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A Financial, Environmental and Social Evaluation of Domestic Water Management Options in the West Bank, Palestine

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Abstract Water is one of the most valuable natural resources in the West Bank, Palestine. Due to its limited availability, it is a resource that needs particular protection. Although agriculture consumes most of the water (70%) in the West Bank, the domestic water supply is strategically not less important. It is the aim of this study to evaluate domestic water management options suitable for Palestinian conditions that contribute to achieving water sufficiency in the domestic water use in the *house of tomorrow*. A number of options were evaluated economically, environmentally and socially using the concept of life cycle impact assessment (LCIA). Results of the study showed that by introducing a combination of domestic water management options, a substantial decrease in the water consumption of more than 50% can be

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achieved, thereby reducing the pressure on the scarce water resources. The annual environmental impact of the in-house water use can be reduced in the range of 8%, when using low-flow shower head to 38% when using rainwater harvesting systems. Some of the options (faucet aerators, low-flow shower heads and dual flush toilets) were found to be financially attractive with a pay back period of less than their expected lives, others (rainwater harvesting, graywater reuse and dry toilets) were found to be financially unattractive because of the high investment. In the social context, it was found that introducing such options can improve the quality of life of those not having enough water. There is already a popular willingness to take part in water conservation in the domestic sector in the West Bank. The strongest driving force for using water conservation measures is the awareness that water is a scarce resource. It was concluded that, theoretically, the house of tomorrow can be largely independent in terms of water and sanitation. Education and awareness campaigns in the context of water management with a focus on non-traditional options are key to achieve such a house.

Keywords Environmental impact · Financial assessment · House-hold water management · Social impact assessment · Water reuse · Water scarcity · West Bank

1 Introduction

Continuing growth in population and development increases the pressure on water resources all over the world. As a consequence, the number of countries dealing with water scarcity is increasing. This growing water scarcity can clearly be seen in the Middle Eastern region including the West Bank in Palestine.

The political situation in the area makes the water issue in the West Bank complicated. Since 1967, when Israel occupied the West Bank, the water resources have been controlled by Israeli military orders which have severely restricted Palestinian use. The Palestinians are denied access to River Jordan water. Moreover, there is currently an inequitable distribution of the water resources in the area between Palestinians and Israelis; the per capita water use, for all purposes, of the Israelis is six times that of the Palestinians. In addition, the future water allocation is even more problematic (Nazer 2009). The per capita water availability in 2005 in the West Bank was 80 m^3/year and this number is expected to decrease to 45 m^3/year by the year 2025 (Nazer et al. 2008). This number is very low by any standard.

Water scarcity is not only driven by politics it is also exacerbated by the way water is used in the West Bank. Water is used and disposed of without considering further uses. In most cases the used-water, or what is called wastewater, is discharged into the *wadis* (dry riverbeds) without any type of treatment, reducing water quality and, therefore, reducing the availability of good quality water (Nazer 2009). This so-called *use and dispose* approach to water needs urgent reconsideration so as to arrive at a sustainable water use where wastewater is viewed as a resource, ready to be used again. In the so-called *use-treat-reuse* approach, both the water use and the environmental impact of domestic water use are significantly reduced. Waste is treated on site and benefits may be derived from what is considered waste by reusing it or recovering some of its components. In line with this thinking, in the remainder of this paper wastewater is referred to as "used-water". A large range of options exist to achieve significant reduction in overall water use, making each drop of water more productive (Cunningham and Saigo 1999; Matsui et al. 2001; Rosegrant et al. 2002; Nazer et al. 2008).

The objective of this study is twofold:

1. To evaluate the environmental, financial and social impacts of potential domestic water management options using Life Cycle Impact Assessment (LCIA). These options can be alternatives for water saving or conservation, development of new resources and water reuse.
2. To propose a water use scheme for the *house of tomorrow*, in line with the *use-treat-reuse* approach. In this study the *house of tomorrow* refers to separate houses, housing complexes or buildings.

2 Background

2.1 Sustainable Development in Domestic Water Use

Sustainable development was defined by the United Nations' World Commission on Environment and Development as "development that meets the needs of the present without compromising the ability of future generations to meet their needs" (WCED 1987). Sustainability has environmental, financial and social dimensions, that is, for an activity to be sustainable it should be ecologically sound, socially acceptable and economically viable (Hauschild et al. 2005).

In the West Bank industrial water use is small relative to other water uses, but exact numbers are not available. Industrial consumption is usually included in the domestic water consumption, and together industrial and domestic comprise 30% of the total water use (Nazer 2009; PWA 2005, personal communication). Although the domestic and industrial sectors use far less water than agriculture (30% versus 70%), water demand in the domestic sector is growing rapidly. Water sustainability could be achieved through implementing water saving practices and using newly developed water management approaches. Some examples are listed, these examples can be categorized as:

1. Rainwater harvesting systems (RWHS); in these systems rainwater is collected from roofs or rocks and stored in cisterns to be used afterwards thus providing an alternative water resource (Baguma et al. 2010)
2. Demand management alternatives which consist of

   Water saving alternatives

   - Faucet aerators (FA) and low-flow shower head (LFSH): these devices restrict the amount of water going through the faucet or shower heads, but add air so the flow of water appears the same (Mayer et al. 2004).
   - Dual flush toilets (DFT): these are toilets that use less water than conventional toilets and have two volumes of flushes (Mayer et al. 2004).
   - Dry toilets (DT): toilets that do not use water or use a small amount of water. Some of these toilets separate urine from faeces (Matsui et al. 2001). These toilets have dual advantage, less water use and less chances of water

resources destruction due to pollution. Moreover, these are considered options for resource recovery as the waste can be used for energy and fertilizer production.
- Leakage prevention (LP): this refers to fixing leaking appliances.

Water reuse alternatives

- Gray-water reuse systems (GWRS): gray-water is defined as untreated, used household water from showers, bathrooms, wash basins and washing machines (Bennett 1995).

