, potatoes, sweet potatoes, and yams; Sugar and sweeteners: sugar raw equivalent and honey; Oil crops list: soya beans, groundnuts, sunflower seed, rape and mustard seed, cottonseed, coconut, sesame seed, palm kernels, and olives; Vegetable oils list: soya bean oil, groundnut oil, sunflower seed oil, rape and mustard oil, cotton seed oil, coconut oil, sesame oil, palm kernels oil, palm oil, olive oil and maize germ oil; Vegetables list: tomatoes and onions; Fruits list: oranges, lemons, grapefruit, bananas, apples, pineapples, dates, and grapes; Stimulants: coffee, tea, and cocoa beans; Meat: bovine meat, mutton, and goat meat and poultry meat.

TABLE 4. The Per Capita Consumption Component of the Water Footprint of the West Bank and of Neighboring Countries

		Water Footprint by Consumption Category				
	Water Footprint	Domestic	Agricultural		Industrial	
Country	Per Capita (m^3/cap/year)	Internal (m^3/cap/year)	Internal (m^3/cap/year)	External (m^3/cap/year)	Internal (m^3/cap/year)	External (m^3/cap/year)
West Bank	1,116	16	548 (455 olives)	541	Included in the domestic	11
Jordan	1,303	44	301 (158 olives)	908	7	43
Israel	1,391	75	264 (28 olives)	694	18	339
Egypt	1,097	66	722	197	101	10
Global average	1,243	57	907	160	79	40

Notes: The figures of the West Bank were calculated in this study, while the figures of Jordan, Israel, Egypt, and global average were taken from (Chapagain and Hoekstra, 2004; Chapagain, 2006; Hoekstra and Chapagain, 2007).

Nevertheless, societal use of water generates polluted water which itself is not only unfit for direct societal use but which, when discharged in surface water, makes much of the dilution water unfit for use. If so this polluted water is to be considered part of the water footprint.

Here, it is suggested to add a second component, other than the consumption component, to the water footprint, which is the volume of freshwater negatively affected by the activities of consumption and use of the individual, business or nation, contamination component.

Quantifying the second component of the water footprint is a difficult issue. One liter of wastewater has the capacity to contaminate many liters of freshwater if disposed off in a water body without treatment. This is true both for wastewater is disposal into surface water as well as through infiltration into the ground water. For example, the WHO limit for lead (Pb) in potable water is 0.01 mg/l. This means that 1 l of a wastewater containing 1 mg/l of lead will need 100 l of freshwater to dilute it to the permissible value, so 1 l of this wastewater has the potential to contaminate 100 l of freshwater if disposed in a water body without treatment. Considering the occurrence of self purification, this number may be lower for "clean" organic wastewater. On the other hand the limits for various organic and inorganic constituents of wastewater limits are significantly below that of lead increasing the extent of the contamination component proportionally. In the West Bank, the wastewater in most cases is disposed off into the *wadis* without treatment. It is difficult to estimate how much freshwater will be contaminated from wastewater infiltrating into the ground water. This wastewater has the potential to contaminate the shallow aquifers, but deep aquifers may be considered protected from contamination from wastewater infiltration. In any case this means that the contamination component of the water footprint will be "many" times greater than the consumption component making the already scarce resource even more scarce.

Water Availability, Water Scarcity, and the Traditional Throw Away Approach

Total Water Availability. The water issue in the West Bank is complicated, partly because of the political situation in the area. The aquifers are controlled by Israel. However, Article 40 of the Oslo II Agreement (1995) defines the quantity of water which the Palestinians are allowed to withdraw from their aquifers regardless of how much water is available in these aquifers. So the total water available for the Palestinians in the West Bank was estimated at 198million m^3/year. This number is the sum of the water withdrawal from wells, springs, and rainwater harvesting cisterns (123 million m^3/year) plus 75 million m^3/year agreed upon in the Oslo II Agreement as the future needs of the Palestinians in the West Bank. Therefore, if one assumes that the 2.5 million Palestinians have got the water available for them through Oslo II agreement in 2005, then the totally available water is 80 m^3/cap/year in 2005. And if not, the water availability will be the same as the consumption that is the total per capita water consumption in the West Bank will be 50 m^3/cap/ year. In both cases, the West Bank can be classified as in the conditions of water scarcity according to Falkenmark and Carl (1992) definition.

