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Artificial Recharge of Groundwater with Stormwater as a New Water Resource - Case Study of the Gaza Strip, Palestine

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Zusammenfassung

Auf Grund des Defizits in der Wasserbilanz im Gazastreifen kommt es zu einer Verschlechterung der Grundwasserqualität. Ein Beispiel hierfür ist die Erhöhung der Salinität auf mehr als 1500 mg/l (als Chlorid). Weiterhin ist der Grundwasserspiegel in den meisten Gebieten knapp unterhalb des Meeresspiegels gesunken. Die durchschnittliche jährliche Regenhöhe beträgt 350 mm (114 Mm^3). Hiervon versickern etwa 45 Mm^3 und stehen somit der Grundwasserneubildung zur Verfügung. Der Rest verdunstet oder fließt in die See.

Nicht-konventionelle Wasservorkommen wie zum Beispiel Meerwasserentsalzung, Abwasserwiederverwendung oder das Auffangen und anschließende Versickern von Regenwasser nach Starkregenereignissen sind mögliche Alternativen, um das vorhandende Defizit in der Wasserbilanz zu verringern. Meerwasserentsalzung ist jedoch sehr kosten- und energieintensiv und kann unter den Bedingungen im Gazastreifen nicht umgesetzt werden. Die Nutzung vorgereinigten Abwassers zur künstlichen Grundwasseranreicherung ist im Gazastreifen noch in einer Erprobungsphase. Problematisch ist hier, dass das vorgereinigte Abwasser weder den internationalen, noch den palästinensischen Standards zur (direkten) Grundwasseranreicherung noch zur Bewässerung genügt. Durch die Nutzung von Regenwasser zur Grundwasseranreicherung steht zwar quantitativ weniger Wasser zur Verfügung, dieses ist jedoch wesentlich sauberer und kann deshalb direkt zur Grundwasseranreicherung genutzt werden.

Die Nutzung von Regenwasser spielt eine wichtige Rolle im Management von Wasserressourcen. Die potentielle Regenwasserabfluss im Gaza-Streifen beträgt etwa 28 Mm^3, wovon 22 Mm^3 allein aus städtischen Gebieten stammen. Größere Projekte zum Auffangen und Versickern von (Stark-) Regen wurden im Norden und Süden, sowie im zentralen Gaza-Streifen umgesetzt. Aufgrund mangelhafter Steuerung der Projekte waren diese nicht erfolgreich. Das Sammeln von Regenwasser von Dächern bei nachfolgender, gezielter Versickerung reduziert insgesamt die Gefahr von Überschwemmungen nach Starkregenereignissen.

Länder, in denen ein Wassermangel herrscht, unterstützen Systeme zur Nutzung von Regenwasser zur Grundwasseranreicherung. Insbesondere in ländlichen Gebieten, welche nicht an ein zentrales Leitungssystem angeschlossen sind, gibt es praktische Erfahrungen in der Nutzung von Regenwasser. Hier war und ist die Nutzung von Regenwasser überlebensnotwendig.

Als Ergebnis einer sozioökonomischen Studie, welche in Gaza durchgeführt wurde, ergab sich, dass sich die Bevölkerung von Gaza der Notwendigkeit von neu zu erschließenden Wasserressourcen bewusst ist und zunehmend Regenwasser als Wasserressource nutzt. Durch Investitionen der lokalen Behörden und Institutionen kann aus der neuen Technologie eine erfolgreiche Wasseralternative werden.

Mithilfe der Nutzung von GIS konnte für den Gaza-Streifen eine Regengesamtmenge, welche auf Hausdächer und andere versiegelte Flächen aufgefangen werden kann, von 5,2 Mm^3 abgeschätzt. Dies entspricht 24 % der gesamten, in städtischen Gebieten im Gaza-Streifen fallenden Regenmenge. Diese Menge könnte der künstlichen Grundwasseranreicherung zur Verfügung stehen und in Versickerungsbecken im Nahbereich von Wohnhäusern, Schulen und anderen öffentlichen Gebäuden versickert werden.

Ein hauseigener Regenwasserauffang wurde innerhalb eines Pilotprojektes getestet und sowohl die Gesamtmenge als auch die Wasserqualität wurden überwacht. Es ergab sich, dass die Gesamtmenge des Regenwasserabflusses von versiegelten Flächen mit steigender Regenintensität und Regendauer proportional ansteigt. Der Abflusskoeffizient erreichte mehr als 0,9 für Starkregenereignisse und 0,4 für Regenfälle mit geringer Intensität. Für den Untersuchungszeitraum ergab sich ein Mittelwert von 0,74. Weiterhin ergab sich, dass ein Infiltrationsbecken mit einer Durchmesser von 1 m pro 100 m^2 Dachfläche ausreicht, um 90 % der auf ein Dach fallenden Niederschlagsmenge aufzufangen und zu versickern.

In Bezug auf die Wasserqualität zeigte sich, dass das auf Dächern aufgefangene Regenwasser für die künstliche Grundwasseranreicherung geeignet ist und den Standards der WHO Regularien entspricht. Die Konzentrationen an Blei, Cadmium, Eisen, Zink, Chrom, Aluminium und Kupfer lagen innerhalb der Grenzwerte für Trinkwasser nach WHO. Es wurden jedoch relativ hohe Konzentrationen an gelöstem organischem Kohlenstoff im Straßenabfluss gefunden. Die Konzentrationen der toxischen Schwermetalle, wie z. B. Cadmium und Blei, lagen im Bereich der international, regional als auch lokal gültigen Standards für künstliche Grundwasseranreicherung. Es kann davon ausgegangen werden, dass die gelösten Schwermetalle im Infiltrat nicht mobil sind. Dies kann damit begründet werden, dass alle gemessenen pH-Werte des Regenwassers um 7,0 lagen. Bei diesem pH-Wert werden die meisten Schwermetalle während der Infiltration an der Bodenmatrix sorbiert oder fallen aus.

List of Papers

This thesis is based on the following papers and manuscript, where these papers are appended at the end of the thesis.

I. Hamdan, S., Troeger, U. and Nassar, A., 2007. Stormwater availability in the Gaza Strip, Palestine. Int. J. Environment and Health, Vol. 1, No. 4, 2007. Inderscience Enterprises Ltd: 580-594.

II. Hamdan, Sami 2009. A literature based study of stormwater harvesting as a new water resource. Water Science & Technology-WST 60.5/2009. IWA Publishing 2009: 1327-1339

III. Hamdan, S., Troeger, U. and Nassar, A., 2011. Quality risks of stormwater harvesting in Gaza. Journal of Environmental Science and Technology 4 (1), 2011. Asian Network for Scientific Information: 55-64.

IV. Hamdan, S., Nassar, A. and Troeger, U., 2011. Impact on Gaza Aquifer from Recharge with Partially Treated Wastewater. International Journal of Desalination and Water Reuse, IWA Publishing 2011. Volume 1, Number 1, March 2011: 36-44

List of abbreviations and acronyms

As	-	Arsenic
Ca^{+2}	-	Calcium
Cd	-	Cadmium
Cl^-	-	Chloride
COD	-	Chemical oxygen demand
Cr	-	Chromium
Cu	-	Copper
DOC	-	Dissolved carbon
EC	-	Electrical conductivity
K^+	-	Potassium
Mg^{+2}	-	Magnesium
Na^+	-	Sodium
NO_3^-	-	Nitrate
Pb	-	Lead
TDS	-	Total dissolved solids
TOC	-	Total organic carbon
Zn	-	Zinc
a.m.s.l.	-	above mean sea level
ET	-	Evapotranspiration
GIS	-	Geographic Information System
ha	-	Hectare
l.c.d.	-	Liters per capita per day
Mm^3	-	Million cubic meter
P	-	Precipitation
p.p.m.	-	parts per million
CMWU	-	Coastal Municipal Water Utility
PWA	-	Palestinian Water Authority
RWH	-	Rainwater harvesting
SAT	-	Soil aquifer treatment
WHO	-	World Health Organization

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Abstract

Due to the existing deficit in the water resources budget in the Gaza Strip, the groundwater quality was deteriorated and salinity reached more than 1500 mg/l as chloride ion. Moreover the groundwater level declined continuously until it reached few meters below sea levels in most areas. The average annual rainfall amounts to 350 mm giving a bulk volume of rainfall fallen on the Gaza Strip amounting to 114 Mm^3 every year, from which only 45 Mm^3/year is infiltrated naturally to groundwater, and the rest either evaporates or flows to the sea.

Non-conventional water resources such as desalination, wastewater reuse and storm water harvesting are needed to bridge the gab in water resources budget. Desalination is faced by financial constraints in addition to problems of available power. Wastewater reuse and artificial recharge with effluent is still at early stages since the quality of the effluent does not meet the local nor international standards for either direct reuse for irrigation and artificial recharge of the aquifer. According to a pilot project operated for five years in Gaza City for recharging treated effluent to aquifer, it was found that there was negative impact on the local groundwater quality. However, storm water utilization has less potential quantities than those from desalination and effluent reuse, but it has the advantage that it is cleaner and suitable for artificial recharge of the aquifer.

Urban stormwater harvesting became an important water resource that plays a significant role in enhancement of water resources management. It has a potential input of about 28 Mm^3 per year as runoff, from which 22 Mm^3 come from urban areas in cities only based on the existing landuse. Some large scale storm water harvesting projects were constructed in north, central and south of Gaza Strip, but there was no perfect control which hindered the function of these projects. Collection of storm water running from rooftops and yards of buildings and diverting it into local onsite artificial infiltration systems will decrease the road flooding and water quantities reached the central rainwater collection lagoons.

Most of the scarce water countries promote rainwater harvesting system (RWH) as one of the strategic water resources due to growing demand of water. RWH is practised commonly in remote areas especially in the villages, where connecting water pipes is not economically feasible. RWH was a must for their survival and enters its efficient practice after legal regulations are set. This will need to change the procedures of issuing licences of new constructions to have RWH system in each building such as playgrounds, parks and yards. The system could be implemented as initiative behaviour of the people, since they are aware of the scarce water problem in their country. This approach should be incorporated into bye-laws for all new constructions including all residential, institutional and commercial utilities.

From the socioeconomic study made in Gaza, it was noted that there has been an increasing awareness for the need of RWH and could be adopted as a new water resource. Since the people are well aware of the severe water problem, they are willing to adopt this technique in the form of onsite rooftop rainwater infiltration at their houses. However, financial incentives are needed from the local authorities to make this option successful. The onsite rooftop rainwater infiltration system is encouraged in individual houses in urban areas, where free land is available around the house.

Using GIS, it was estimated that the total rainwater harvested from house roofs and open yards belong to buildings was 5.2 Mm^3, which forms 24% of the whole urban storm water in the Gaza Strip. This quantity could be artificially recharged to the aquifer through infiltration pits around the houses themselves or in the yards of schools and other public buildings.

Onsite RWH was tested at one pilot concrete house located at the middle of the Gaza Strip, and the collected water quantity and quality were monitored in the rainy season 2007/2008. Quantitatively, it was found that rain runoff coefficient from roofs and yards increases with the increase of rainfall intensity and rainstorm duration. The runoff coefficient reached more than 0.9 for high intensity rain events and 0.4 for low intensity ones. Unlike the value of runoff coefficient of buildings listed in hydrology literatures for building, the runoff coefficient at the pilot concrete roof house has been weighted to have an average value of 0.74 in the monitored rainy season. To harvest

90% of rainwater fallen on the roofs, it is enough to construct one infiltration pit with 1.0 m diameter for every 100 m^2 of the roof area without the need of storage facility.

Qualitatively, the harvested rooftop stormwater runoff in Gaza has proved to be suitable for artificial recharge and close to WHO drinking water standards, where low concentrations of chloride and nitrate were found. The measured concentrations of lead, cadmium, iron, zinc, chromium, aluminum and copper were in the acceptable limits set by WHO for drinking purposes. However, relatively high concentrations of total organic carbon (TOC) were found in urban road runoff water. This can be explained by minor mixing with wastewater when sewage manholes flood to roads. The results of heavy metal analyses were also acceptable for both rooftop and road storm water. The concentrations of poisonous metals, such as cadmium and lead, were found to be close to the international, regional and local standards for artificial recharge purposes. There is no danger from the mobility of these metals in the infiltrating water, since the pH values of all the measured storm water samples were close to 7.0, under which most of the heavy metals will be either absorbed, precipitated or co-precipitated in the soil aquifer matrix through its infiltration to the groundwater.

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1. Introduction

Water is essential for life of human, animals and plants, and its scarcity is the major constraint of human development. There is a need to protect water resources through reuse of these available resources, which could be achieved here in both direct and indirect ways for both rainwater harvesting and treated wastewater. In former times, rainwater was collected in storages in the wet season and used later in the dry period for drinking and other domestic uses. The treated wastewater effluent could also be pumped or diverted to the farms for direct irrigation of crops. Indirect reuse of water could be achieved through artificial recharge of rainwater runoff or well treated effluent using different methods of artificial recharge of groundwater. The methods of artificial groundwater recharge differ from one area to another depending on local conditions such as topography, geology, hydrogeological conditions and land availability. The used recharge methods known are injections wells, longitudinal ditches and infiltration basins. The acceptance of utilizing these resources depends mainly on the treatment level of each source of recharged water from both rainwater runoff and treated wastewater effluent.