2.2 Cleaner Production

Cleaner Production is commonly defined as "the continuous application of an integrated preventive environmental strategy applied to processes, products and services to increase overall efficiency and reduce risks to humans and the environment" (UNEP 1999). Although this definition needs a slight adaptation in the context of urban water, the essential elements of Cleaner Production, i.e. the proper choice of materials, process efficiency, reuse and recycling of materials and least impact treatment with recovery of resources, remain valid (Gijzen 2001; Siebel and Gijzen 2002). It could be said that, Cleaner Production thinking has penetrated the way we deal with water: 130 to 500 l/cap/day of drinking water are used, but less than 10 l are actually needed for drinking and food preparation. The difference is largely used to flush away waste (Gijzen 1998; Siebel and Gijzen 2002).

2.3 Life Cycle Impact Assessment (LCIA)

Life cycle impact assessment (LCIA) is the process of quantifying the impacts of products, processes and services over the entire period of their life cycle. In carrying out a LCIA, all major impacts should be taken into account (UNEP 1996; EEA 1997). LCIA was first developed in the seventies and has been further developed and become the standard when comparing alternatives. More recently a similar approach has been used in the financial area to quantify financial impacts of products, processes and services (Barrios et al. 2008). Moreover, developments in LCIA are moving towards the inclusion of the social dimension (Udo de Haes et al. 2004; Hauschild et al. 2005; Siebel et al. 2007). A combination of the three dimensions of sustainable development (environmental, financial and social) results in an attractive approach, but at the same time poses the risk of impossible data and resource requirements (Udo de Haes et al. 2004).

2.3.1 Environmental Life Cycle Impact Assessment (E-LCIA)

The production or use of a product or the rendering of a service involves a number of steps. These steps include extracting and converting resources, manufacturing products, providing infrastructure for transportation and manufacturing, using the product or service, and recycling or disposing of the product that no longer serves its purpose. These steps consume resources, produce pollution and, hence, cause environmental impacts. After an inventory phase in which data about all types of substances that affect the environmental impact is collected, the impacts are categorized and assessed so as to be expressed in a single quantity. In this study, the environmental impact was assessed using the Eco-indicator 99 method (Goedkoop et al. 2000).

2.3.2 Financial Life Cycle Impact Assessment (F-LCIA)

In analogy to E-LCIA, F-LCIA is defined as the process of quantifying the financial impacts of a product, process or service during all phases of its life cycle (production, operation and disposal). There are mainly three groups of financial elements that may play a role in F-LCIA:

1. One-time cost these relate to investment for the acquisition of land area, the construction of buildings, the purchasing of production or transport equipment and, at the end of the lifetime, the costs of disposal of facilities.
2. Recurrent costs these relate to operational costs such as cost of labor, of raw materials and energy, of operating equipment and of maintenance. In addition, revenues from the sale of products or services are recurrent costs.
3. Cost-related parameters these relate to interest, inflation and depreciation.

F-LCIA can be used to compare the life cycle costs of system alternatives serving the same purpose (Siebel et al. 2007). A cost comparison of alternatives can be done on the basis of a true financial comparison of alternatives taking into account all present and future costs. The present worth (PW) is one such method which relates the cost of any activity at a certain time to the cost at another time given certain values for discount rate (Philippatos and Sihler 1991; Blank and Tarquin 2005). The PW of costs and benefits can be calculated according to Eq. 1.

$$PW = A\left[\frac{(1+k)^n - 1}{k(1+k)^n}\right] - I_0 \tag{1}$$

Where,

PW: Present worth, is the monetary value at present or at time zero (US$).
A: Net annual benefits, (US$/year)
k: Discount rate,
n: Number of years (year).
I_0: Investment in year zero (US$).

2.3.3 Social Life Cycle Impact Assessment (S-LCIA)

In analogy to E-LCIA and F-LCIA, S-LCIA is defined as the process of quantifying the social impacts of a product, process or service over its life cycle. The production of a product, or the rendering of a service or the change therein, almost always has consequences not only in environmental and financial areas but may also affect those directly influenced by these changes, i.e. the consumers/users or those involved in the production of the products or the provisions of the services (Siebel et al. 2007). For example, as a result of a technological innovation, relatively low quality jobs may be replaced by a few relatively high quality jobs causing unemployment for many. It can be argued that a decrease in the availability of water may result in a decrease in the quality of health or may strain social (family) relations. Therefore, the level of happiness of those involved may be affected. On the other hand, water sufficiency will positively impact upon the quality of physical and social health and, therefore, increase the level of happiness.

In conventional development theory, “happiness” equals money and prosperity. It was measured by gross national product (GNP). In 1972, Jigme Singye Wangchuch, the newly crowned king of the Himalayan Bhutan Kingdom, created the concept of gross national happiness (GNH) to measure prosperity rather than GNP. The king maintains that the economic growth does not necessarily lead to contentment, and instead focuses on the four pillars of GNH: economic self-reliance, a pristine environment, the preservation and promotion of Bhutan’s culture and good governance in the form of democracy (Ezechieli 2003; Bandyopadhyay 2005).

“Happiness” as a unit of social impact was first used by Hofstetter et al. (2006) who listed an extensive number of happiness enhancers and gave each a certain weight. Layard (2005) stated that happiness is a feeling that varies over time throughout our life. The average happiness is determined by one’s pattern of activities, one’s nature and attitudes and by key features of one’s situation, social relationship, health, worries, etc. There are countless sources of happiness and countless sources of pain and misery. Layard (2005) stated that there are seven enhancers of happiness i.e. family relationships, financial situation, work, community and friends, health, personal freedom and personal values. Similarly, Siebel et al. (2007) proposed five categories of happiness, job quality, quality of physical health, quality of social health, earthly possessions and various.

Siebel et al. (2007) developed a simple approach to quantify the social impact of societal or industrial activities. The approach is based on the assumption that each person starts out with a given value of happiness, expressed as Socio-points in S-LCIA (in analogy with Eco-points for E-LCIA and Euro-points for F-LCIA). Over the years, this initial happiness value will change as a result of concrete physical or emotional experiences such as a painful accident, not passing an important exam, a prison sentence, or from less identifiable influences such as having been born into a happy family, having had a bad youth or having a born physical handicap. Some of these experiences will reduce the initial value of happiness, others will increase it. By categorizing the various social impacts into the various happiness categories, and by equating each social impact with the maximum value in that category, the happiness of people can be quantified or the change in happiness of people can be assessed when determining the happiness value before and after the change. By determining the happiness values various times before and after a specific social change, the short and long-term impact of a certain social change can be determined.