According to Falkenmark and Carl (1992) "a country whose renewable freshwater availability is less than 1,700 m^3/cap/year experiences periodic or regular 'water stress.' When freshwater availability falls below 1,000 m^3/cap/year countries experience chronic 'water scarcity.'"

The situation is becoming more severe in the future because of the rapidly growing population from 2.5 million in 2005 to 4.4 million by 2025 (PCBS, 1999), which means that in that specific year the per capita water availability will drop to 45 m^3 (Figure 4).

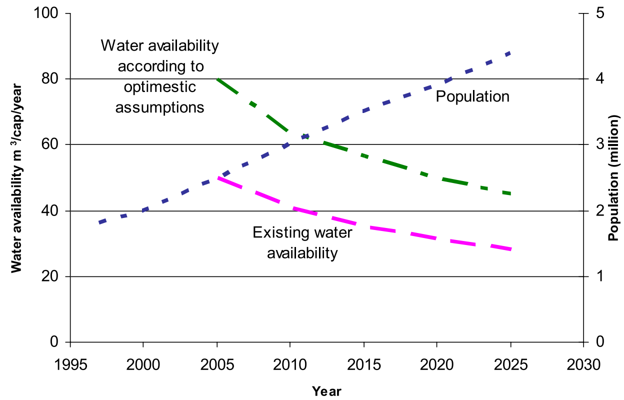

FIGURE 4. Future Per Capita Water Availability and Population.

Domestic Water Consumption. According to the results of the study the Palestinians in the West Bank are consuming16 m^3/cap/year (44 l/cap/day). for domestic and industrial purposes. The figure is significantly less than the WHO guidelines for the minimum per capita requirement for domestic needs to maintain good health (150 l/cap/day). The figure is also far below the domestic water consumption of the neighboring countries Israel 75 m^3/cap/year (205 l/cap/day) and Jordan 44 m^3/cap/year (120 l/cap/day) (Table 4) (Chapagain and Hoekstra, 2004).

It should be noted that the above concept of water scarcity is determined by assuming that the water is used once before thrown away. Present water management practices will, therefore, increasingly identify conditions of water scarcity because of dwindling resources in combination with increasing population. The common approach of high per capita water consumption, therefore, needs urgent review (Figure 5A)

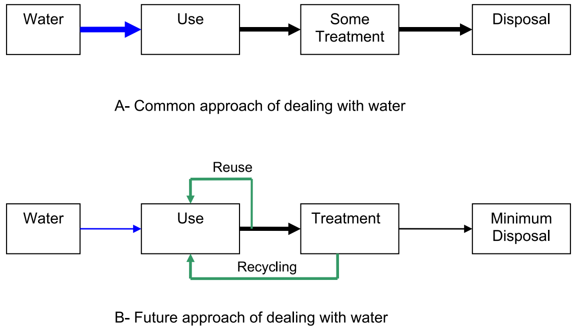

FIGURE 5. Traditional and Future Approaches of Dealing With Water (please note the size of the arrows).

so as to arrive at a situation where the environmental impact of both domestic and industrial water use are significantly reduced (Figure 5B). A large range of options to achieve this significant reduction exist or are in the phase of research testing.

CONCLUDING REMARKS

The objective of the study was to calculate the water footprint for the Palestinians in the West Bank. Within the limitations of the research the following conclusions were drawn:

- The consumption part of the per capita water footprint (Q_{FPc}*) in the West Bank was found to be 1,116 m^3/cap/year of which only 50 m^3/cap/year was withdrawn from local water resources. The contamination component was estimated many times larger than the consumption component making the water footprint many times larger.
- According to the commonly accepted limits, the West Bank is suffering from a severe water scarcity.
- The approach of "use, treat, and reuse" may help to improve the situation of water scarcity.

ACKNOWLEDGMENTS

The author would like to thank the Saudi Arabian government, Ministry of Higher Education in the West Bank, and the NUFFIC fellowship program in the Netherlands for sponsoring the research. Thanks are also extended to the Palestinian Water Authority PWA in personal and especially engineer Adel Yasin for his help in providing data about the water resources in the West Bank.