Rainwater harvesting (RWH) is defined in this research thesis as the utilization of collected rainfall for direct use such as drinking, domestic or irrigation purposes or indirect use through artificially recharging it to the groundwater system and recovering it through recovery water wells or existing operating water wells. RWH can be a significant mitigation strategy against the impact of droughts, which are hazard in every society although their impact is less life-threatening in countries with higher levels of socioeconomic development (Bruins et al 2005). Captured rainfall can be stored either in cisterns for drinking purposes, in the soil for plant production, or in the aquifer through artificial recharge to improve the local water resources. The latter option provides the opportunity of water treatment in the soil aquifer matrix through infiltration. A study of risk assessment of storm water reuse showed that there is sufficient treatment capacity within the aquifer to reduce risk from organic chemical hazards (Vanderzalm et al 2007). RWH for drinking purposes is found in dry zones in the world, but water quality problems were encountered. For example in Sri Lanka, RWH system was applied in a dry zone of an area of 946 Km^2 with population of

518,500 people, and about 86% of the beneficiaries expressed their overall satisfaction with the facility (Kumara and Wickramasinghe, 2003).

Beyond the utilization of storm water runoff as a water resource, best management practice (BMP) is urgently needed to protect the cities from frequent flooding in the rainy seasons. This could be achieved if the magnitudes of runoff quantities are damped through onsite infiltration from roofs and yards. According to (Qin et al. 1995):

"BMPs may be divided into three categories: (1) source controls, (2) passive controls, and (3) active controls. Source controls target the source areas of runoff generation and constituents and generally are nonstructural management measures. Passive and active BMPs are typically structural measures. Passive BMPs do not require active operational control or adjustment beyond routine maintenance, while active BMPs do"

1.1 Problem Description

The available water resources in the Gaza Strip are limited and do not fulfill the increasing water demand. The Strip depends mainly on the groundwater from the coastal aquifer, which has a safe yield of only 98 Mm^3 per year (Hamdan 1999), while the overall water demand was estimated at 160 Mm^3 per year in 2010 (CAMP 2001). This leads to an annual water deficit in the water resources of about 70 Mm^3, which has its impact on the supplied water quantities as well as their water quality due to sea water intrusion and deep groundwater upconing. The average annual rainfall gives a bulk amount of water of about 114 Mm^3 (PWA 2007), from which only 45 Mm^3 infiltrate naturally to the aquifer which forms only 40% of the total rainfall (Hamdan and Muheisen 2003).

There is a need for new water resources from either inside the Gaza Strip such as desalination, wastewater reuse and rainwater harvesting or from outside such as importing water from countries in the region. However, the second scenario is mostly halted by political constraints resulting from political conflicts in the region and international treaties signed with other countries sharing them with the catchment areas of their water resources. RWH is one of the new water resources that could help in bridging the gap between the overall water supply and demand. Treated wastewater effluent in the Gaza Strip does not meet the WHO or the Palestinian standards for artificial recharge of groundwater. However, a pilot project for the reused of effluent through artificial recharge of groundwater has been made in Gaza city and monitoring of the underground aquifer was carried out throughout five years in operating water wells around this project. There was increase in the groundwater levels and decrease in the nitrate concentration. However, bad impacts were recorded in the rise of chloride and boron concentrations in the groundwater beneath the region of the infiltration basins, and the project was not functioning after five years of operation.

RWH became the weapon to face the drought and urban expansion that both decrease the water amounts naturally infiltrated to the aquifer. The runoff floods seen in the wet season are either evaporated or wasted to Wadis and the sea. Alternatively, it could be harvested through onsite infiltration of rooftop rainwater before reaching the central collection lagoons, where collected water is also pumped to the sea or evaporate. The onsite rainwater harvesting will decrease the load on the large scale rainwater harvesting infrastructures, and harvest more rainwater quantities in addition to get better quality of collected rainwater before water pollution occurs through its running over roads in its way to the lagoons. Water collected from rooftop and yards of buildings could be infiltrated artificially through onsite structured percolation pits, trenches or other simple infiltration schemes.

In general, most people prefer to obtain their water supply facility through pipe network or at least from a shallow tube well. In environments where it is difficult to access the water network such as in the West Bank in Palestine, people are more aware of RWH as a water resource which was practiced long time ago for drinking purposes. In contrast, accessing water network and shallow groundwater easily in the Gaza Strip did not attract the people in Gaza to consider RWH as an option for new water resource. Since water resources in the Gaza Strip are facing severe problems due to over pumping, RWH should be seen as a viable option so as to conserve these resources. The objective of RWH in the Gaza Strip is to conserve water resources unlike the case in the rural areas of the West Bank, where RWH aims at getting the water for direct use for drinking due to unavailability of water supply network itself.

The quality of rainwater from rooftop differs from that found in roads and central rainwater collection pools, where road runoff carries pollutants from the roads and it is risky to reuse this water directly without enough treatment. Soil aquifer treatment during infiltration to groundwater is seen as the maim treatment process, and identification of the chemical constituents of the collected rainwater from rooftop and streets will help the public to deal with this new water resource. To adopt this onsite rainwater harvesting system, willingness of the local people to participate in the implementation and maintenance is the main factor in the success of the new system.

1.2 Objectives

The overall objective of the research is to find new water resource to help in bridging the gap in the water resources budget in the Gaza Strip. In this respect, the available quantities of rainfall that could be harvested are studied, in addition to identification of the changes in water quality for different types of harvested rainfall flowing over rooftop, collected in storage tanks at house, flowing over streets and collected in central stormwater lagoons. The participation of the public is an important issue, and their willingness to adopt this technique is the key factor for its success. The objectives of this research are meant at more detailed level as follow:

- Investigate the potential amounts of available stormwater quantities that could be harvested from different types of landuse based on existing and planned situations.
- Review the experience and lessons learned by international community concerning risks of water quality changes of running rainfall over different types of roofs.
- Investigate the risks of water quality changes through rainwater runoff on a typical house concrete roof in the Gaza Strip compared to water quality of urban stormwater runoff on roads and collected in central lagoons.
- Investigate the possibility of implementing onsite rainwater harvesting (RWH) system at house composed of collection pipes, storage and infiltration pits.

- Quantify stormwater coming from rooftop and yards belong to buildings in urban areas of cities in the Gaza Strip.
- Investigate the socioeconomic aspects of implementing rainwater harvesting system in the Gaza Strip on two levels distinguished as firstly, Palestinian water professionals and secondly local people, where rainwater harvesting system could be implemented at their houses.
- Assess the Palestinian experience on using treated effluent for artificial recharge of groundwater through a demonstration project implemented by local authorities.

2. Description of Study Area

2.1 Background

As an outcome of the Arab Israeli war in 1967, West Bank and Gaza Strip became two separated entities and management of the water resources in each entity has different ways. The study in hand deals with the rainwater harvesting in the entity of the Gaza Strip.

2.1.1 Institutional Status of Water Sector

The Palestinian Authority has been established in May 1994 according to Oslo peace agreement in September 1993. Until that time, the water sector was controlled by many institutions, governmental, international and NGO's. UNRWA was taking care of refugee camps, where it supplies them by domestic water with intermittent status. Each municipality was taking care of water services in its city and collecting water bills from customers. The agricultural department which belonged to the former Israeli civil administration was responsible for the irrigation water wells, and it gave licenses with a definite quota of water allowed to be pumped.

The establishment of the Palestinian Water Authority was announced in Oman in 1995 as the regulator of water sector in Palestine. Now, the water sector is classified into three main categories which are:

a) Policy level which is represented in the Palestinian National Water Council (NWC) composed of ministers of water related ministries in addition to representative from universities and NGO's. NWC is responsible for the general policy of water in addition to regional and international cooperation. The Palestinian Water Authority (PWA) is acting as the secretariat of NWC.

b) Regulatory level which is here the Palestinian Water Authority which is responsible for developing the strategic plans for water and wastewater in addition to setting standards for quality assurance. PWA is drafting licenses to .. It also sets. PWA coordinates with other regulating governmental ministries who are members in NWC such as Ministry of Agriculture, Ministry of Health and Environmental Quality Authority.

c) Service providers which are responsible for operation and maintenance of water supply and sewage collection, treatment and disposal based on the standards set by the regulator (PWA). At the moment, there is one water utility in the Gaza Strip which does this job which is Coastal Municipal Water Utility (CMWU).

There is still no institutional setup to deal with rainwater harvesting and management of wastewater reuse. The role of these institutions is to monitor the systems and assure safe management to avoid health risks. In some countries rainwater harvesting association can play a major role in this aspect than set up guidelines in the national water policy of the country as guiding framework to achieve decentralization, user involvement and public-private partnership, and the association plays the role of a facilitator and not service provider through demand-responsive approach (Baguma et al 2010).

2.1.2 Geography

The Gaza Strip is one of two entities forming the Palestinian Territories (PT). It lies on the southern coastal plain with an area of 365 km^2. It has a length of 46 km north-south and 7 to 12 km wide (Fig.2.1). Its population was 1.42 million in year 2007, and with growth rate of 3.5% it reached 1.6 millions inhabitants (PCBS 2009). Its topographic feature is flat with a maximum height of 80 meters a.m.s.l. The Gaza Strip is located at the south-eastern edge of the Mediterranean and has arid to semi-arid climate having rain in the winter cold months after hot and dry summer season. It receives an annual rainfall fluctuating from 236 mm in the south to 433 mm in the north falling in 40 rainy days from October till April (MOA 2008). The rainfall intensity reached more than 50 mm in the rainy winter season 2002/2003 and 2006/2007, but most of the rain (85%) fell in intensities less than 10 mm/hour (PMD 2007). The thunderstorm rainfalls are responsible for most of the precipitation in the Strip coming from the cyclones crossing the Mediterranean Sea and bringing cold air masses from Europe (Al-Kharabsheh 1995). The average temperature fluctuates from 25 ^oC in the summer to 13 ^oC in the winter with a potential evaporation of 1572 mm per year (Hamdan 1999), and evapotranspiration of 1900 mm per year (WRAP 1994). According to (Seiler and Gat 2007), semi-arid regions are those with annual rainfall more than 250 mm per year and a ratio of P/ET less than 0.5, and consequently the Gaza Strip is considered as arid region in the south and semi-arid in the middle and the north.

Unlike semi-arid regions in North America and north-east Brazil having rain in warm months, precipitation in the Mediterranean region occurs in the cold months, and excess of rainwater for recharge is available to be harvested. However, the deficit in the soil water saturation due to evapotranspiration in the dry month decreases the efficiency of water reaching the groundwater, and consequently recharges favors sites with thin soil layers above rock formation (Seiler and Gat 2007). Vegetations is changing continuously due to urban expansion. The main crops available are palm trees, citrus, olives and seasonal vegetables such as tomatoes and cucumber.

2.1.3 Geology

The ground surface in the Gaza Strip is formed of elongated ridges and depressions parallel to the Mediterranean coast, and it is composed of sedimentary rocks belong to Quaternary Era and divided into two main formations, Holocene at the top is composed of continental alluvial and aeolian deposits called continental kurkar composed of calcareous sandstone (Salem 1963) covered by recent calcareous sand dunes accumulation lying in 1-4 km belt along the coast which is suitable for natural water recharge (Al-Agha and El-Nakhal 2004). The lower formation, Pleistocene is composed of near shore deposits and called marine kurkar. The kurkar deposits are porous, and this makes it important as a groundwater aquifer showing high hydraulic conductivity. The thickness of both formations constituting the Quaternary formation is estimated at 160 meters (Salem 1963), where the kurkar formation is subdivided into sub-aquifers by local aquicludes at the first four kilometers parallel to the coast which are composed of clay and marl beds making confined aquifers. Black shale of 100m of Pliocene age deposits are found beneath the Quaternary sediments and known locally as Saqiya formation (Al-Agha and El-Nakhal 2004) which forms the base of the water bearing layer i.e. the coastal aquifer of the Gaza Strip.

2.2 Water situation

The natural water resource is found in the coastal aquifer which has been over abstracted and polluted due to the increasing water demand that much exceeds the total water supply of the aquifer. The ground water system was controlled by subsequent parties in the last decades, Egyptians, Israelis, share management between the Palestinians and Israelis and finally the Palestinians. Over four thousands water wells are penetrating the shallow aquifer of the Gaza Strip and pump more than its safe yield, which led to negative impact on both groundwater aquifer and consequently on quantity and quality of public water supply.