3 Materials and Methods

3.1 Research Approach

An overview was made of potential domestic water management options on the basis of their financial, environmental and social impacts. One option focuses on developing a new water resource, i.e. rainwater harvesting system (RWHS) and one focuses on water reuse, i.e. grey-water reuse system (GWRS). Moreover, four indoor water saving options were evaluated; two were related to the toilet as the largest indoor water consumer in the West Bank (34%), i.e. the dual flush toilet (DFT) and the dry toilets (DT). Also the low flow shower head (LFSH) was chosen to cover the bath and shower water consumption (22%) and the faucet aerators (FA) was chosen to cover the bathroom sink and the kitchen with 14% and 13% respectively of the indoor water use. Remaining consumption (17%; laundry, cooking and drinking and house cleaning) was relatively small (Nazer et al. 2007).

The comparison of the options was made on the basis of evaluating the expected change (increase or decrease) in the environmental, financial and social impacts due to the implementation of these options. The do-nothing alternative was the reference for calculating the change. An inventory analysis was carried out to determine the changes associated with the implementation of each option, i.e. water use, used-water production and energy consumption. The calculations were based on the per capita water consumption in the West Bank distributed over the different indoor water consumption points (toilet, kitchen, bath, laundry etc) (Nazer et al. 2007).

3.2 Life Cycle Impact Assessment

LCIA was chosen to evaluate the change (increase or decrease) in the environmental, financial and social impacts as a result of the implementation of the studied options. Although LCIA involves the three phases of the life cycle, i.e. production (manufacturing/construction and installation), operation and disposal/demolition, the analysis in this study is made for the production and operation phases only because systematic investigation about disposal and demolition of house-hold sanitary systems does not exist in the West Bank.

3.2.1 Environmental Life Cycle Impact Assessment (E-LCIA)

The following steps were carried out:

1. The environmental impact of producing (manufacturing/constructing and installing) each option was determined using the Eco-indicator 99 database (Goedkoop et al. 2000) in which the environmental impact was given in eco-point/unit weight of material. For each option, the materials used in the production of that option were investigated in terms of type and weight, and then the environmental impact was calculated.
2. On the basis of the inventory analysis of implementing the water management options, the changes in pollutant emissions to air, water and soil resulting from the changes in water use, used-water production and energy consumption were determined. According to these emissions the change in environmental impact was determined.

3.2.2 Financial Life Cycle Impact Assessment

In order to evaluate the financial costs of each water management option the following steps were carried out:

1. Determination of the investment (US$).
2. Determination of the annual operational costs (US$/year).
3. Determination of the annual savings in operational costs (US$/year).
4. Determination of the present worth of the costs and benefits (US$/year).

Calculations were carried out for a period of 10 years. Discount rate and operation and maintenance were estimated at 5% per year (CIA 2009; Hutton and Bartram 2008). Discount rate is the average discount rate of Israel and Jordan provided by CIA (2009) because a discount rate for Palestine is not available.

3.2.3 Social Life Cycle Impact Assessment

To approach the social aspects of the various water management options in this study, the impact of these options on the level of happiness of people using or willing to use these options was assessed. A questionnaire was prepared for this purpose; the questionnaire contained both closed and open questions. The closed (yes/no) questions were about the willingness to use and to pay for the different options, while the open questions were about the reasons behind accepting or rejecting certain options. After an explanation of each option, the respondents were asked if they were willing to use an option and the reasons behind their willingness to use or not to use it. The respondents were also asked if they were willing to pay for the option in question and why. The respondents could give one or more reasons.

Three groups with a total of 244 adults were involved in the study. The first group (92 participants) was chosen from general users of water from different segments of society: students, employees, house-wives. These people were approached through workshops in different localities in the West Bank. The workshops began with an introduction about the West Bank water resources and the water scarcity in the area. The in-house water consumption pattern was then explained followed by an overview of potential options available for reducing in-house water use and their associated financial and environmental costs and benefits. Finally the participants were asked to fill out the questionnaire. The second group (120 participants) filled out the questionnaire with the help of university students who first explained the options. The third group (32 participants) was formed by professionals in the water sector.

The average initial value of happiness of a Palestinian in the West Bank was set at 500 Socio (happiness)-points. This initial value is expected to change as a result of life experiences. In this study the difference between living in a country characterized by a situation of serious and increasingly serious water stress vs. living in a country in which this situation of water stress is reduced as a result of measures meant to reduce water consumption and, therefore, water stress, was quantified and related to the happiness of the people. The questionnaire was meant to quantify the change in the feelings of people relative to the situation before and after taking appropriate measures to improve water availability (i.e. reduce water stress). In doing so, it was assumed that if a person is willing to use an option, then using this option increases the initial value of happiness of this person by a value of a socio-points because of the perception of contributing to a good cause, a better life, etc. Furthermore, if that person is willing to pay for that specific option, the value of happiness of the person increases further by another value of b socio-points. On the other hand, if a person is rejecting (equal to: not willing to use) the option, the happiness level of this person is expected to drop by a socio-points. The use of a particular option could, for example, become enforced as part of a government measures to reduce water stress. If this person is not willing to pay for this specific option, it means that paying for that option is expected to further decrease the level of his happiness by b socio-points.

In a group of people, the overall level of happiness is influenced by the level of variation in happiness of this group. The happiness level may increase for some participants, may decrease for others, or remain the same. Accordingly, the change in happiness of a group of people is the increase in happiness of some minus the decrease in happiness of others. Therefore, the change of happiness for a group of people, or the social impact as it will be called in the rest of the paper, can be calculated according to Eq. 2.

$$\Delta S = a\alpha_u + b\beta_p - a\alpha_{nu} - b\beta_{np} \tag{2}$$

where

- ΔS: Change in the level of happiness or the social impact of a group (socio-points),
- α_u: Willingness to use, given as the fraction of respondents willing to use the option (range: 0–1),
- β_p: Willingness to pay, given as the fraction of respondents willing to pay for the option (range: 0–1),
- α_{nu}: The fraction of respondents not willing to use the option (range: 0–1),
- β_{np}: The fraction of respondents not willing to pay for the option (range: 0–1),
- a, b: Constants describing the effect of not having water on the person's level of happiness.