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APPENDIX 1

Calculation of Agricultural Water Use

a. Calculation of agricultural water use for wheat

1. Calculate the Crop Water Requirement for wheat

$$\mathrm{CWR} = \sum_{d=1}^{lp} \mathrm{ET_c},$$

where E_{Tc} is the crop evapotranspiration (mm) (Chapagain and Hoekstra, 2004).

$$ET_c = K_c \times ET_0,$$

where ET_0 is the reference evapotranspiration in (mm); K_c is the crop factor; lp is the length of the growing period [days]. ET_0, K_c, and lp were taken from (Chapagain and Hoekstra, 2004). CWR for wheat = 533 mm.

2. Calculate the Specific Water Demand

$$\mathrm{SWD} = \frac{\mathrm{CWR}}{\mathrm{Yield}}$$

(Hoekstra and Hung, 2002; Chapagain and Hoekstra, 2004). *Yield* of wheat in the West Bank = 172 kg/1,000 m^2 (Chapagain and Hoekstra, 2004). So SWD for wheat = 3,098 m^3/ton, where Ton = 1,000 kg.

3. Calculate the agricultural water useQ_{AWU} = SWD × Quantity (Quantity refers to the production of wheat in Palestine = 37,000 tons (Food balance sheet FAOSTAT data, 2005) as average over 1998-2003. So $Q_{\mathrm{AWU}} = 115 \times 10^6\ m^3$.

b. Calculation of total agricultural water use

1. The total internal agricultural water use was calculated by the summation of Q_{AWU} of all crops produced in the area.
2. To calculate the external Q_{AWU}, the imported quantity of each crop was used in the Equation 3 instead of production quantity.
3. The exported Q_{AWU} was then calculated using the exported quantity. Imported and exported quantities taken from (Food balance sheet FAOSTAT data, 2005) as average of 1998-2003.
4. For the crop products such as oil and sugar the Q_{AWU} was multiplied by the value fraction of the product and divided by the product fraction. Value fraction and product fraction were taken from Chapagain and Hoekstra (2004).

APPENDIX 2

Calculation of Virtual Water of Animal Products

Total virtual water for animal $\mathrm{VWC_{total}} = \mathrm{VWC_{drink}} + \mathrm{VWC_{serv}} + \mathrm{VWC_{feed}}$ (m^3/1,000 kg), where $\mathrm{VWC_{drink}}$ is the water consumed by the animal for drinking (m^3/1,000 kg animal); $\mathrm{VWC_{serv}}$ is the water use for the service of animal such as cleaning (m^3/1,000 kg animal); and $\mathrm{VWC_{feed}}$ is the virtual water needed to produce the food for the animal (m^3/1,000 kg animal). $\mathrm{VWC_{drink}}$ and $\mathrm{VWC_{serv}}$ were taken from Chapagain and Hoekstra (2003).

The $\mathrm{VWC_{feed}}$ for animals produced domestically was taken zero because the virtual water for the feed was included in the calculations of the Q_{AWU} for crops, which includes the crops consumed by animals. For imported animal products, $\mathrm{VWC_{feed}}$ was included and was taken from Chapagain and Hoekstra (2003).

$$Q_{\mathrm{AWU}} \text{ for animal products} = \frac{\mathrm{VWC_{total}} \times \text{Value fraction}}{\text{Product fraction}} \times \text{Quantity (produced or imported)},$$

value fraction and product fraction was taken from Chapagain and Hoekstra (2004).

6

Institute of Environmental and Water Studies Updates

Workshops and Training

Training Course on Integrated Management of Wastewater in the Mediterranean

- In cooperation with the Palestinian Water Authority and within the framework of INNOVA project, the Institute of Environmental and Water Studies (IEWS) organized a training course entitled: “Integrated Management of Wastewater in the Mediterranean Region” in the period 25-26 May 2009, which comes as part of the project activities implemented by IEWS and funded by the European Union, under the Sixth Framework Program (FP6).