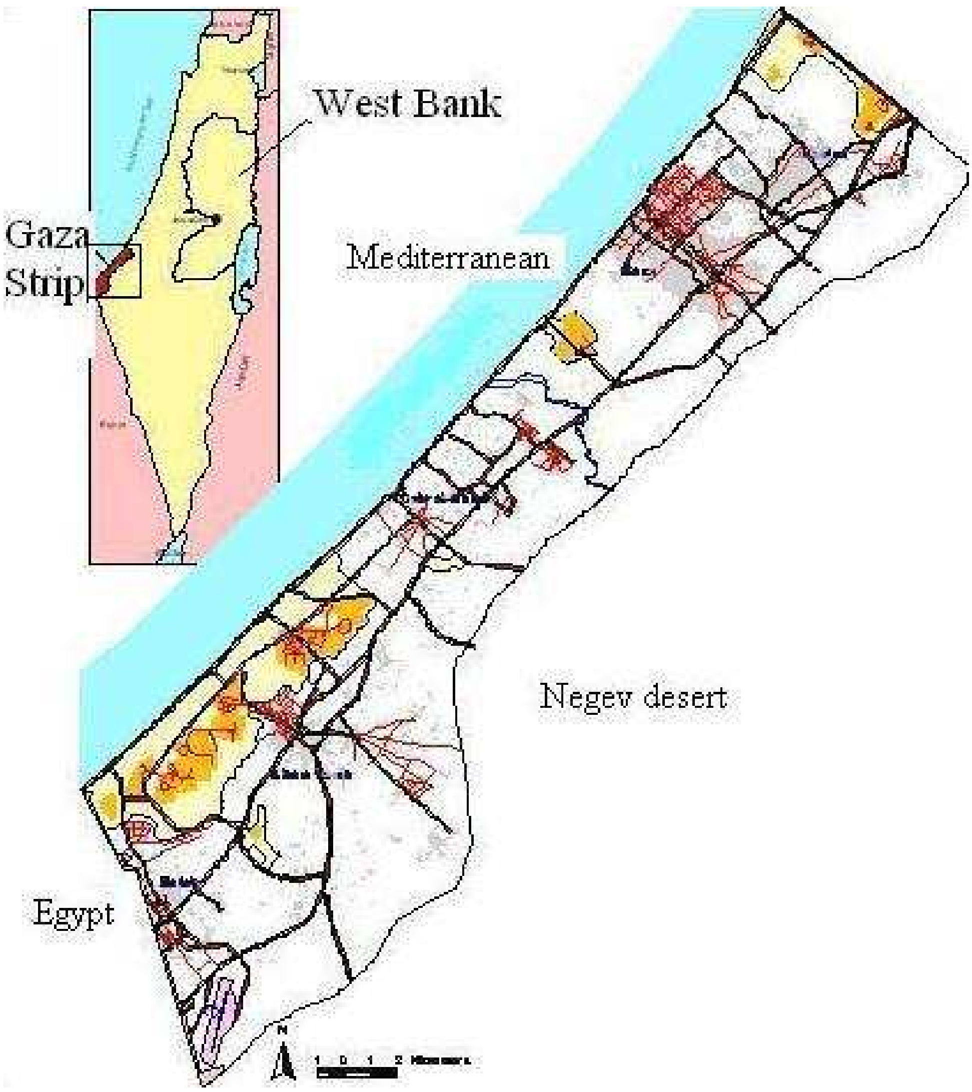


Fig. 2.1 Gaza Strip location map

2.2.1 Groundwater

The Gaza Strip depends mainly on groundwater as a conventional water resource which is replenished from natural infiltration of rainfall that recharges the Pleistocene sandstone aquifer. The depth of the unsaturated layer above groundwater generally increases to the east when going far from the coast. The ground surface has three rising ridges parallel to the coast at distances one to two kilometers apart.

The thickness of the unsaturated layer fluctuates from few meters close to the coast and reaches 80 meters to the eastern border of the Gaza Strip. This thick unsaturated layer gives the chance for purification of infiltrated water either from storm water or treated wastewater through the soil aquifer matrix. The saturated thickness of the aquifer is more than 120 meters at the coast in the west and decreases to the east until reaching few meters at the eastern border of the Gaza Strip. The groundwater generally flows from east to the west since it has a gradient level varied from 0.1% to 0.3% (Melloul et. al. 2006). However, due to over pumping of the aquifer, the groundwater levels reached some meters below the sea level, and groundwater flow direction altered towards the local cones of depressions.

According to pumping tests carried out by the Palestinian Water Authority in 1999, the transmissivity of the aquifer ranged between 705 to 6,000 m^2/day with an average value of 1,850 m^2/day. The average hydraulic conductivity was 55 m/day having a maximum value of 140 m/day and a minimum value of 15 m/day. The thickness of the base layer of the aquifer e.g. Saqeyya layer has a total thickness ranging from 500 meters in north Gaza Strip to 1000 meters in the south (Al Yaqobi and Hamdan 2005).

The average annual bulk amount of rainwater is estimated at 114 Mm^3 using Thiessen polygons and around 15 rain gauge stations distributed over the Gaza Strip (PWA 2005). From this bulk amount, only 45 Mm^3 infiltrate to the aquifer and the rest either evaporates or runs to the sea. The domestic water supply in the year 2005 was estimated at 76 Mm^3 (PWA 2006). But due to population growth, current domestic supply is estimated at 85 Mm^3/year, and the total agricultural consumption is almost constant throughout the last years and estimated at 75 Mm^3 (PWA 2006). This leads to a total water demand of 160 Mm^3 for both uses. The over all supply of the aquifer comes from rainfall natural infiltration (45 Mm^3), subsurface groundwater flow from east south (10-20 Mm^3) with average value of 15 Mm^3/year, irrigation return flow (20 Mm^3) and seepage of wastewater through septic tanks (30 Mm^3) leading to total aquifer inflows of 85 Mm^3. This leads to an annual deficit in the water budget of about 50 Mm^3 according to the water balance equation shown below, and this urges us to find other new water resources.

∑ **Total inflows =** 45 + 15 + 20 + 30 = 110 Mm3

∑ **Total outflows** = 85 + 75 = 160 Mm^3

Water balance = ∑ total inflows – ∑ total outflows

Water balance = 110 - 160 = - *50* Mm^3 every year.

The negative water resources balance is compensated with upconing of deep saline groundwater and seawater intrusion which had their impact on the ground water level that reached more than eight meters below a.m.s.l. in some areas (fig 2.2). This is clearly found in the south west of the Gaza Strip where relatively high abstraction is practiced and less amount of precipitation falls.

The groundwater quality was deteriorated too, where concentrations of chloride and nitrate ions exceeded the standards of WHO in most areas. Chloride ion exceeded 1500 p.p.m. in some areas (fig 2.3). The problem is growing and water deficit is increasing with population growth with the limited water resources, and consequently the water quality is deteriorated dramatically. According to the chemical investigation carried out by (Al-Agha and El-Nakhal 2004), groundwater has twp types of water, type I ($Ca+Mg–CO_3+HCO_3$) which is alkaline in the western parts of the Strip, and type II ($Na+K-Cl+SO_4$) which is saline water in the eastern parts.

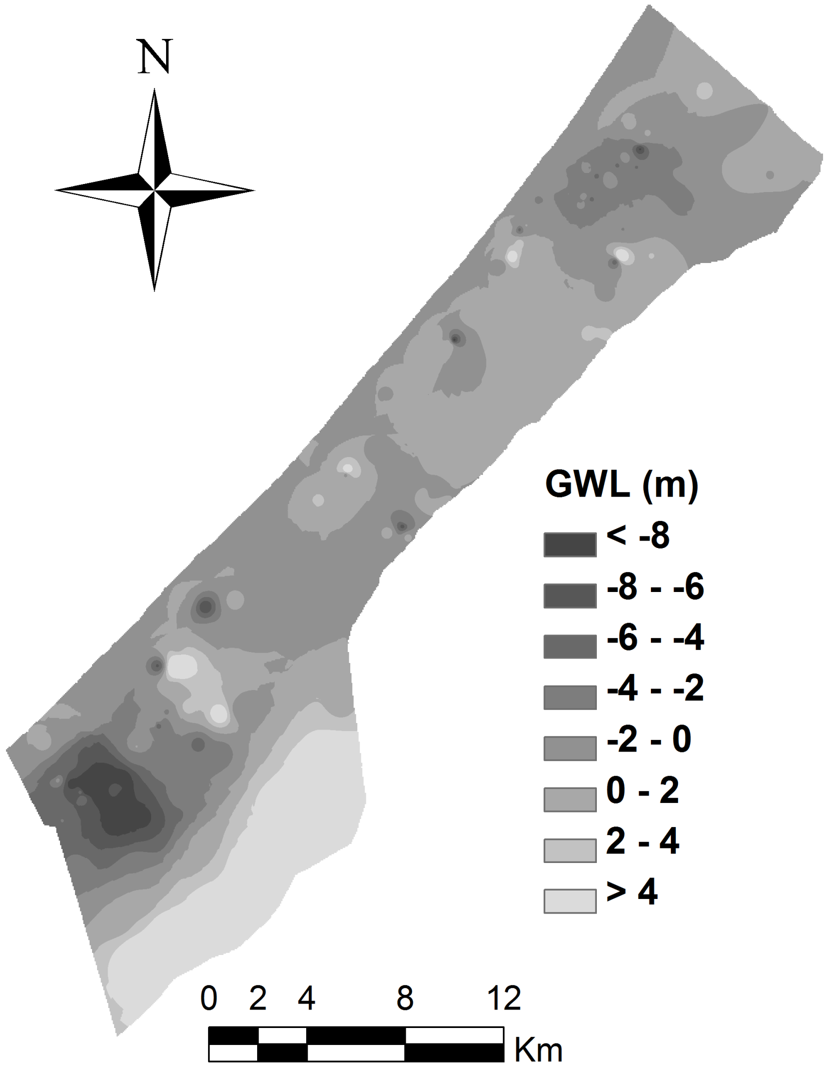


Fig. 2.2 Groundwater levels in the year 2008

Nitrate concentration is increasing continuously due to two main reasons, firstly intensive application of fertilizers in agricultural areas, and secondly seepage of raw sewage from areas not served with sewers pipes networks. Nitrate levels reached more than 400 mg/l in some areas in the north an south of the Gaza Strip (fig. 2.4).

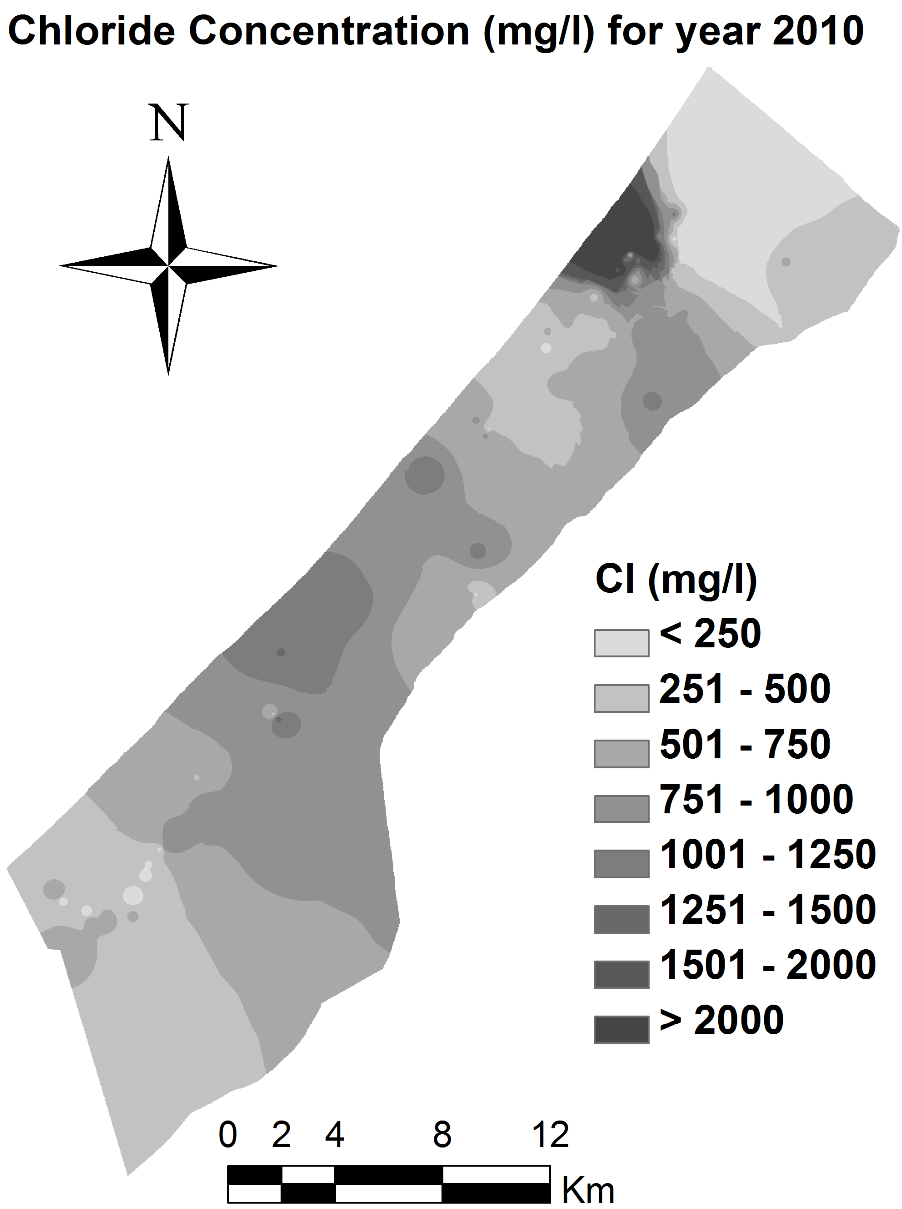


Fig. 2.3 Chloride ion concentration

The fresh groundwater typically occurs in the form of lenses that float on the top of the brackish and/or saline ground water, which means that approximately 70% of the aquifer is brackish or saline water, and only 30% of groundwater is fresh. This in turn threatens the aquifer to diminish if no appropriate integrated planning and management actions are taken immediately.

