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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 Out of this number 50 m^3/cap/year was withdrawn from water resources available in the area.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

$$Q_{FP} = Q_{FP}^{*} + Q_{FP}^{**}, \quad (1)$$

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).

$$Q_{FP*} = Q_{IFP} + Q_{EFP}, \quad (2)$$

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.

$$Q_{IFP} = Q_{AWU} + Q_{IWW} + Q_{DWW} - Q_{VWEdom}, \quad (3)$$

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).

$$Q_{EFP} = Q_{VWI} - Q_{VWEre-export}, \quad (4)$$

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

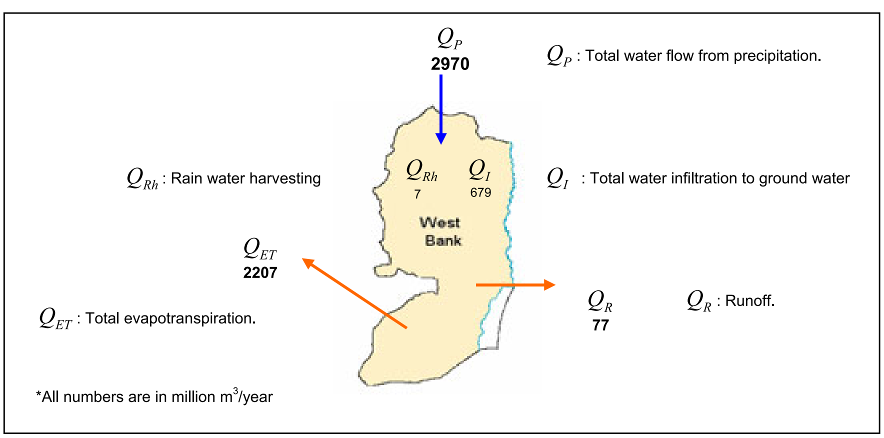

FIGURE 2. Water Balance for the West Bank.

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.