Given that the respondents were asked to express their willingness to use or pay for (yes/no answers), this implies that:

$\alpha_{nu} = 1 - \alpha_u$ and $\beta_{np} = 1 - \beta_p$. Therefore Eq. 2 becomes

$$\Delta S = 2a\alpha_u + 2b\beta_p - (a + b) \tag{3}$$

In the case of a situation of serious water stress, it is assumed that willingness to pay approaches the willingness to use a certain option. In that case a and b are equal and the Eq. 3 simplifies to

$$\Delta S = 2a(\alpha_u + \beta_p - 1) \tag{4}$$

In order to determine the values of a and b, a group of 52 people, randomly chosen from the telephone book of the residents of West Bank, were asked how much their happiness would be affected if they wanted to do something that needed water such as taking a shower, washing, cleaning, etc. only to find out that there would be no water to do so. They were asked to rate the ups or downs of their happiness level on a scale of 0–100. The response of the respondents suggested that the level of happiness will decrease by 70%. The situation of not having water when needed may affect two of the big seven enhancers of happiness proposed by Layard (2005), i.e. health and family relationships. Assuming that each of the big seven enhancers has an equal effect on happiness, then not having water will affect 2/7th of the total decrease in happiness (70%). Therefore, the initial level of happiness will be decreased by (2/7 of 70%) = 20%. So a value of 100 (20% of 500 the initial average) socio-points for the total decrease or increase in the level of happiness (a plus b) could be reasonable. Assuming that a and b are equal, then each of them will take a value of 50 socio-points.

3.3 List of Assumptions Regarding Water Management Options

There are a variety of ways to produce the chosen water management options which vary significantly with regard to the materials used for producing or constructing them, cost, environmental impact etc. For example, a rainwater harvesting reservoir could be made of plastic, concrete or any other material according to which the cost and the environmental impact may vary significantly. Therefore, assumptions were made in this study for the sake of the calculations:

1. The average family size in the West Bank is 6 (PCBS 2007).
2. The water consumption pattern is according to Nazer et al. (2007) study. In this study, indoor water consumption was measured with the help of school students. The results of the study indicate that a person in the West Bank on average uses 38 l/d. The water consumption in the bathroom (toilet flushing, bath and shower and sink) accounts for 70% of all indoor water use. The heaviest user is the toilet, accounting for 34%. In contrast cooking and drinking together account for the smallest fraction, 4%, of the total water use.
3. It is assumed that dry toilets do not use any water, are made of polypropylene and have a total weight of 13 kg. Calculation of the compost for dry toilet is based on a production of 12 kg/person/year (Matsui et al. 2001). Price of compost was estimated on the basis of local market at $US 0.3/kg of compost (personal communication).
4. A dual flush toilet uses one full flush/cap/day (6 l) and two reduced flushes/cap/day (3 l) (EPA 1995). It is made of ceramics with a total weight of 35 kg.
5. A gray-water reuse system uses the water used in the sink, bath, shower and laundry. It consists of a plastic reservoir and plastic piping system.
6. A Low-flow shower head saves about 40% of the water used by traditional shower heads (EPA 1995). They are made of plastic with a weight of 0.15 kg.
7. Faucet aerators can reduce the water used in the faucets by 60% (EPA 1995). They are made of plastics.
8. Leakage in the West Bank accounts for some 30%–40% of the consumption (PECDAR 2001). Due to system improvements and increased awareness of water scarcity, leakage prevention saves 10% of the total consumption.
9. Rainwater harvesting, these are reinforced concrete reservoirs with an average volume of the cistern of 80 m^3 (MOPIC 1998). The size of the cistern was cross-checked using the methodology developed by Van der Zaag (2000); the idea is to calculate the size of a rain water harvesting storage tank that can satisfy a household for a given satisfactory level (30–90%).

4 Results and Discussion

4.1 Inventory of Change in Resource Use

Table 1 presents the annual resource (water and energy) use and the used-water (wastewater) production before implementing (do-nothing alternative) and after implementing the different water management options together with the change in resource use.

4.2 Environmental Impact

Table 2 presents the environmental impact of the production (manufacturing/construction) and the annual reduction in the environmental impact due to the implementation of the different water management options as well as the annual net reduction in the environmental impact. Although the environmental impact of

Table 1 Annual reduction per family (six persons) in resource use due to the implementation of domestic water management options in the operational phase

Option type		Do-nothing alternative	New resource	Water saving options					Reuse option
Option			Rainwater harvesting system	Low-flow shower head	Faucet aerator	Leakage prevention	Dual flush toilet	Dry toilet	Gray-water reuse system
Resource use after using the option	Groundwater use (m^3/year)	83	3	76	69	75	70	55	47
	UW production[c] (m^3/year)	83	83	76	69	75	70	55	47
	Energy consumption[b] (kWh/year)	324	68	296	269	293	273	215	183
Reduction in resource use due to using the option	Groundwater use (m^3/year)	0	80	7	14	8	13	28	36
	UW production[c] (m^3/year)	0	0	7	14	8	13	28	36
	Energy consumption[b] (kWh/year)	0	256	28	55	31	51	109	141

[a] All calculations were made for a family of six and on the basis of the water consumption pattern given by Nazer et al. (2007)
[b] Calculations of energy use based on the following information:

1. The energy use for water abstraction and transportation is 3.2 kWh/m^3 (JWU 2007)
2. No energy needed for water treatment because the only treatment used is chlorination (JWU 2007)
3. The energy use for wastewater treatment is 0.7 kWh /m^3 (personal communications with engineer Naief Tumaleh, resident engineer in Al-Bireh Wastewater Treatment Plant 2007)

[c] UW stands for used-water (wastewater)

Table 2 Environmental impact of production, annual reduction and net reduction in the environmental impact for the different water management options relative to the "do-nothing" alternative