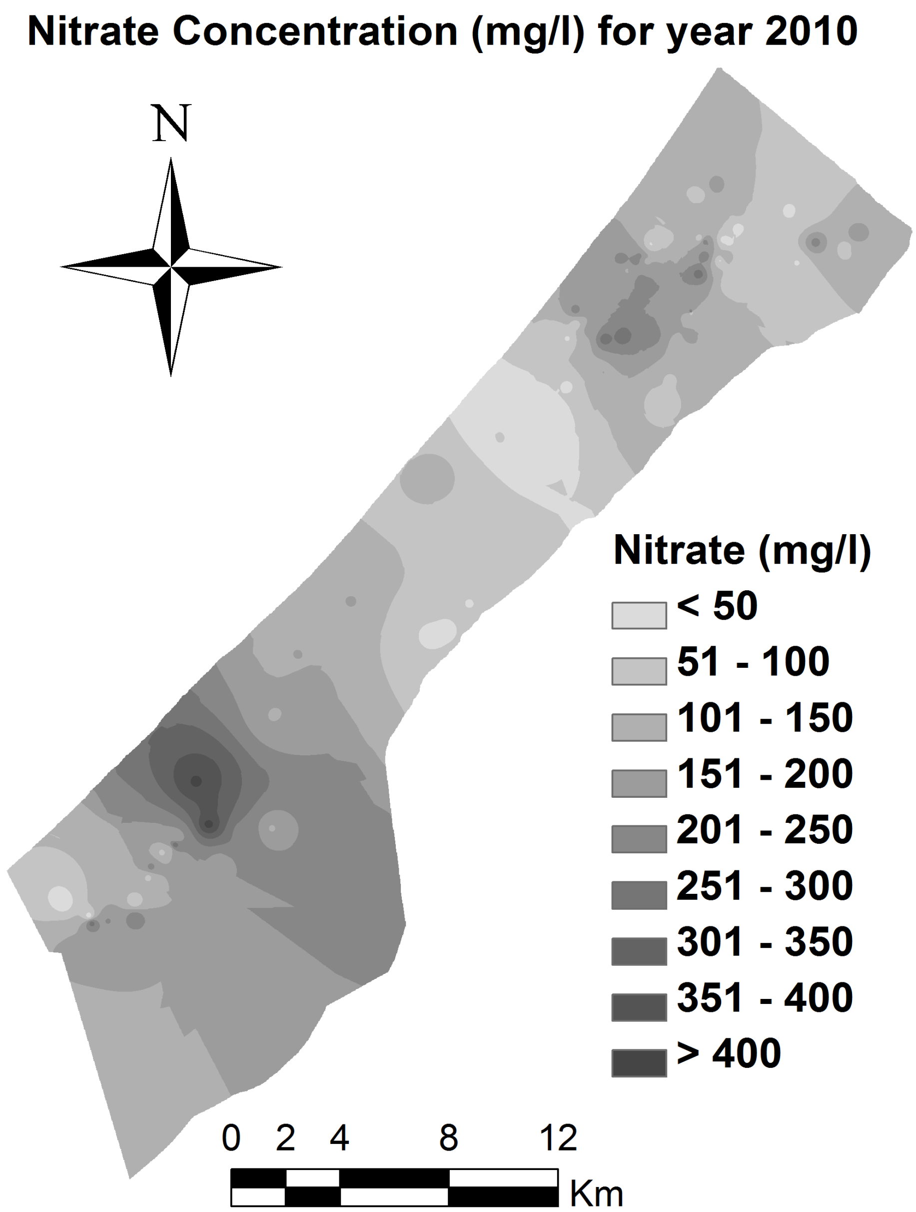


Fig. 2.4 Nitrate concentration

2.2.2 Water Supply

The deterioration of groundwater quality due to negative balance in the water budget has resulted in a bad public water supply in both quantitative and qualitative aspects. The whole Gaza Strip suffers from intermittent water supply, where water is supplied for limited hours every day or every two days.

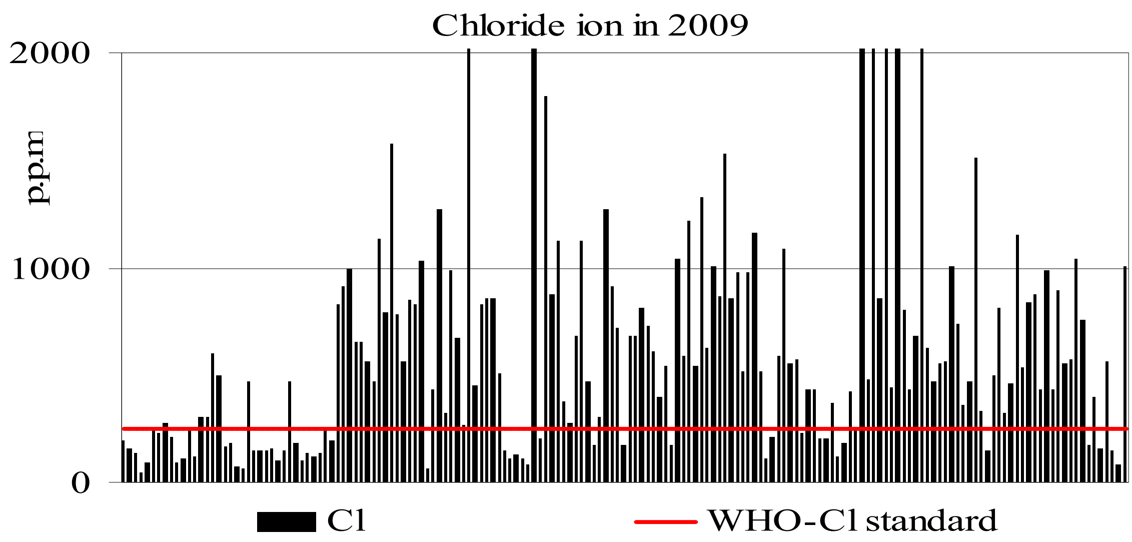


Fig. 2.5 Chloride levels in domestic water wells

Despite the low per capita water consumption, the quality of the domestic supplied water does not meet the internationally accepted guidelines for domestic supplies which creates significant public health issues such as kidney disease and blue baby syndrome due to the high nitrate levels.

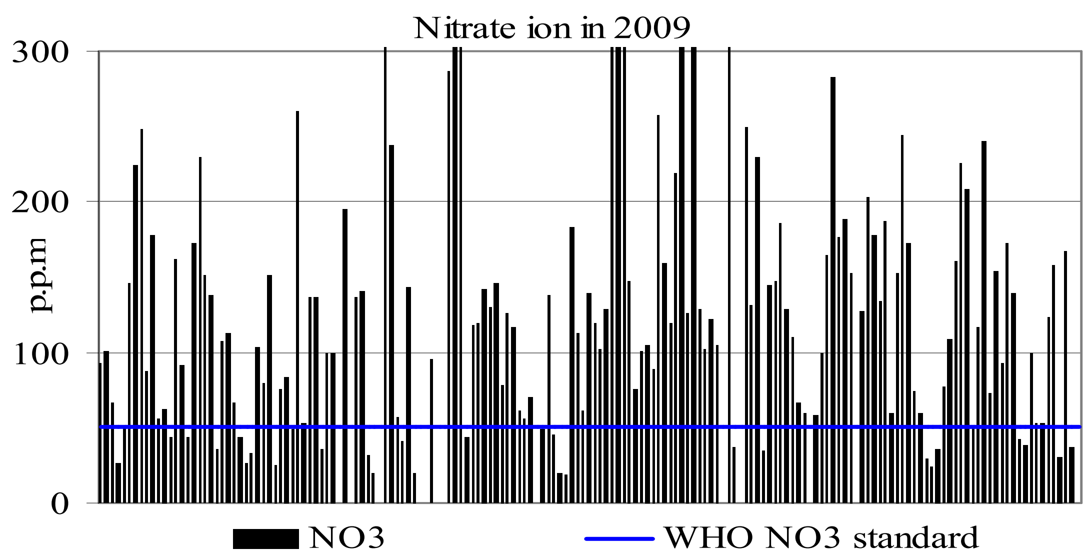


Fig. 2.6 Nitrate levels in domestic water wells

The total consumption of public water supply is estimated at 85 Mm^3 every year i.e. an average daily consumption of 140 l.c.d. The chloride ion nitrate ions concentrations of water pumped from domestic water are shown in (fig 2.5) & (fig

2.6). These values much exceed the acceptable WHO limits which are 250 p.p.m for chloride and 50 p.p.m for nitrate.

2.3 Non Conventional Water Resources

Scarcity of water resources and increasing water demand and fixed supply of the groundwater system in Gaza, are the main reasons to look for new non-conventional water resources to fill the gap in the water resources budget and keep the environment and natural resources in a sustainable case. The potential resources could be used are seawater desalination, wastewater reuse and storm water harvesting.

2.3.1 Desalination

Desalination became a strategic option in scarce water countries with less negative environmental impact. Its cost in large scale desalination plans competes with other non-conventional water resources. This technology has been practiced in the Gaza Strip since 20 years, where four small scale brackish groundwater reverse osmosis (RO) desalination were constructed on water wells with a capacity of 45 m^3/hour each in the years 1991, 1997 and 1998 (Baalousha 2006). Another small seawater desalination with a capacity of 2400 m^3/hour has been built and operated in the year 2003. Large scale project was planned but implementation has been suspended due to politics and fund freezing which made this strategic option not functioning. The cost of RO sea water desalination depends mainly on the size of the plant, operation hours per day, power cost and labor cost. The operation cost of RO seawater desalination in the Gaza Strip for a plant produces 2400 m^3 every day at its full capacity operation was estimated at 1.25 USD per cubic meter (Al Sheikh et. al. 2004).

The planned amounts of water resources from seawater desalination are estimated at 55 Mm^3 in the year 2020 (Metcalf & Eddy 2000). However, large scale desalination plants to participate in solving the problem in the water resources budget does not come in effect due to several reason such as high capital and operation cost, politics and deficit in power from which the Gaza Strip suffers most of the times.

In addition to the existing medium-scale desalination plants, there are small ones that sell desalinated water with tankers to consumers. There are about 20 small commercial plants producing desalinated water of quantities fluctuating from 20 to

140 m^3/day, and quality that fits with WHO standards except for biological results, where biological contamination was found in produced desalinated water more than that in raw tap water (Aish 2010).

2.3.2 Wastewater Reuse

Significant amounts of domestic wastewater are discharged to the sea after partial treatment. The sewer network coverage in the governorates of the Gaza Strip fluctuated from 40% to 90% (CMWU 2010) with a weighted average of 71% (table 2.1). The potential quantities for reuse are about 109,000 m^3/day i.e. 40 Mm^3 every year are available as new non-conventional water resources, and these quantities will increase with the increase of sewered areas.

The wastewater is still partially treated, where influent BOD value in Gaza treatment plant in year 2008 was 485 mg/l and was treated to reach 123 mg/l with a removal efficiency of 73% (CMWU 2010). Many studies have demonstrated that a combined approach of recharge and irrigation of treated wastewater is the most effective option for reducing the water resource deficit in Gaza, and aquifer recharge has been identified as a crucial component of effluent reuse strategies (KFW 2005). However, treatment of wastewater to the level suitable for reuse needs capital investments, active institutional setup and skilled water operators.

Table 2.1 Wastewater quantities in the Gaza Strip*

Governorate	Population	% served areas with sewer network	Quantities (m^3/day)
North	300,150	80	20,000
Gaza	569,250	90	60,000
Middle	227,700	55	10,000
Khan Younis	289,800	40	9,000
Rafah	191,500	65	10,000

Weighted average served areas = 71%

Total production= 109,000 m^3/day

* CMWU 2010 databases

The potential annual amount of reused wastewater could reach 60 Mm^3 in the year 2020 (Metcalf & Eddy 2000). According to (KfW 2005), 40 Mm^3 per year based on 110,000 m^3 per day could be infiltrated in the zone of Gaza City and Middle Area of the Gaza Strip. Conventional treatment facilities consisting of primary treatment, biological treatment and clarification processes have limitations in removing the biodegradable organic matter, fine colloids and some dissolved inorganic matter (Huang et al. 2006). Although soil can absorb most of soluble pollutants in the reclaimed wastewater, it should be further treated before irrigating crops to avoid risks to public and environment (Choukr-Allah 2011). To meet the standards of wastewater reuse and recharge, more advanced treatment such as ozonation before recharge to the soil aquifer treatment processes, where degradation of dissolved organic carbon (DOC) decreased from 23% to 48% in SAT when an ozone dosage of 0.7mg O_3/ mg DOC was applied assuming retention time of five days (Drewes and Jekel 1996). Other advanced treatment tested by (Huang et al. 2006) showed that coagulation- air flotation filtration processes can remove residual organic matter at efficiencies of 50%, 39%, 50% and 80% for COD, BOD, NH3_N and SS at costs less than water desalination or water transfer from long distances.

A case study of application of reclaimed wastewater has been conducted in the Gaza Strip, where 10,000 m^3 were applied daily to three infiltration basins, and the water quality of neighboring groundwater wells were monitored. There was impact on groundwater aquifer in both groundwater levels and groundwater quality which was described in (Paper VI). At the moment, aquifer recharge by treated wastewater in Gaza City area is not acceptable due to high nitrogen content in the effluent, 25 mg/l (KfW 2005), which is higher than total nitrogen in the native groundwater in the area. Irrigation with treated wastewater in Gaza is still subject to major concerns because of potential hygienic and environmental problems (Yassin et al. 2008).