Two Workshops on the Usage of Pesticides in Agriculture and Public Health

- In cooperation with the Ministry of Health (MoH), and funded by the Italian Cooperation (IC) within the framework of PAST Program, the IEWS organized two workshops on 18 and 19 March 2009 in Jericho and Jenin. Those workshops were part of the project entitled: “Usage of Pesticides in Agriculture and Public Health”. The workshops recommendations included the need for conducting awareness campaign to monitor and limit the excessive use of pesticides, train agricultural advisors and health inspectors, as is the case in Jenin, Tulkarem, Qalqilia, and the other projects and providing labs and research centers with equipment and qualified staff to carryout analysis on pesticides and their residues. Moreover, the workshop recommended creating awareness among citizens on the “Jericho fly” and seeking a specialized doctor’s help for diagnosis when needed, as well as adopting means for pest control and following the safety instructions guide and public safety methods during the spraying process.
  Participants in the workshops included representatives of the Ministries of Health and Agriculture, different municipalities, UNRWA and pesticides salesmen from the governorates of Jericho and Jenin.

Participants in the workshops within the activities of Pesticides project, March 2009.

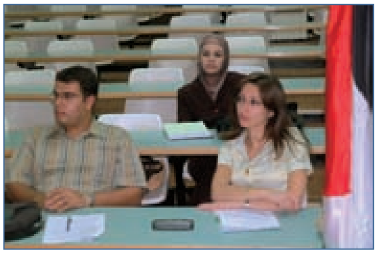
Training of Trainers Program in the Environmental Health Field

- In cooperation with the Palestinian Ministry of Health (MoH) and funded by the Italian cooperation (IC) within the framework of PAST program, the IEWS conducted "Training of Trainers" program in the environmental health field on 16 and 17 February 2009. The program aimed to develop the capacity of health services of environmental health departments at MoH by providing heads of these departments with current principles, exercises and case studies on core training needs such as: communication skills, participatory approach, learning techniques and needs assessment principles, which are needed for improving the relations of MoH with internal and external bodies that affect the performance of environmental health departments at MoH.

Participants in the "Training of Trainers" Program, February 2009.

Workshop on Woman Leader and Water Management

- Funded by the World Bank through "Global Development Learning Programme, GDLN", the IEWS organized a workshop entitled: "Woman Leader and Water Management" via video-conference with audiences from Egypt, Morocco, Tunisia and the United Arab Emirates on 9 October 2008. The workshop emphasized the added value of woman leaders in management positions as well as the importance of empowering women in all sectors, particularly in the water/environmental sectors which can be achieved through consistent capacity building and training programs and special awareness campaigns in gender fields.
  The workshop was attended by representatives of Ministry of Agriculture, Birzeit Municipality, Al-Bireh Municipality, Jerusalem Water Undertaking, as well as local experts and a number of Masters students.



Participants in the workshop: "Woman Leader", October 2008.

Workshop on Water Reuse

- Funded by the World Bank through "Global Development Learning Program, GDLN", the IEWS organized a workshop entitled: "Water Reuse" via videoconference with audiences from Egypt, Palestine, Uzbekistan, Tanzania, Uganda and Ethiopia which on 9 September 2008. During the workshop participants representing Ministry of Agriculture and Water Authority demonstrated that Palestinian water resources are governed by the Israeli occupation which leading to more water scarcity and consequently threatening the agricultural sector in Palestine. Another workshop addressing the theme: “Values for a Water/Life-Sustaining Civilization: Learning and Communications to Transform Society” was previously held on 6 August 2008.

Participants in the workshop:
"Values for Water/Life Sustaining Civilization", August 2008.

Staff News

- Ziad Mimi and Maher Abu-Madi participated in the World Water Forum 2009 which was held in Istanbul in the period 15-22 March 2009 and was attended by about 25,000 participants from 199 countries. The World Water Forum is the biggest meeting on water issues where the world comes together to share concrete solutions for water problems. The overall theme for the 5th World Water Forum was” Bridging Divides for Water” during which sessions, the achievements of the IEWS and Birzeit University were shared with large number of participants from allover the world.