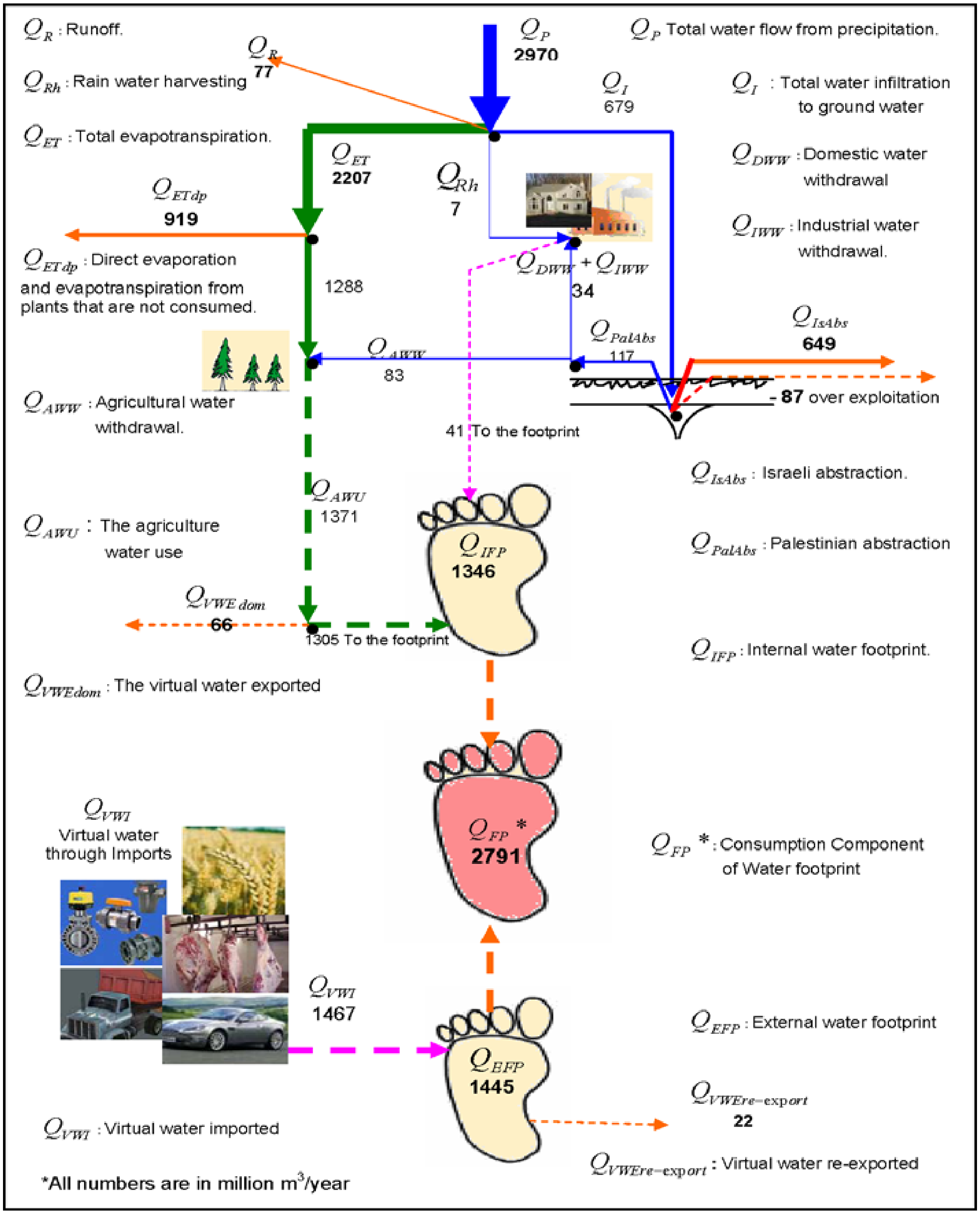

FIGURE 3. Water Footprint of the West Bank.

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).

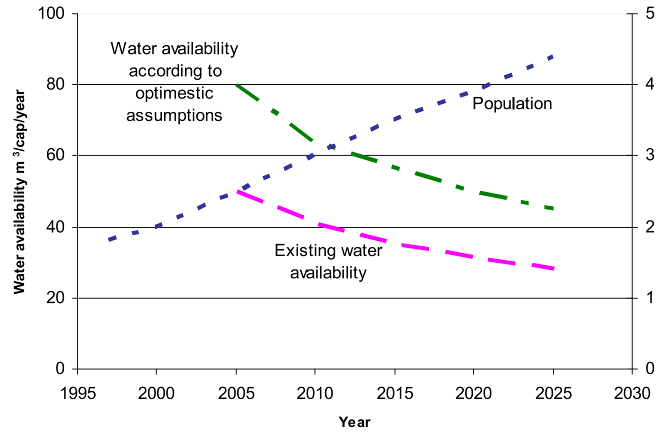

FIGURE 4. Future Per Capita Water Availability and Population.

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)

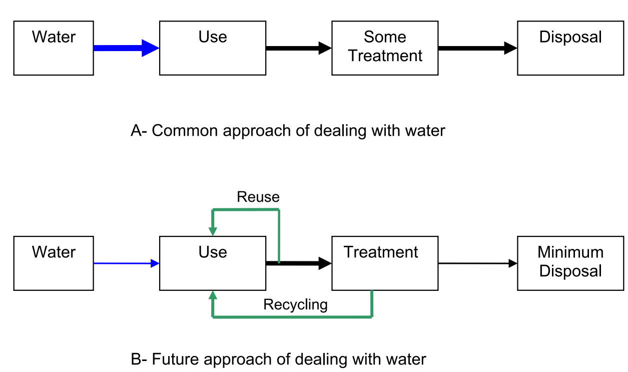

FIGURE 5. Traditional and Future Approaches of Dealing With Water (please note the size of the arrows).

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.

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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

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

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

$$ET_{\mathrm{c}} = K_{\mathrm{c}} \times ET_0,$$

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).