2.3.3 Rainwater Harvesting and Stormwater Availability

Stormwater management has the advantage of harvesting runoff as a new water resource and decreasing the peak flow of street runoff that accumulates in the depressions and blocks the movement. In developed countries it is used as a means toward reducing the peak flow to treatment plants that receive both wastewater and stormwater through combined sewers.

In the Gaza Strip, the manholes are opened in some cases in the winter season when runoff blocks the streets, and stormwater is connected to the main sewer networks leading to increase in the peak flow and hydraulic load on the treatment plants which are already suffering from hydraulic overflow that much exceeds their design capacity. This results in direct discharge of mixed raw sewage and stormwater to the sea causing environmental hazards.

2.3.3.1 Local Vision

Rainwater harvesting has been identified in the Palestinian national water plan as one of the strategic options of the water resources management in the form of introduction of flood alleviation measures at the source and construction of cisterns for domestic, small scale agricultural and industrial supplementary emergency supplies (NWP 2000). Moreover, it is planned that 7.1 Mm^3 from available stormwater in Gaza Strip will be artificially recharged to the aquifer in the year 2020 (Metcalf & Eddy 2000) which is much less than the potential quantities of available stormwater that reach 28 Mm^3 every year (paper I)

Table 2.2 Maximum hourly rainfall intensity in Gaza city*

	Jan	Feb	Mar	Apr	May	Sep	Oct	Nov	Dec
2002	0	0	14	12.8	19.6	0	54	11.2	19.2
2003	40.4	24.4	16	9.2	0	0	0	4.8	20
2004	20.4	22	9.2	14.4	10.8	0	0	30.4	12
2005	12	8.8	12	1.6	0	0	31.6	34	14
2006	19.2	9.6	16.4	0	0	5.6	66.4	11.6	29.2
2007	22	16	13.2	0.4	0	0	0	0	0
Maximum	40.4	24.4	16.4	14.4	19.6	5.6	66.4	34	29.2

* Maximum intensity mm/hour based on 15 minutes duration measurements

From analyses of the rainfall intensity data collected by the Palestinian Meteorological Department in Gaza city for the period 2002 until 2007, the maximum intensity measured was found to be 66.4 mm/hour in October 2006 (PMD 2007). Other maximum hourly intensities are shown in table 2.2 which are used in the design of the infiltration systems at houses and public areas.

2.3.3.2 Large Scale Stormwater Projects

To mitigate stormwater runoff in cities, large scale projects were implemented in the Gaza Strip. The main three projects are described in this section. Firstly, Sheikh Radwan stormwater collection pool which collects runoff from catchment area of 900 ha in addition to other 950 ha coming through Waqf (Asqola) retention basin. The capacity of this pool is 5,6000 m^3 in addition to 20,000 m^3 could be stored in the incoming box culvert. The infiltration from the lagoon bottom is very little since the bed soil is silty sand, so water was supposed be artificially recharged to groundwater through injection wells, but these wells have never been operated. The collected water is pumped to the sea through 500 m^3/hour capacity pump which is considered as a waste of water resource.

A second large stormwater drainage project was implemented Khan Younis city area to collected stormwater from Khan Younis governorate and divert water through constructed pipes and box culvert to 10 ha infiltration basin to the west of Khan Younis city. However, due to unavailability of sewerage system in the city, local people connected their sewage to the main pipes leading the stormwater infiltration basin leading to more environmental hazards..

A third project was implemented in 1999 in North Gaza to collect the stormwater from Jabalia camp by surface drainage to Abo Rashid pool, and then water is pumped to designed infiltration basins close to the existing wastewater treatment plant in the north. In winter, the basins are used for stormwater infiltration, but in dry summer, partially treated wastewater is pumped to these basins for infiltration to mitigate flooding of wastewater in the existing nearby wastewater treatment plant and collapse of lagoon shoulders.

From the local experience from the large scale projects, it is concluded that difficulties were encountered in the management of the large scale stormwater lagoons to achieve infiltration of clean storm water to the aquifer. The harvested stormwater is either pumped to the sea because of the unsuitability of the basin bottom to allow infiltration, or stormwater is mixed with wastewater or partially treated wastewater to mitigate flooding of wastewater in the streets or in the existing wastewater treatment plant.

2.4 Socioeconomic

In most cases education should be multidirectional dialogue among policy makers, water users, water stakeholders and water experts to understand the multiple dimensions of groundwater problems and management options (Burke and Moench 2000). The responsibility of stormwater management lies on all levels including individual home owner, municipalities and water institutions and water governmental bodies.

After practicing RWH system, people become aware of its importance and willing to adopt it. According to social survey conducted in Satkhira district in Bangladesh by (Karim et. Al. 2005), it was shown that 64% of RWH units were excavated by house owners, 30 % by NGOs and only 4% by their government, in addition people become aware of technical issues. In the same study, most of the people (57%) collect water after 10 minutes of rainfall and 40% of them collect rainwater after five minutes of rainfall, which means awareness of local people about impurities of roof rainwater accompanying the first flush and how to manage it. Education and law enforcement are both needed for controlling stormwater management (Pocono Northeast 2007).

In some countries, short-term priorities for resource exploitation override the need for protection of natural water resources necessary for the long-term, although the communities recognize the need for environment protection. For example, the water used for irrigation is frequently under-priced, and this encourages the inefficient use of water (Howard et al 2006). An important approach to protect groundwater is to deal with water as a commodity and put an economic and social value for the groundwater resources. This will support social and economical development in supporting industry and agriculture, in addition to the value of protection of health and environment through aquifer supply of clean water. Moreover, the value of scarcity is important, when other new water resources are needed such as seawater desalination or import of water from long distance adding to them the political constraints in finding these resources.

To protect groundwater, there should be regulations enable the responsible organization in protecting the water resources. It should have clear mandate including power to inspect and take actions against organizations and individuals who breach the regulations, where this could be branches of civil police as the case in Italy (Chave et al. 2006). The law enforcement and the people's awareness to obey the existing rules are positive steps to start RWH management (Brontowiyono 2008). In Latin America and the Caribbean, the rainwater harvesting projects that operated by local people showed high success than those operated by people foreign to the area, and their success is associated with communities considering water supply as a priority (Osaka/Shiga 1997).

3. Materials and Methods

In this chapter, the potential quantities of rainwater that could be harvested were identified for both urban and rural areas. However, the quality of harvested stormwater is the main issue for adopting this new water resource. A comprehensive literature study of stormwater harvesting based on international experience was carried out, in particular water quality. The available stormwater quantities in the Gaza Strip were quantified, and then rainwater quantities from only buildings rooftop and their yards were quantified too using GIS. After reviewing the international experience of rainwater harvesting, a pilot house rooftop rainwater harvesting was carried out in one of the houses in the middle of the Gaza Strip to quantify the rooftop rain runoff and its onsite artificial recharge to the underground aquifer. Also, the water quality was monitored after runoff over the house concrete roof. The quality of urban stormwater ran over streets and collected in central lagoons was examined too. Socioeconomic study for rainwater harvesting was carried out for two categories of local people, local water resources experts and local house owners. Finally, as comparison with another no-conventional water resource other than RWH, a study of the possibility of recharging the aquifer with treated wastewater and its recovery was evaluated through a pilot project carried out for five years.

3.1 Stormwater Availability and natural infiltration

The groundwater level fluctuations were compared to the natural rainfall fallen in the same zones to examine the response of the aquifer. Using GIS, the potential quantities of stormwater runoff in the whole Gaza Strip were estimated to all types of landuse made by the Palestinian Ministry of Planning.

3.1.1 Aquifer response to natural infiltration of rainfall

The rainfall quantities fallen in the Gaza Strip in the last three decades were analysed, and the capability of the aquifer to response to rainfall infiltration through the soil was also evaluated through monitoring of water table in two wells located in two different areas, in the north and the south. Groundwater level fluctuation in these two wells was studied together with rainfall at the same time.

3.1.2 Quantification of stormwater runoff

Stormwater quantities in the Gaza Strip were estimated based on the rational formula for runoff. Different landuse and soil types categories available in Gaza were harmonized with those values found in (Kiely 1996) to use runoff coefficient. Using Thiessen polygons, the Gaza Strip was divided into seven geographical zones (fig. 3.1), where daily rainfall records are available for more than 30 years for each zone. Using GIS, areas of all types of landuse derived from areal photos were calculated, and then stormwater quantities were estimated for existing and planned landuse. The available stormwater quantities from both urban and rural areas were estimated too.

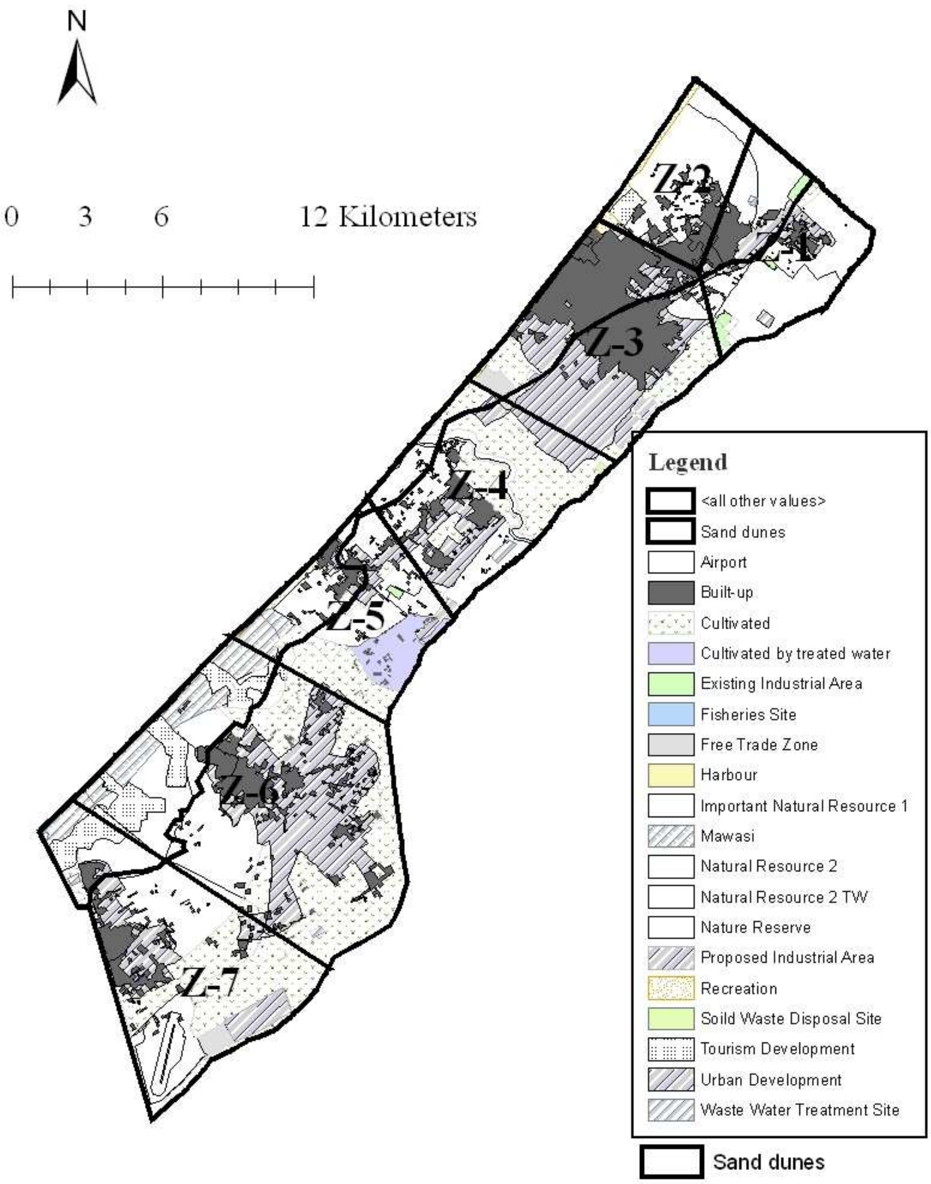


Fig. 3.1 Geographical zones used for stormwater quantification

3.2 Literature Study of Rainwater Harvesting

A literature review study was carried from resources in the internet and the libraries in Germany. The bases of RWH systems were reviewed in countries implemented this technique long years ago, and lessons were learnt in stormwater harvesting. The research was presented in detail and published in (Paper II).

3.2.1 Historical Background

Rainwater harvesting is known since thousand of years in many regions in the world. It has been practiced in the Middle East, North Africa, Mexico and southwest USA. The historical and international experience in stormwater harvesting using new technologies for years was studied in this literature based study.

3.2.2 Quality Risks of using Stormwater

Pollution coming from industrial areas and fuel stations are major sources that endanger the quality of stormwater. The study deals with methodologies used to control stormwater runoff quality through pretreatment or diversion of extremely polluted stormwater away to sewage networks before mixing with the main stormwater collecting system, and how these extremely polluted sources are treated all the year as first flush stormwater that should always be diverted away from the stormwater harvesting system.

Many studies examined water quality issues relating to stormwater runoff dealing with major cations and anions, organic matter and heavy metals such as Cd, Zn, Pb, Fe, Cu and Al. According to field study carried by (Karim 2010), it was found that low to medium risks of contamination, and non of the investigated RWH systems fell into high to very high risk category. To get close to the problem, the change of water quality through runoff over different types of roofs and road was searched. The quality parameter studied were compared with the quality of the pure rainfall fallen in these areas of the world.