Option type		New resource	Water saving options					Reuse option
Option		Rainwater harvesting system	Low-flow shower head	Faucet aerator	Leakage prevention	Dual flush toilet	Dry toilet	Gray-water reuse system
Environmental impact due to production [a]								
Total impact of production (mPt)		167,000	148	1.5	–	980	364	8,880
Expected life (year)		50	10	10	–	20	20	10
Annual environmental impact of production (mPt/year)[b]		3,344	15	0.2	–	49	18	888
Reduction of environmental impact due to implementation								
Water treatment	Water use reduction (m^3/year)	0.0	7	14	8	13	28	36
	Chlorine reduction (kg/year)[c]	0.0	0.0	0.01	0.0	0.01	0.02	0.02
	Envi. impact reduction (mPt/year)[c]	0.0	0.0	0.38	0.0	0.38	0.76	0.76
Used-water (waste-water) production	Reduction (m^3/year)	0.0	7	14	8	13	28	36
	COD reduction (Kg/year)[d]	0.0	12	22	13	21	45	58
	Envi. impact. reduction (mPt/year)[e,f]	0.0	35	63	37	60	130	167
Energy	Reduction (kWh)[g]	256	28	55	32	51	109	141
	Envi. impact reduction (mPt/year)	6,656	728	1,430	823	1,326	2,834	3,666
Total reduction of environmental impact (mPt/year)		6,656	763	1,493	860	1,386	2,965	3,834
Net reduction of environmental impact (mPt/year) = total reduction − annual impact of production		3,312	748	1,493	860	1,337	2,947	2,946
Percentage reduction compared to the do-nothing (%)*		38	8	17	10	15	33	33

*Note: The environmental impact of the do-nothing alternative is 8,806 (mPt/year)
All calculations were made for a household of a family of six persons
[a]The environmental impact of production was calculated using the Eco-indicator 99 (Goedkoop et al. 2000)
[b]The impact has been annualized, converted to reflect the impact on yearly basis
[c]Water treatment: only chlorination is used, 0.6 mg/l is used (JWU 2007). Environmental impact = 38 mPt/kg chlorine (Goedkoop et al. 2000)
[d]COD concentration = 1,586 mg/l (Mahmoud et al. 2003)
[e]mPt is the unit of environmental impact in milli eco-points
[f]Environmental impact of 1 kg COD is 2.88 mPt (Nazer et al. 2006) and for kWh energy is 26 mPt (Goedkoop et al. 2000)
[g]The energy use for water abstraction and transportation is 3.2 kWh/m^3, no energy needed for water treatment because the only treatment used is chlorination (JWU 2007). The energy use for wastewater treatment is 0.7 kWh/m^3 (personal communications with engineer Naief Tumaleh, resident engineer in Al-Bireh Wastewater Treatment Plant 2007).

constructing the rain water harvesting system is very high relative to other options, it is the most environmentally sound option with respect to the net reduction in the environmental impact, followed by the dry toilet and gray-water reuse systems. In the case of the dry toilet, the reduction in the environmental impact, due to the use of compost produced in the toilet as a substitute fertilizer, was not included in the calculation. Nevertheless, this will increase the environmental benefits. It can be seen that the largest fraction of environmental impact reduction is from energy reduction.

4.3 Financial Impact

Initial investments for the management options vary significantly between options according to type, manufacturer and place of installation. For example, costs of gray-water systems vary from simple inexpensive diverters which cost less than $200 a piece to complex treatment, storage and irrigation systems that cost several thousands of dollars (PLANETARK 2007). Cost calculations in this study were based on investment costs given by the specified reference in Table 3.

From Table 3 it can be seen that the present worth (*PW*) of the rainwater harvesting gray-water reuse, and dry toilets is negative which means that these are financially unattractive. This can be explained by the high investment needed for these alternatives. However, the social benefits including the gain in productive time resulting from improved health, the time saving associated with better access to water and sanitation, and economic gains associated with saved lives were not included in the calculations; Hutton et al. (2007) estimated the average rate of return of these benefits at a global average of US$ 8.1 per dollar invested for combined water supply and sanitation. It should be noted that the calculations in this study were based on the existing prices of water and energy. These are expected to rise in the future due to the increasing water scarcity with a consequent increase in the benefits of any water saving system.

The faucet aerator was found to be the most financially feasible on annual basis followed by, low flow-toilet and low-flow shower heads (Table 3). The pay back period for faucet aerators, low-flow shower heads, dual flush toilets options, was less than their expected life. In this context Mayer et al. (2003, 2004) said that an analysis of cost and benefit for installing low flow-toilets and low-flow shower heads showed that these products pay for them selves in water and sewer cost savings. The payback time for installing low-flow toilets (from savings on water and wastewater charges) was under 2 year, for a showerhead was 1.6 years and for a faucet aerator was under 1 year.

4.4 Social Impact

Figure 1 presents the expected change in the level of happiness of people as a result of implementing the different options for the three groups of people investigated. Table 4 presents the detailed results of the group who did not attend the workshops as an example. It can be seen that the most socially acceptable water management options are leakage prevention (LP) and rainwater harvesting (RWHS). The dry toilet (DT) is the least socially acceptable.

Results of the study showed that attending the workshops succeeded in improving the participants' awareness about water conservation options, including such

Table 3 Annual benefits, costs and the present worth of net benefits for the different water management options relative to the "do-nothing" alternative

Option type	New resource	Water saving options					Reuse option
Option	Rainwater harvesting system	Low-flow shower head	Faucet aerator	Leakage prevention	Dual flush toilet	Dry toilet	Gray-water reuse system
Investment							
Initial investment (cost and installation)	4,000	15	45	10/year	200	900	700
Expected life of equipment	50	10	10	–	20	20	10
Investment for 10 years (I_0)	800	15	45	100	100	450	700
Reference number[c]	3	1	1	5	1	4	2
Annual operational benefits (B)[a]							
From water savings ($)	96	8	17	10	16	34	43
From wastewater treatment savings ($)	0	2	4	2	4	8	11
From energy savings ($)	36	4	7	4	7	15	20
From using compost as fertilizer ($)	na	na	na	na	na	22	na
Total annual benefits ($)	132	14	28	16	27	79	74
Annual operational costs (C)							
Operation and maintenance cost ($)	−40	−1	−2	0	−5	−23	−35
Net annual benefits ($) = B − C	92	13	26	16	22	56	39
Present worth PW[b]	−92	85	155	23	69	−19	−400
Pay back period (year)		<1	<1	<1	1.6		