- Nidal Mahmoud was in a staff exchange mission at the UNESCO-IHE, Delft, Netherlands in the period 15 June-15 July 2009. During his stay, Dr. Mahmoud worked on developing the following two educational modules for the Msc programs in Water and Environmental Engineering and Sciences:
  1- Industrial wastewater treatment
  2- Urban drainage

- Rashed Al-Sa`ed has a one-year consultancy contract with the Palestinian Water Authority (PWA) that started in January 2009, where he acts as a Technical Advisor on strategic wastewater management issues. Dr. Al-Saed provides expert advice and technical evaluation applying sound scientific knowledge to enhance capacity building, strengthen informed decision making and promote research and development within the PWA.

New Funded Projects

- The Arab Gulf Program for United Nations Development Organization (AG-Fund) has funded a new research proposal submitted by IEWS entitled: “Enhancement of Integrated Healthcare Waste Management in Two Districts in the North of the West Bank of Palestine”. The project aims to improve the management of Healthcare Waste in Palestine by involving various community stakeholders and offering opportunities for women and women associations to participate in solving healthcare waste problems.

- The International Development Research Center (IDRC) funded a new research proposal submitted by IEWS entitled: “Involvement and Influence of Women in Innovation Processes within Integrated Water Resources Management (IWRM)”. The project aims to increase the access, participation and contributions by women to the innovation processes and to examine areas where females can add value as contributors to the IWRM field, in addition to bringing insight into the social influences and their impact on women performance as leaders and innovators within IWRM.

- The Italian Cooperation (IC) and within the framework of P.A.S.T. Program funded a consultancy proposal submitted by IEWS entitled: “National Environment Control Project – Awareness Campaign” that aims to strengthen the planning and operational capacity of the environmental health departments at the Palestinian Ministry of Health (MoH).

- The Italian Cooperation (IC) and within the framework of P.A.S.T. Program funded a research proposal submitted by IEWS entitled: “Survey on the Usage of the Pesticides in the West Bank and Gaza Strip” that aims to evaluate if the pesticides are rationally used in terms of quantities and qualities in Palestine.

- The UNESCO-IHE Partnership Research Fund (UPaRF) and within the activities of PoWER Partnership has funded the following research proposals submitted by IEWS under categories II and III:

<u>UPaRF category II research projects:</u>

A call for proposals for medium- to large size research projects (Category II) was launched on 5 January 2009 which aimed to identify a number of research projects for implementation from mid-2009 onwards. The call was intended for UNESCO-IHE and its eligible partner institutes, but proposals were initiated and lead by UNESCO-IHE. IEWS has won the following research proposals in this category:

1. **Natural systems for wastewater treatment and reuse: technology adaptation and implementation in developing countries.**

   Partners: UNESCO-IHE (Netherlands), Universidad del Valle (Colombia), Birzeit University (Palestine) and King Abdullah University of Science and Technology (Saudi Arabia).

2. **Impact of untreated wastewater on natural water bodies: integrated risk assessment.**

   Partners: UNESCO-IHE, Birzeit University (Palestine) An-Najah National University (Palestine) and Palestinian Water Authority.

UPaRF category III research projects:

A special collaborative research call was launched on 22 January 2009 for proposals for small size projects (Category III). This call aimed to identify a number of research projects for implementation in 2009 and 2010, and specifically intended for partner institutes of UNESCO-IHE. IEWS has won the following research proposals in this category:

1. **Development of an integrated low cost anaerobic-aerobic biological system for grey water treatment capable of natural removal of organic, nitrogen and pathogens.**

   Partners: Birzeit University (Palestine) and Sana'a University (Yemen).

2. **Hydrogeochemical characterization of the presence of arsenic in the Puelche aquifer in the area of Mataderos, Argentina, and the Mountain aquifer, Palestine.**

   Partners: Blas Pascal University (Argentina) and Birzeit University (Palestine).

3. **Assessing the impacts of variable oil prices on the economic sustainability of water and wastewater facilities: cases from Ghana and Palestine.**

   Partners: Birzeit University (Palestine) and Kwame Nkrumah University of Science and Technology (Ghana).

4. **Environmental flow regime in rivers as a tool for integrated water and basin resource management and climate change adaptation.**

   Partners: Universidad del Valle (Colombia) and Birzeit University (Palestine).

It is worth mentioning here that the IEWS represented by Dr. Maher Abu Madi is currently the Partnership Collaboration Coordinator for PoWER.