3.2.3 Experiences in Specific Countries

Quality of roof and urban roads runoff was tackled in international scale such as Australia, Bangladesh, Greece, USA, Germany and Japan. Case studies were presented in the literature study from different countries such as Australia, Bangladesh, Germany, Greece, Japan, Palestine and Unites States.

3.3 Onsite Recharge of Rooftop Rainwater

Quantities from buildings roofs and their open yards are estimated based on three parameters which are, firstly total areas of roofs and open yards belong to buildings, secondly runoff coefficient of local concrete roof and finally average rainfall measured. The first parameter was estimated using ArcGIS, where the areas of roofs and yards belong to buildings in urban areas were known. The second parameter was measured through an experiment which was carried out at a concrete roof of one house. Then, the third parameter was reached based on the average annual rainfall in the five governorates of the Gaza Strip recorded in the last ten years from 1998 until 2007. These three parameters were used in the rational formula (1) to estimate the stormwater coming from roofs and yards and could be onsite recharged to the underground aquifer.

*Roof Runoff = Roof area * Roof coefficient (efficiency) * Rainfall head* ………. (1)

3.3.1 Estimation of Areas of Roofs and Yards in Urban Areas

As preceded in section 3.1 and published in (Paper I), quantification was made for the potential stormwater runoff in the whole Gaza Strip including, roofs, yards, agricultural areas, urban and rural areas. In this section, quantification of stormwater from only roofs and yards belong to buildings in urban areas were calculated. ArcGIS- Spatial Analyst extension was used and dealt with the aerial photograph of the Gaza Strip and created a drawing of all polygons representing roofs and yards. The Gaza Strip has five governorates, North, Gaza, Middle, Khan Younis and Rafah. Statistics for each governorate was displayed showing the count of buildings and yards in addition to their sum of areas and other statistics. Fig. 3.2 shows statistics made by ArcGIS for Gaza city roofs and yards. The same procedure was repeated individually for each of the remaining four governorates. The areas obtained were used to estimate the potential stormwater runoff delivered from only roofs and yards using the runoff coefficient obtained from the measurements made at the pilot house roof located locally in the middle of the Gaza Strip.

3.3.2 Estimation of Runoff Coefficient of Local Roof

An experiment was carried out at one house with a roof area of 236.3 m^2 in the middle of the Gaza Strip. Fig. 3.3 shows a schematic sketch of the experimental pilot house, where a drilling machine was used to drill two boreholes of a diameter of 60 cm each (fig. 3.4). A clay layer of thickness of about six meters was removed until the permeable layer named locally Kurkar or sandstone was reached (fig.3.5). A new water collection system including new pipes of 75mm diameter and a storage tank were constructed. The four outlets gutters of the pilot house roof were connected together with one common outlet pipe of 75 mm diameter too. The common outlet pipe is going down a plastic storage tank of 500 liters volume. Then, the collected rainwater in the tank flows from the tank through an outlet located at an elevation of 350 mm above the floor of the tank to allow for sedimentation of suspended solids accompanying rain runoff (fig.3.6).

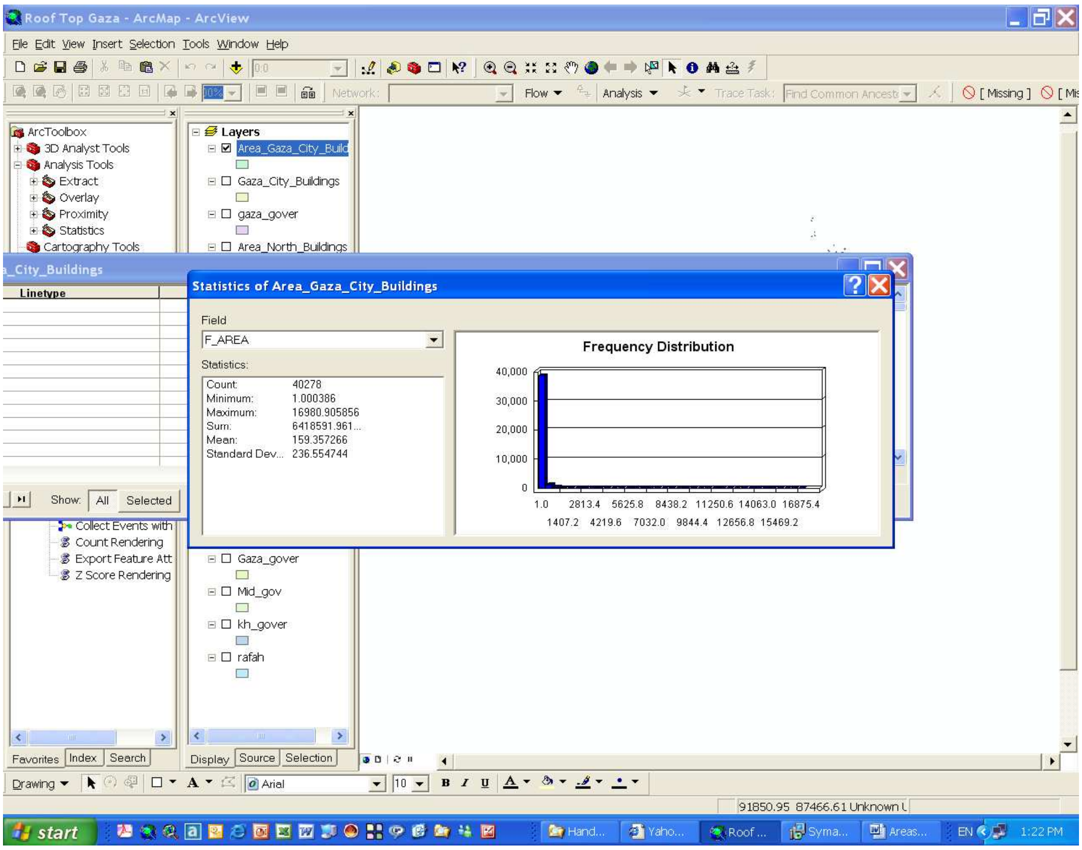


Fig. 3.2 Statistics of rooftop and yards in Gaza City

A rain gauge to measure rain intensity was installed on the house roof (fig.3.7), where readings were taken every fifteen minutes when it rains. The roof runoff was collected to one down pipe and water flow was measured by two inches flowmeter (fig.3.8) which was installed at the pipe between the tank and the first infiltration pit. After passing the flowmeter the collected rainwater flows toward two infiltration pits of 60 cm diameter connected to each other with three inches pipe. Fig. 3.9 shows picture of the first infiltration pit with a depth of about one meter. The bottoms of the infiltration pits are filled with gravel layers of 15 cm thickness. When the first pit is overflowed, the excess water flows to the second pit.

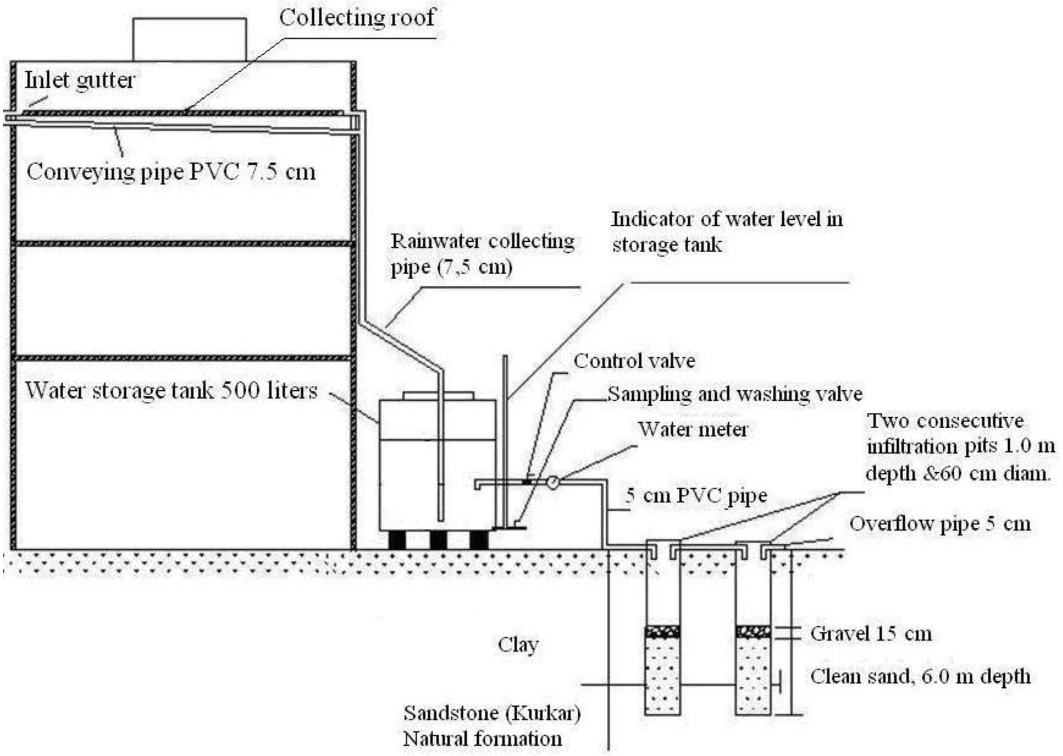


Fig. 3.3 Schematic sketch of the pilot roof

Then the flowing rooftop rain runoff amounts measured by the flowmeter was compared to the falling rainfall intensity measured at the same roof to estimate the efficiency or runoff coefficient which is the second factor or parameter discussed in section 3.3. Runoff coefficient or efficiency is obtained from the following equation:

*Efficiency =[measured rain runoff flow /(measured rainfall * roof area)]*100 %* ..(2)

Fig. 3.4 Drilling for infiltration pit close to pilot house

Fig. 3.5 Drilled borehole (8 m) depth until Kurkar (sandstone) layer reached

Fig. 3.6 RWH unit of the pilot house

Fig. 3.7 Installed rain gauge on the house roof

Fig. 3.8 Flowmeter between storage tank and first infiltration pit

Fig. 3.9 Infiltration pit for rooftop rainwater

3.3.3 Average Annual Rainfall in Governorates

This is the third factor used in the estimation of rooftop quantities which is the average annual rainfall that falls in each of the five governorates in the Gaza Strip and shown in table 3.1.

Table 3.1 Average Annual Rainfall in Gaza Governorates (1998-2007)*

Governorate Name	North	Gaza	Middle	Khan Younis	Rafah
Average (mm/year)	433	437	349	252	236

*Based on MoA 2008

3.3.4 Rooftop and Yards Water Availability for Infiltration

The runoff coefficient of the roof is calculated as:

C = DV / BV ……………………………………………………... (3)

DV = Drained volume of rainwater passing the storage tank and measured by flowmeter
BV= Bulk volume which results from multiplication of pilot roof area of 236.3 m^2 and the rain head of the storm measured by the rain gauge at the same roof.

The roof runoff was measured for each rainstorm and compared to the rainstorm amount itself. Then the weighted average efficiency of the roof was used as the second factor to estimate the collected runoff in all governorates of Gaza Strip using ArcGIS.

3.3.5 Measurement of Onsite Infiltration Capability

To test the possibility of onsite rainwater harvesting through artificial recharge, two boreholes were drilled in the corridor around the house. The soil cover was impermeable clay layer of depth 6 meters, so the two boreholes were drilled up to 8 meters depth to reach the permeable sandstone formation locally called Kurkar.

Then, the boreholes were filled with clean permeable loose sand until one meter deep from ground surface. Concrete rings of 60 cm and thickness of 5 cm were laid at the top one meter, where clean sand was filled in the space surrounding them. Gravel was placed to occupy 15 cm at the bottom of the infiltration pits. A pipe of 5 mm diameter conveys water from the storage tank to these two infiltration pits.

Infiltration measurements were made at the pits themselves in the same pilot house. The heads of water in the infiltration pits were measured versus time passed. When the water head reached 20 cm in the pit, it is refilled again through a control valve in the pipe between storage and flowmeter. When the head reaches 90 cm, measurements are taken again. Infiltration tests were carried out in the infiltration pits at the end of the rainstorms, where water head loss in the infiltration pit was measured against time. Due to decrease of infiltration capacity, infiltration was measured at different periods in the studied rainy season.

3.4 Quality Testing of Rooftop and Road Rainwater

The change in water quality during its runoff over a concrete rooftop was examined on the pilot house roof, where it is expected that the rooftop rainwater is relatively clean, and the quality is acceptable for many uses with little or even no treatment (GDRC 2007 and Brontowiyono 2008). Potential pollutants arise from air pollution and roof surface contamination, e.g. silt and dust (Bhattacharya and Rane 2007). Heavy metals in water could be adsorbed to the soil particles depending on nature, clay contents and pH e.g. Arsenic is retained by soil at high pH value, where the adsorption characteristics of soil colloids are one of the main mechanisms controlling the mobility of Arsenic in water-soil system (Imamul Huq 2008). To test the hypothesis that rooftop rain runoff is clean and close to drinking water WHO standards (GDRC 2007), samples were taken after each rainstorm exceeding 5 mm. On the other hand, water quality of stormwater running over streets and collected in two large lagoons was examined too.

The chemical analyses were carried out for those samples in laboratories in Gaza and Berlin. The results of chemical characteristics of stormwater from rooftop and central collection lagoons for the season 2007/2008 were presented in detain in Paper III. The studied chemical parameters were chloride ion, nitrate ion, total organic carbon and heavy metals such as cadmium, lead, chromium, zinc, copper, iron and aluminum.