[a]Calculations were made over a period of 10 years and according to the following
Average cost of water for domestic use = 1.2 US$/m^3 (PWA, Personal communications 2007);
Average cost of energy = 0.14 US$/kWh and cost of wastewater treatment = 0.3 US $/m^3 (personal communications with engineer Naief Tumaleh, resident engineer in Al-Bireh Wastewater Treatment Plant 2007)
Annual operation and maintenance 3% of investment;
Cost of compost is estimated on the basis of local market at $US 0.3/kg, a person produce some 12 kg/year (Matsui et al. 2001)
[b]*PW* is calculated according to the equation 3.1 (Blank and Tarquin 2005); *k* is the real discount rate = 5%
na stands for not applicable or not available
[c]References for the investment: 1: (Mayer et al. 2003), 2: (PLANETARK 2007), 3: (Krishna 2005), 4: (personal communication UNESCO-IHE 2007)
5: it was assumed that US$ 10/year will be spent for leakage fixing

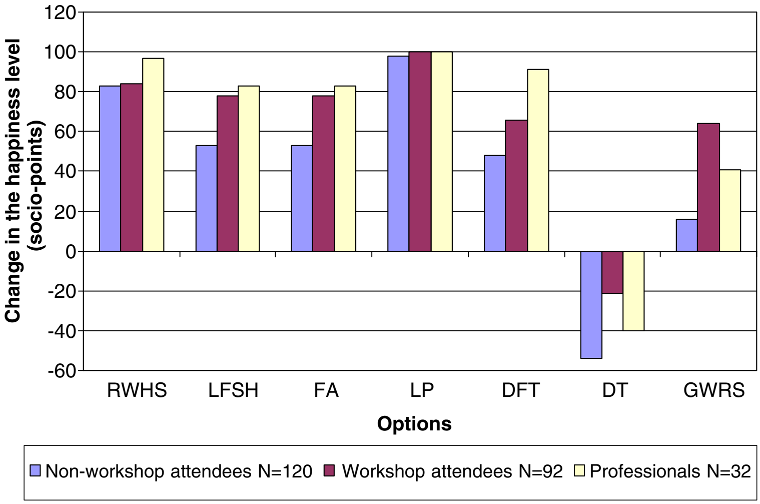


Fig. 1 Expected change in the level of happiness as a result of implementing water management options among the sampled societal groups

non-traditional options as the dry toilets. For example, the social impact of using dry toilets was minus 54 socio-points in the non-workshop attendees (participants who did not attend workshops); while the impact increased to minus 21 socio-points among the workshop attendees (participants who attended the workshops). Social impacts of gray-water reuse, dual flush toilets and faucet aerators also increased among the workshop attendees relative to the non-workshop attendees (Fig. 1). Hence, we can conclude that wider awareness raising programs such as a televised national debate or discussion could be very useful.

In order to explain statistically the relationship between the level of awareness and the willingness to use and pay for each option, or in other words to explain the difference in the change of happiness between the workshop attendees and the non-workshop attendees, the chi-square test was used.

The calculated chi-square value for dry toilets and grey-water reuse systems exceeded the critical value 3.84 at 5% level of significance (Table 5) meaning that attending the workshops had a significant positive effect on the participants willingness to use and pay for the presented options. However, for rainwater harvesting systems and leakage prevention there was no significant difference between the two groups (Table 5). This can be explained by the fact that these options are well-known and widely used in the West Bank. There was also a significant difference between the professionals and the group of the non-workshop attendees. The social impact was greater in the professionals' group. This can be explained by the fact that the professionals were well aware of these water management options because of their professional background in the water sector. However, the social impact of dry toilets and grey-water systems in the professionals group is less than the impact in the workshop attendees group. This may be because the professionals are educated with the idea that "water is plentifully available" and "all problems of water can easily be solved" (just like a medical doctor is raised with the concept of "treatment first"). Therefore, in the professionals' mind, tools that save water or eliminate the use of

Table 4 Expected change in the level of happiness as a result of implementing water management options for the group who did not attend the workshops

Option Type	New resource	Water saving options					Reuse option
Option	Rainwater harvesting system	Low-flow shower head	Faucet aerator	Leakage prevention	Dual flush toilet	Dry toilet	Gray-water reuse system
Willingness to use							
Total number of respondents	120	119	119	120	121	120	120
Number of respondents willing to use the option	118	108	108	120	100	37	82
Number of respondents not willing to use the option	2	11	11	0	21	83	38
α_u: the fraction of respondents willing to use the option	0.98	0.9	0.9	1	0.83	0.31	0.68
Willingness to pay							
Total number of respondents	120	119	119	120	121	120	120
Number of respondents willing to pay for the option	102	75	75	118	78	18	58
Number of respondents not willing to pay for the option	18	44	44	2	42	102	62
β_p: the fraction of respondents willing to pay for the option	0.85	0.65	0.65	0.98	0.65	0.15	0.48
Social impact $\Delta S^{a,b}$	83	53	53	98	48	−54	16
Willingness to pay/willingness to use $\frac{\beta_p}{\alpha_u}$	0.87	0.72	0.72	0.98	0.78	0.48	0.71

[a] Social impact (change in happiness ±) was calculated according to the equation 3.4 $\Delta S = 2a(\alpha_u + \beta_p - 1)$

[b] (+) means increase in happiness and (−) means decrease in happiness

Table 5 The calculated and critical value of chi-square between the workshop attendees group and the non-workshop attendees group for the different water management options

Option		Rainwater harvesting system	Low-flow shower head	Faucet aerator	Leakage prevention	Dual flush toilet	Dry toilet	Gray-water reuse system
Calculated chi-square	Willingness to use	0.7	3.3	3.3	0.0	3.6	6.2	17.8
	Willingness to pay	0.04	8.2	8.2	1.3	2.1	5.3	10.1

Note: Critical value of chi-square is 3.84 at 5% level of significance, a value < 3.84 means no significant difference between the groups and a value > 3.84 means there is a significant difference (Chase and Bown 1986)

water in clear cases of potential negative impact on the public health, are simply not done, these are outside their professional interest.