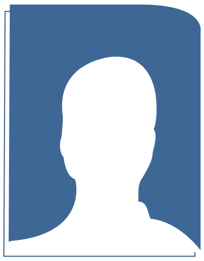
New Defended Masters Theses

The following theses were successfully defended at the IEWS from July 2007 to August 2009. Hard copies of the theses are available at the main library at Birzeit University:

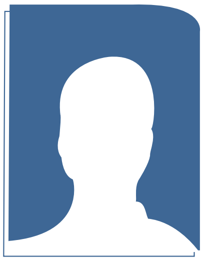
NO.	TITLE	STUDENT NAME
1	Assessment of Water Quality of Cisterns in Hebron City	Adel Al-Salaymeh
2	Health Risks Associated with Consumption of Untreated Water from Household Roof Catchment Systems	Abdellatif Daood
3	Assessing the Costs of Achieving the Water and Sanitation Target of the Millennium Development Goals in Ramallah and Al-Bireh Governorate-Palestine	Atiyyeh Al-Ramahi
4	Spatial and Temporal Variations in the Hydrochemistry and Isotopic Compositions of the Groundwater in the Jordan Rift Valley	Fayez Abu-Helo
5	Improving the Keeping Quality of Green Bell Peppers Irrigated with Saline Water through the Adaption of Environment Friendly Techniques	Kamal Zorba
6	Rainwater Harvesting for Domestic Uses in Two Palestinian Rural Areas with Emphasis on Quality and Quantity	Mahmoud Musaffar
7	Development of an Environmental Management System for Selected Palestinian Dairy Industries	Manal Ibrahim
8	Community Onsite Anaerobic Sewage Treatment in Hybrid UASB Septic Tank Systems	Nour Al-Huda Al-Hindi
9	Groundwater Vulnerability Assessment in the Western Aquifer Basin Portion in the West Bank	Shereen Nazzal
10	Climate Change and Its Impacts on Water Supply and Demand in Palestine	Sireen Abu-Jamous

Graduates of the Masters Programs In Water and Environmental Engineering and Sciences 2008/2009

Masters Program In Water and Environmental Engineering



Ahmad Ibrahim Amro



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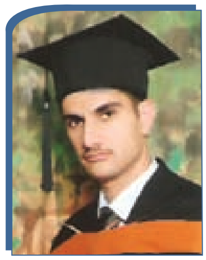
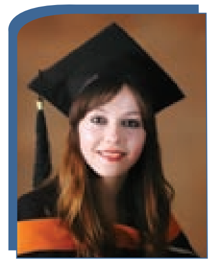
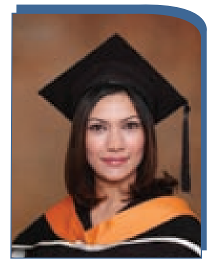


Nidal Khalid Khawaldeh

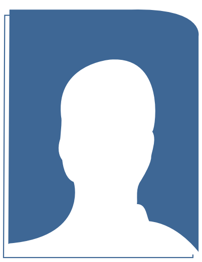


Ola Farouk Safi



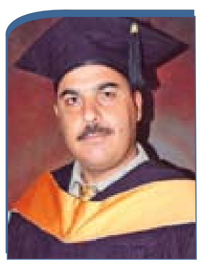
Sireen Jihad Abu-Jamous

Masters Program In Water and Environmental Sciences

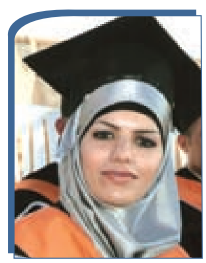


Adel Abdul-Halim Al-Salaymeh

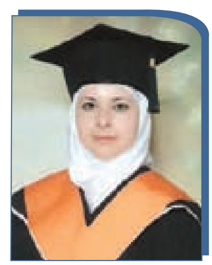
Ahed Khalil Halayqah



Ayman Abdul-Hafeth Abdul-Halim



Eman Ahmad Hasan



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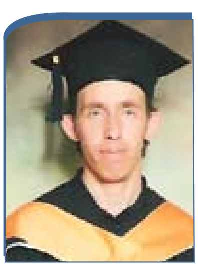

Nour Al-Deen Anwar Halayqah

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