To clarify, the difference in pollution load in rooftop rainwater and street rain runoff, the chemical analyses of stormwater collected from rooftop and streets were compared. Samples from pure rainfall were taken four times in the studied rainy season from a pan situated at the pilot roof (fig.3.10). Roof samples were taken from the sampling point from the collection storage (fig.3.11), while samples of street stormwater runoff were taken from the central lagoons of Asqola and Sheikh Radwan. The later were taken from deep water at one meter away from the gabion boxes as shown in (figs 3.12 & fig. 3.13).

Then, water samples were filtered (45µm) in 100 ml bottles. Two plastic and one glass bottles were made for each sample (fig.3.14). The glass bottle and one of the plastic bottles were sent to the laboratory in Gaza on the same day. The plastic bottle was for analyses of major cations and anions, and the glass bottle was for analyses of total organic carbon as indicator for organic matter (fig.3.15). The sample in the second plastic bottle was preserved by adding some drops of (HCl) acid, and it was put in the freezer. The frozen samples were later transported to the laboratory of TU-Berlin for analyses of heavy metals.

Due to sedimentation on the roofs in the dry period, samples were taken from roof twice for each rainstorm, one at its start and the second at its end. Since the end of the storm is not known, sampling was done continuously for each sub-storm, and the last one was considered as its end. Sampling from storms less than 5 mm was not considered. However, in the studied rainy season, most of rainfall fell in storms more than 5 mm. There were 10 storms with heads more than 5 mm and total of 210 mm. The total rainfall in the season was 221 mm. This means that only 11mm rainfall in the whole season was neglected in sampling.

Fig. 3.10 Pan for collecting pure rainfall

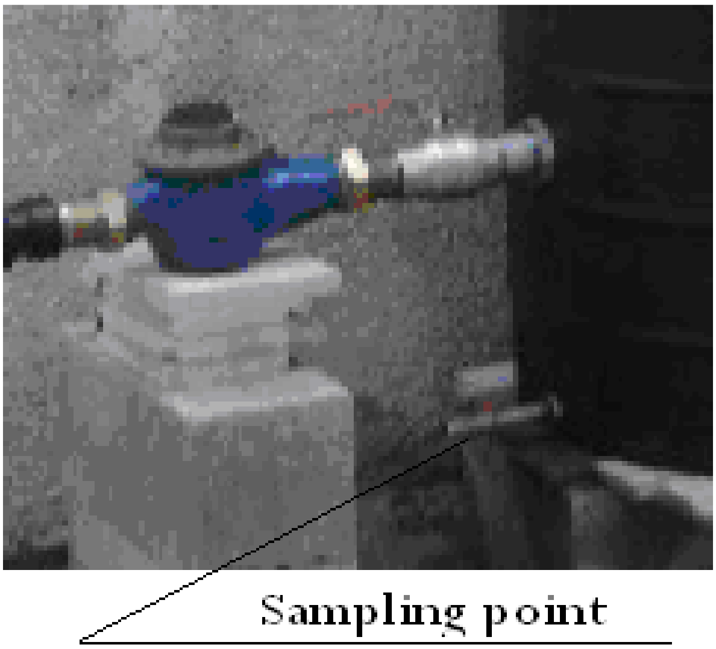


Fig. 3.11 Sampling point of rooftop runoff

The area of pilot roof amounts to 236 m^2. It is from concrete which is typical in the great majority of the Gaza Strip. The roof was not used for growing birds and small animals nor used as storage for non used things. The pilot house was typical for potential houses to be used for RWH. Sources of salinity were expected in the studied roof to come from domestic water tanks which cover all houses of the Gaza Strip due to intermittent public water supply. Another source of pollution may arise from solar heating systems that are manufactured from steel, copper and glass. Other pollution may come from bird drops and air sediments.

Fig. 3.12 Sampling from Asqola pool

Fig. 3.13 Sampling from Sheikh Radwan pool

Fig. 3.14 Preservation of samples

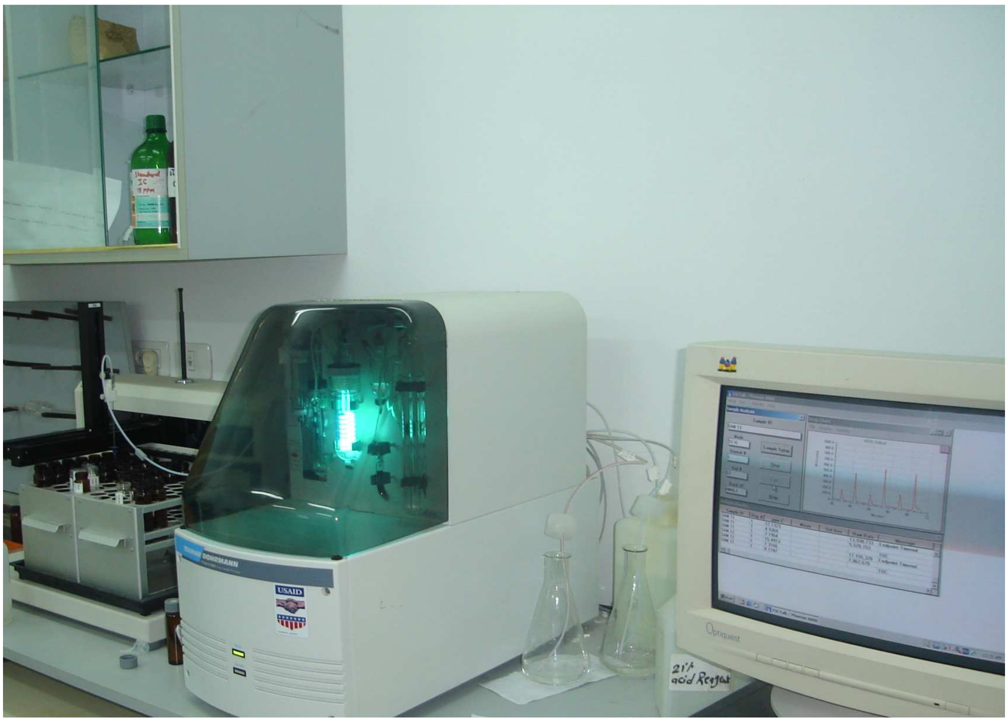


Fig. 3.15 Laboratory analyses of samples for Organic and Inorganic Carbon

3.5 Socioeconomic Survey and Questionnaires

Protection of groundwater resources is a public concern, therefore the public is responsible and its active participation is needed. Rainwater harvesting system has been previously used in the Gaza Strip in two cases, firstly in the form of large central collection lagoons, and secondly in the form of small scale collection from greenhouses in the agricultural areas for irrigation purposes. The new technique of rainwater harvesting, namely onsite rooftop rainwater harvesting was presented to participants from public during this research. As social, cultural and economic considerations play an important role in how this new technology will be adopted, and in how far the new technology fits with the household capabilities, two questionnaires were designed to measure the attitudes of two groups of people who have been identified in this research; water professional who have experience in the water sector in the Gaza Strip, and local people as house owners. The used questionnaires for water experts and house owners are appended in Appendix F.

3.5.1 Local Water Experts

About 40 questionnaires were distributed to the water experts who attended local water resources and wastewater workshops and represented most of the water professional in the Gaza Strip. They work in governmental, international, NGO's and private sector who work in water and environment sector. Respondence came from 25 professionals in the fields of water resources, engineering, environment and the private sector who received English language questionnaires. The questionnaire covered subjects related to experience, satisfaction of water services, methodology of rainwater harvesting according to building type, uses of harvested stormwater, institutional arrangement and methods of RWH units, operation and maintenance. Their experiences ranged from 5 to 25 years.

3.5.2 Local House Owners

For house owners about 200 questionnaires were distributed and directed to all community levels, where questionnaires were distributed to employees, labors, owners of enterprises, activists in sport clubs and random sample in supermarkets and streets. Respondence received from 137 house owners. The sample included different house categories; 62 individual houses in the cities of the Gaza Strip, 33 apartments in tower buildings, 7 houses in villages, 23 houses in refugee camps, 2 factories, 6 hotels and 4 public academic buildings. The sample included 37 one-storey, 42 two-storey, 20 three-storey and 38 four and more storey buildings. It also included different building areas where half of the sample had a building area of less than 200 m^2 with a land area of less than 250 m^2. This questionnaire covered building type and size, area of land and building, number of storey, water sources for drinking and domestic, satisfaction of house owner to the water services; quantity and quality, their wishes to use harvested rainwater and in which purpose, willingness to undertake RWH construction and maintenance in addition to financial contribution to adopt RWH units in their houses. Their willingness to participate in operation and maintenance was also tackled.

Crosstabs

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
type of building * Willing to clean roof	133	97.1%	4	2.9%	137	100.0%

type of building * Willing to clean roof Crosstabulation

Count

		Willing to clean roof				
		Yes every month	Yes according to sediments	Once a year befor winter	Non willing to clean	Total
type of building	apartment in tower	12	15	5	1	33
	single house in city	27	19	9	5	60
	single house in village	4	0	1	1	6
	house in refugee camp	10	5	3	4	22
	academic institution	3	0	1	0	4
	hotel	5	1	0	0	6
	factory	2	0	0	0	2
Total		63	40	19	11	133

Fig. 3.16 Analyses of socioeconomic survey using SPSS

The completed questionnaires were analysed using the Statistical Package for the Social Sciences (SPSS), where an example of SPSS is shown in (fig. 3.16). The results are then transferred to Excel to facilitate the visualization and interpretation of the results. The objective of this study is to test the acceptability of local people and the support of local water experts to adopt RWH in urban areas. After identification of the technical and engineering aspects of RWH, taking socioeconomic factors into account is very important to make any RWH project successful and to ensure beneficiary satisfaction when implementing this new technique.

3.6 Assessment of Recharge with treated wastewater effluent

According to the Palestinian water resources strategy, minimal amount of groundwater will be used for agricultural purposes such as soil flushing and irrigation of high value crops. It is planned that wastewater reuse will be 34 Mm^3 in year 2010 and increases to 63 Mm^3 in the year 2020. Part of the reused amount will be diverted directly to the farms. The quality of treated effluent is still not suitable for irrigating crops if no more treatment is made to reach Palestinian accepted standards before delivering it to the farms.

If no post treatment is made to the effluent, then it will be recharged artificially through infiltration basins and other schemes to undergo Soil Aquifer Treatment (SAT) processes that purify the effluent. To verify this option, a pilot project was implemented jointly by municipality of Gaza, Palestinian Ministry of Agriculture, Palestinian Ministry of health and Palestinian Water Authority. About 10,000 m^3 of treated wastewater effluent from the existing wastewater treatment plant in Gaza was diverted to three spread infiltration basins with areas of 1.1 ha 1.3 ha and 1.3 ha (Paper IV).

The project was operated for five years (2000-2005), where wetting of the basins for one day and drying for two days were made during the operation. The groundwater levels in water wells around the infiltration was monitored and interpreted versus the groundwater baseline before implementation of the project. Water samples were taken from other water wells which are considered as recovery wells. The impact of recharged effluent on the native groundwater was evaluated, where historical data on the existing native groundwater were available. The trend in the changes in parameters such as Chloride ion concentration (Cl^-), Nitrate ion concentration (NO_3^-) and Boron (B^-) in the groundwater were evaluated too.

Finally, socioeconomic aspect was tacked concerning the acceptance of local people for this new resource in relation to their religion and culture taking into consideration the Palestinian water national plan for water resources. Economic review was made for reuse of treated wastewater for both irrigation and artificial recharge of groundwater.

4. Results and Discussion

4.1 Availability of Stormwater in Gaza

There was clear response in the groundwater levels in the rainy season due to natural infiltration. At the same time, the study showed significant amounts of stormwater runoff that did not infiltrate to the aquifer.

4.1.1 Response to natural infiltration of rainfall

The available groundwater system which is part of the coastal aquifer showed fast response to natural rainfall infiltration. In the two studied sites, where sand dune is covering the ground surface, the increase of groundwater level was observed to be around 0.6 meters in the wet months November 2004 to March 2005. However, in the dry season, the decrease in the water table was around 1.5 meters due to groundwater abstraction. This means that the supply to the aquifer is much less than the demand through abstraction. At the same times, there it gives us an indication that, artificial recharge of groundwater with stormwater will have quick positive effect to balance the gab between aquifer supply and demand (Paper I).

4.1.2 Stormwater Runoff Quantities

The available stormwater quantities that flow from the existing urban areas in Gaza were calculated to be 22 Mm^3 every year. Since urbanization in the Gaza Strip is a continuous process, the flowing stormwater quantities from the planned landuse were estimated to be 37 Mm^3 every year (Paper I). The total stormwater quantities from all landuse e.g. urban areas and rural areas are 27.8 Mm^3 in the existing situation and expected to reach 42.6 Mm^3 in the planned landuse (table 4.1). Detailed quantities in the zones one to seven are shown in Appendix A. This means that 78% of stormwater of the existing landuse in Gaza come from the urban areas, and 84% of stormwater in planned landuse come from urban areas. So, urban stormwater management is crucial issue in the water resources management in Gaza.

Table 4.1 Stormwater runoff in existing and planned landuse

Zone number	Stormwater of all existing landuse	Stormwater of all future development	Stormwater of all existing and future landuse
Z-1	2505088	131106	3816104
Z-2	1635648	504113	2139761
Z-3	8096080	5668629	13764709
Z-4	5046782	125817	5172599
Z-5	1858521	548122	2406643
Z-6	4996234	4829861	9826095
Z-7	3701098	1770300	5471398
Total in(m^3)	*27839450*	*14757859*	*42597309*
Total in (Mm^3)	**27.8**	**14.8**	**42.6**

4.2 Literature-Based Study of Stormwater Quality

The literature based study tackled the experience in rainwater harvesting at three aspects, historical background, water quality of harvested stormwater and specific international experience.