It can be concluded that making people aware of certain water management options, including such non-traditional options as the dry toilets, increases the willingness to use and pay for these options and, hence, the social impact (change in happiness level) due to using these options.

It was found that the willingness to pay for an option is less than the willingness to use that option, $\alpha_u \leq \beta_p$ and therefore $\frac{\beta_p}{\alpha_u} \leq 1$ (Table 4). However, the willingness to pay for the option is expected to increase with increasing importance of that option. For example, a person may be willing to use a rainwater harvesting system but may not be willing to pay for it if the availability of water is not a critical issue. But if water availability is a daily issue, that person's willingness to pay will approach his or her willingness to use. From Fig. 2, it can be seen that $\frac{\beta_p}{\alpha_u}$ for options considered important

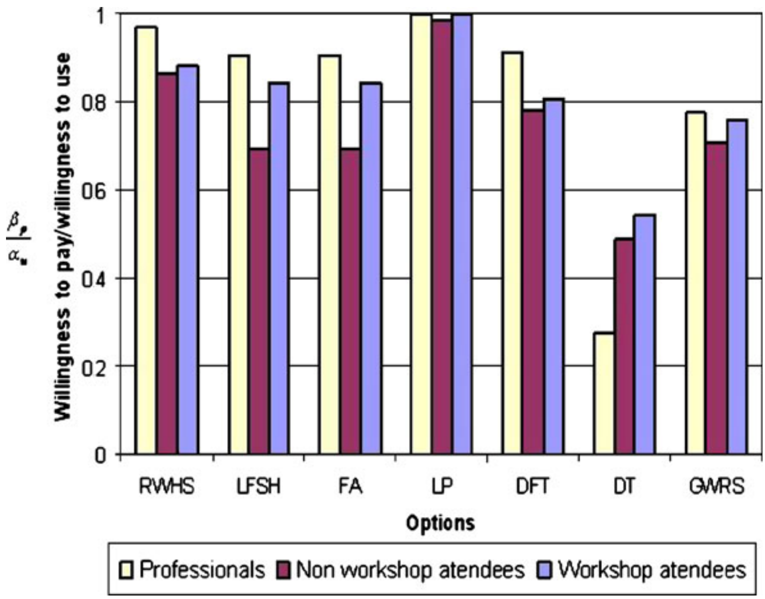


Fig. 2 Willingness to pay/willingness to use, $\frac{\beta_p}{\alpha_u}$ for the different water management options

such as leakage prevention is approaching 1 while that for options considered not important it is less than 1. Therefore, efforts should be devoted towards increasing the awareness about the options which are considered of low importance.

4.4.1 Reasons Behind Accepting or Rejecting Water Conservation Options

The respondents of the three groups were asked about the reasons behind their willingness or un-willingness to use and to pay for the options.

Dry Toilets (DT) Participants who rejected DT explained their rejection for emotional, religious, public health and financial reasons amongst others. The emotional reason was the dominant: 48% of participants who reject these toilets said they just could not use these toilets. Public health concerns scored 30%, religious concerns scored 18% of those not willing to use dry toilets (122). Those who said they were willing to use these toilets (90 respondents) did so for reasons of water saving (63%), money saving (9%), environmental saving (10%) and other reasons (18%).

Gray-Water Reuse Systems (GWRS) Participants who are willing to use GWRS (160 respondents) did so for reasons of water saving (49%), money saving (6%) and environmental saving (4%). Public health concern was the most dominant reason for rejecting these systems (42%) followed by the emotional reasons (22%) of those not willing to use GWRS (46 respondents).

Dual Flush Toilets (DFT) Seventy-five percent of the participants who are not willing to use DFT (28 respondents) often felt that these devices are water wasting because of the large volume of water these devices use relative to the volume of hand flushing containers which they use. It is common in the area to use special containers to flush away the waste. The volume of these containers varies between 1 and 2 l.

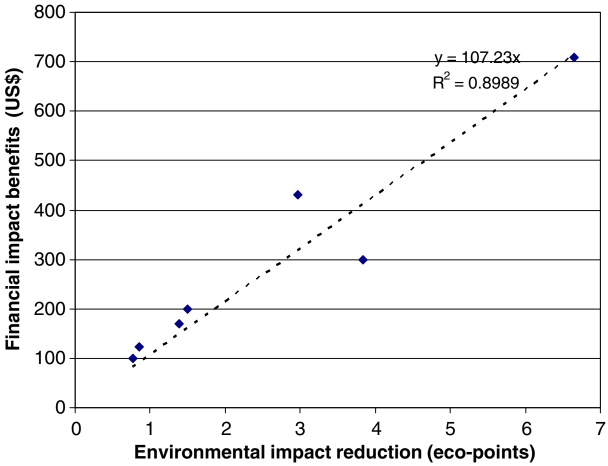
Rainwater Harvesting Systems (RWHS) Almost all workshop participants (98%) were willing to use RWHS. These are considered as an alternative water resource to ensure water security when the piped water supply is cut off. Many participants suffer from losing access to water especially in summer when water is cut off for long periods. Some participants (5%) said that it is the only water resource they have. Eighty-six percent of the workshop attendees and 85% of the non-workshop attendees have the willingness to pay for constructing a RWHS regardless of the high cost of these systems.

4.5 Relating Environmental, Financial and Social Impacts

Figure 3 shows a strong correlation between the environmental and financial benefits of the options during the operational phase: the coefficient of determination R (0.89) is greater than the critical value of R (0.708) for a level of significance of (0.01) (Chase and Bown 1986). For one eco-point decrease in the environmental impact, there is an increase in profit of US$ 107.

In contrast, it was found that the relationship between the social impact and both financial and environmental impacts is weak, the coefficients of determination R, 0.52 and 0.45 respectively, are less than the critical value of R (0.708) for a level of significance of 0.01 (Chase and Bown 1986). This can be explained by the

Fig. 3 Relationship between environmental impact and financial impact of the operational phase



reasons behind the participants' willingness to use and pay for the options: the most motivating reason was water availability (46%) rather than money saving (6%) or environmental concerns (4%). Moreover, the Palestinians have long ago adapted to water scarcity as a fact of life. This can be well illustrated by the fact that only 5% of the water use is withdrawn from existing groundwater resources and 43% is consumed from rain water through consuming rain-fed crops. In contrast, 52% of that water is imported in virtual form through imported goods (Nazer et al. 2008).

4.6 The *House of Tomorrow*

According to Nazer et al. (2007) the average in-house water consumption in the West Bank is 38 ± 18 l/cap/day (Table 6). The large variation means that the in-house water consumption varies considerably from place to place. Nevertheless, the numbers in Table 6 were used to show to what extent, even in conditions of limited water use, further water saving is feasible by combining different water management options in the so-called *house of tomorrow*. The implementation of these options can lead to a significant reduction in the per capita in-house water consumption from 38.1 l/cap/day to a minimum of 15.7 l/cap/day (Table 6). The combination proposed in this context is: dry toilet instead of water-based toilet, low-flow shower heads and faucet aerators, potentially resulting in over 50% saving in water (Nazer et al. 2007). A gray-water reuse system can be installed through which the used-water can be reused for irrigating the garden, by doing so the outdoor consumption can be eliminated. According to the numbers presented in Table 6, a family of six will only need 34 m^3/year which could easily be harvested from rain water from a roof of 100 m^2 area. In this context Zhang et al. (2010) stated that a reduction of some 32% of the water use can be achieved by gray-water reuse and rainwater harvesting allows for a reduction of 25%. Ibrahim (2009) also found that rainwater harvesting can be a useful technique for providing safe water in water deficit areas in semi-arid regions.

In the proposed *house of tomorrow* a combination of six options was used. However, in some places some of these options may not be applicable. In such cases other combinations of two or three options could be used according to the specific

Table 6 House-hold water consumption on a per capita basis without implementing water management options and expected per capita water consumption with implementation (Nazer et al. 2007)

Point of use		Per capita water consumption without		Per capita water consumption with	
		Average (l/c/d)	Standard deviation	Proposed water management option	(l/c/d)
Bathroom	Toilet flushing	12.9	9.5	Dry toilet instead of water based toilet	0.0
	Sink	5.3	4.1	Faucet aerators	2.1
	Bath and shower	8.3	7.1	Low-flow shower head	5.0
Kitchen	Dish washing	5.0	3.5	Faucet aerators	2.0
	Cooking and drinking	1.6	1.5	–	1.6
Cleaning	Laundry	3.0	3.1		3.0
	House cleaning	2.0	2.3	–	2.0
Total in-house		38.1	18.4		15.7
Outdoor*		6.7		Gray-water use	0.0
Total		44.8			15.7

Note: outdoor water use was estimated at 15% of the total house use according to PWA (2005, personal communication)

Rain water reservoir with a minimum capacity of 40 m^3 could be installed to guarantee the provision of the water needs of a family of 6 and a gray-water reuse system can also be installed which can make use of the 15.7 l of the used-water in the house

conditions. For example in places where a dry toilet is not applicable, a low-flow toilet may be a substitution.

Using these options means that the four main principles of cleaner production are applied in the house of tomorrow, that is, the proper type of material (here water) is used, reuse of material is practiced, no mix of waste has been practiced and what is traditionally called waste is reused. By doing so less water is used, less used-water needs to be treated and fewer pollutants need to be removed.

In the above analysis, dry toilets play an important role, in spite of the fact that these are the least socially acceptable water conserving device of those investigated. However, it should be noticed that water availability predictions for the West Bank are dire. Less and less water will be available through the years to come leaving no other choice than to go for the most effective water conservations options. Timely planning and awareness raising are, therefore, vital ingredients in averting what is bound to come if no serious measures are taken in time (Nazer et al. 2008).

Pilot projects can play a significant role in awareness raising. Areas without water supply or sanitation system and very low water consumption can be fertile grounds for implementing pilot projects. In this context Matsui et al. (2001) stated that the existing sanitation systems in the developed countries are not suited to a world where environmental protection is a priority. Developing countries, like Palestine, have an opportunity to skip the phase of water wasting sanitary facilities and to move directly into the implementation of water conscious sanitary equipment.

The introduction of these water management options should, in the very near future, be oriented towards a situation in which each single- and multi-family housing property is largely independent in terms of water and sanitation systems. Each property should have its own water resource (RWHS) and its own used-water treatment system (gray-water treatment system in combination with a dry toilet). This can be achieved by adapting building codes accordingly. However, this may not be possible in some places where rainwater harvesting does not yield sufficient water. In such places water, made available by reduced demand, can be supplied from other resources.

5 Conclusions

The objective of this study was to evaluate the environmental, financial and social impacts of potential domestic water management options using life cycle impact assessment (LCIA) and to propose a water use scheme for the *house of tomorrow*, in line with the *use-treat-reuse* approach. The main findings of this study were that by introducing a combination of water management options in the domestic area, a substantial decrease in water consumption of up to 50% could be achieved, thereby reducing the pressure on the scarce water resources. This reduction can be achieved because the water was used more than once and not at the expense of water use purposes; thus reducing the use of groundwater. Environmental and financial impacts can be reduced similarly; the annual environmental impact of the in-house water use can be reduced by some 8% when using low-flow shower heads, and up to 38% when using rainwater harvesting systems. Some of the options investigated were found to be financially attractive such as faucet aerators, low-flow shower heads and dual flush toilets. However, others (rainwater harvesting, gray-water reuse systems and dry toilets) were found unattractive because of the high investment needed. However, the social and health benefits may justify these investments. In the social context, it was found that introducing such options can improve the quality of life of those not having sufficient water. It was concluded that, theoretically, the *house of tomorrow* can be largely independent in terms of water and sanitation. It was also concluded that there is a popular willingness to take part in water conservation in the domestic sector in the West Bank. The strongest driving force for using water conservation measures is the awareness that water is a scarce resource. Education and awareness campaigns in the context of water management with a focus on non-traditional options, such as dry toilets, are key to achieving sustainable water use.

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