4.2.1 Historical Review

Rainwater harvesting was found to be used since centuries in many countries of arid and semi-arid regions until this time, then it was developed as stormwater management and best management practices. It has been practiced in different areas in Middle East, North Africa, Mexico and southwest USA. For example, in South-east Asia, they made small-scale collection of rainwater from roofs and simple dam constructions. In ancient times, rainwater harvesting for water supply was done in perfect ways, where human made the agricultural terracing of hills and water storage behind dams. Rainwater from the roofs was collected into over ground and underground water basins looking like glass bottle with small opening which are easily locked to protect water from external pollution.

In Palestine, rainwater collection systems was known to have existed some 4,000 years ago in the semi-arid and arid regions of the Negev desert, and in Thailand rainwater collection from the eaves of roofs or via simple gutters into traditional jars and pots has been practiced since 2,000 years. Recently, about 40,000 well storage tanks in China were constructed in the period between 1970 and 1974 to stores rainwater and stormwater runoff (Paper II).

4.2.2 Stormwater Quality Risk

The quality of collected storm water depends on many key factors (Paper II) as summarized in table 4.2. Quality of rainfall itself differs from one location to another. In industrial countries, pH value is low due to dissolution of air pollutants resulting from gas emissions. Low pH value facilitates mobility of heavy metal (GDRC 2008), and consequently stormwater treatment through soil infiltration is not efficient. Organic matter in running stormwater depends on the conditions of open catchment area, roofs, yards and roads such as their cleaning and their catchment material itself.

Table 4.2 Factors affecting stormwater quality

Factors	Effect
Rainfall quality (pH), intensity, duration, return period	Transport of air pollution, flushing of roof sediments, mobility of heavy metals in low-pH
Building size, age, location, layout, roof type	Collected stormwater quantities, quality, pH change
Open catchment areas landuse, topography, soil cover	Runoff coefficient, water eutrification
Soil type	Infiltration capacity, stormwater treatment

During the degradation of organic matters, $SO4^-$ is reduced to hydrogen oxide ion (HS^-), which in turn precipitates with heavy metals, and precipitation is retained in the filtering soil. However, in low pH value (pH = 4.5), heavy metals are released again during the oxidation of anoxic sediments (Paper II). In urban areas where stormwater is collected from roofs and city open areas, the quality depends mainly on roof type and geometry e.g. if the roof is declined low pollution occurred in running stormwater.

4.2.3 International Experience

In some countries such at east south Australia collected rainfall is used for drinking purposes after aquifer treatment through artificially recharge and recovery (Vanderzalm et al. 2007). In Greece and Bangladesh harvested rainfall is used for cooking, while in Japan, U.S.A. and Germany it us used for non potable uses such as garden irrigation and toilet flushing. The need for RWH became urgent for water resources management in water-scarce countries. The best management practice is to manage stormwater in different parts in the city in isolation from each other (VANR 2002). Artificial recharge of stormwater to the aquifer through infiltration basins and injection wells are good means of onsite management of stormwater, but maintenance is needed through scraping the top thin layer of the bottom of infiltration basins to remove suspended solids, fungi and bacteria with their netlike surrounding structures (Nilsson 1990).

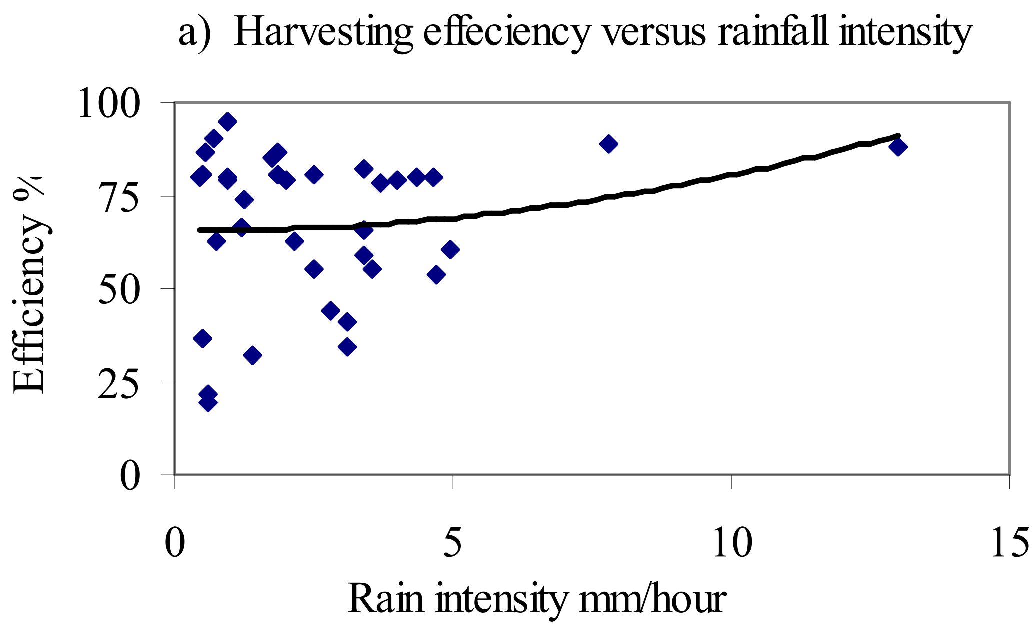
4.3 Rooftop Rainwater Harvesting

The potential stormwater quantities from urban areas in the Gaza Strip including roads, open areas and free zones were estimated at 22 Mm^3 every year (Paper I). From which, 5.2 Mm^3 per year i.e. 24 % of the whole urban stormwater come from roofs and yards belong to buildings. To avoid collection of the whole urban stormwater in central collection lagoons, onsite harvesting of rainfall around houses are promoted. This saves 24% of the whole urban stormwater to be locally infiltrated to the aquifer. A typical experience was found in Delhi, India where runoff from urban areas including roofs, paved areas was infiltrated artificially in abandoned tube and dug wells, trenches and shafts. The groundwater which was declining 0.2 m every year in India increased up to 3.33 m due to harvesting of 3.35 km^2 with average rain of 600 mm (CGWB 2008). In this section, quantities from rooftop and yards belong to buildings in urban areas in Gaza were estimated.

4.3.1 Rooftop Runoff Coefficient

At the rainstorm of up to one mm rain head, there was no runoff and the whole rainfall was absorbed by the roof itself or evaporated. For storm head exceeded one mm, an excess rain was collected as a roof runoff in the storage tank, and this percent (hereinafter called runoff coefficient) of the collected quantity to the whole rainfall fallen increased with the increase of the storm amount itself. For storms of about five mm head the runoff coefficient was found to be (0.4). For storms exceeded 20 mm head, runoff coefficient was about (0.8). In storms with very short duration and high rainfall intensity, the coefficient exceeded (0.9). However the weighted average of group of sub-storms was plotted in the curve and represented by one point as one storm. The whole flow measurements and runoff coefficient (harvesting efficiency) for all rainstorms are shown in Appendix C.

When the quantities of harvested rooftop rainwater were compared to the rainfall intensity, the harvesting efficiency was clearly varying depending on many factors, amongst rain intensity, rain duration and return period. A relationship between the rainfall intensity and harvesting efficiency was plotted for the pilot roof in (fig. 4.1a). The increase of harvesting efficiency was not notable. However, the duration and intensity of the rainstorm forming the storm head was clearly affecting the harvesting efficiency as shown in (fig. 4.1b). This could be explained that a significant amount of rainfall is absorbed by the concrete roof. The absorbed amount affected clearly the efficiency in the short storm duration even the case of high rain intensity. However, when the roof was saturated with water from the previous storms, efficiency was high and reached 88% for rain intensities values of 7.8 and 13 mm/hour.



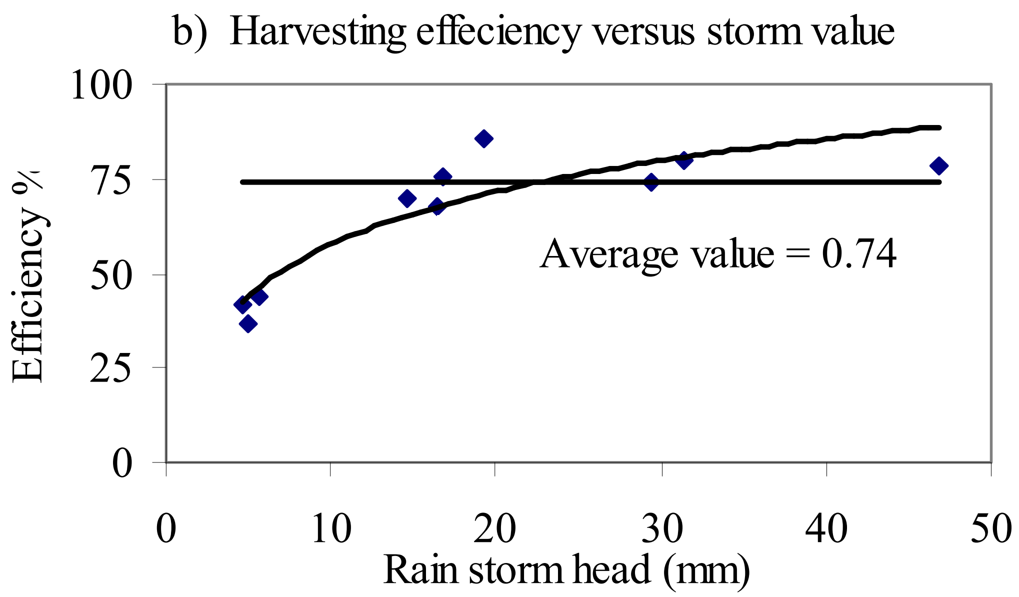


Fig. 4.1 Harvesting efficiency versus storm head and intensity

The weighted average of efficiency of the whole rainstorms was estimated according to the following equation:

Weighted average efficiency = ∑ storm head * efficiency / ∑ storm heads

The average roof efficiency found from the local measured values was calculated to be 0.74 which was used as runoff coefficient in estimating the stormwater collected from roofs and yards in the open areas.

4.3.2 Areas of Rooftop and Yards in Urban Areas

Harvesting of stormwater collected from rooftop and yards can play an important role in the enhancement of groundwater system. Using GIS and areal photos, the area of roofs and yards in five governorates of the Gaza Strip were estimated at 4.57, 6.42, 2.73, 3.40 and 1.61 km^2 for North, Gaza, Middle, Khan Younis and Rafah respectively (table 4.3). Detailed GIS calculations of rooftop and yard areas in the five governorates of the Gaza Strip are shown in Appendix B.

The average rainfall over the last 35 years was 433, 437, 349, 252 and 236 mm/year in North, Gaza city, Middle area, Khan Younis and Rafah respectively. The total stormwater runoff from the roofs and yards in the urban areas in the whole five governorates was calculated to be 5.2 Mm^3 according to the following equation:

Roof and yards stormwater $= \sum C * I * A$

$= \sum 0.74 *$ annual rainfall * roofs and yards area

Table 4.3 Runoff from roofs and yards

Governorate	Area (m^2)	Annual Rainfall (m)	Roof and Yards Runoff (m^3) =0.74*Area*Rainfall
North	4,567,196	0.433	1,483,197
Gaza	6,418,592	0.437	2,075,644
Middle	2,732,254	0.349	705,632
Khan Younis	3,404,840	0.252	634,935
Rafah	1,611,040	0.236	285,154
SUM in (m^3)			5,184,562

The pilot roof is situated in the Middle area which could represent the whole Gaza Strip to find out the runoff coefficient as its annual average rainfall is close to the whole average of the Gaza Strip. The weighted average for the whole rainy season (2007/2008) in the pilot roof was calculated to be (0.74), and this value was used as the runoff coefficient in the above equation to calculate the total storm water runoff in roofs and yards whose areas were calculated from GIS.

4.3.4 Infiltration Capabilities Based on Results of Pilot House

Some large scale stormwater projects were constructed having large infiltration basins for recharging the aquifer. However, many of these projects were very costly and with less efficiency in replenishing the water resources due clogging which was not efficiently controlled. Clogging is faster in case of non-constant head in the infiltration basins and when stormwater contains particles less than 6 µm (Siriwardene et al. 2007). Rainstorms in the Gaza Strip come at intermittent period leading to drying of the basins for long period resulting in quick clogging.

Based on that, onsite infiltration of rainwater became more practical, more economic and easily maintained. At the same time it does not need large infrastructures which are costly in both construction and operation. Rainfall intensity in the pilot house was measured for one rainy season 2007/2008, while intensity data is available for five rainy seasons in Gaza City. Interpretation was needed to identify the range of intensity at which most of rain falls.

The possibility of recharging the collected roof rainwater was tested in one of the two infiltration pits in the corridor of the pilot house using the same stormwater. It was noticed that infiltration capacity of the pit decreased with the decrease of water head above pit floor in all days where tests were carried out. The infiltration rate starts at a value of more than 100 m/day at full head (90 cm) and reached only 10 m/day when the water head in the pit reached 20 cm (fig. 4.2a). Measurements of infiltration rates in the house infiltration pit are found in Appendix E.

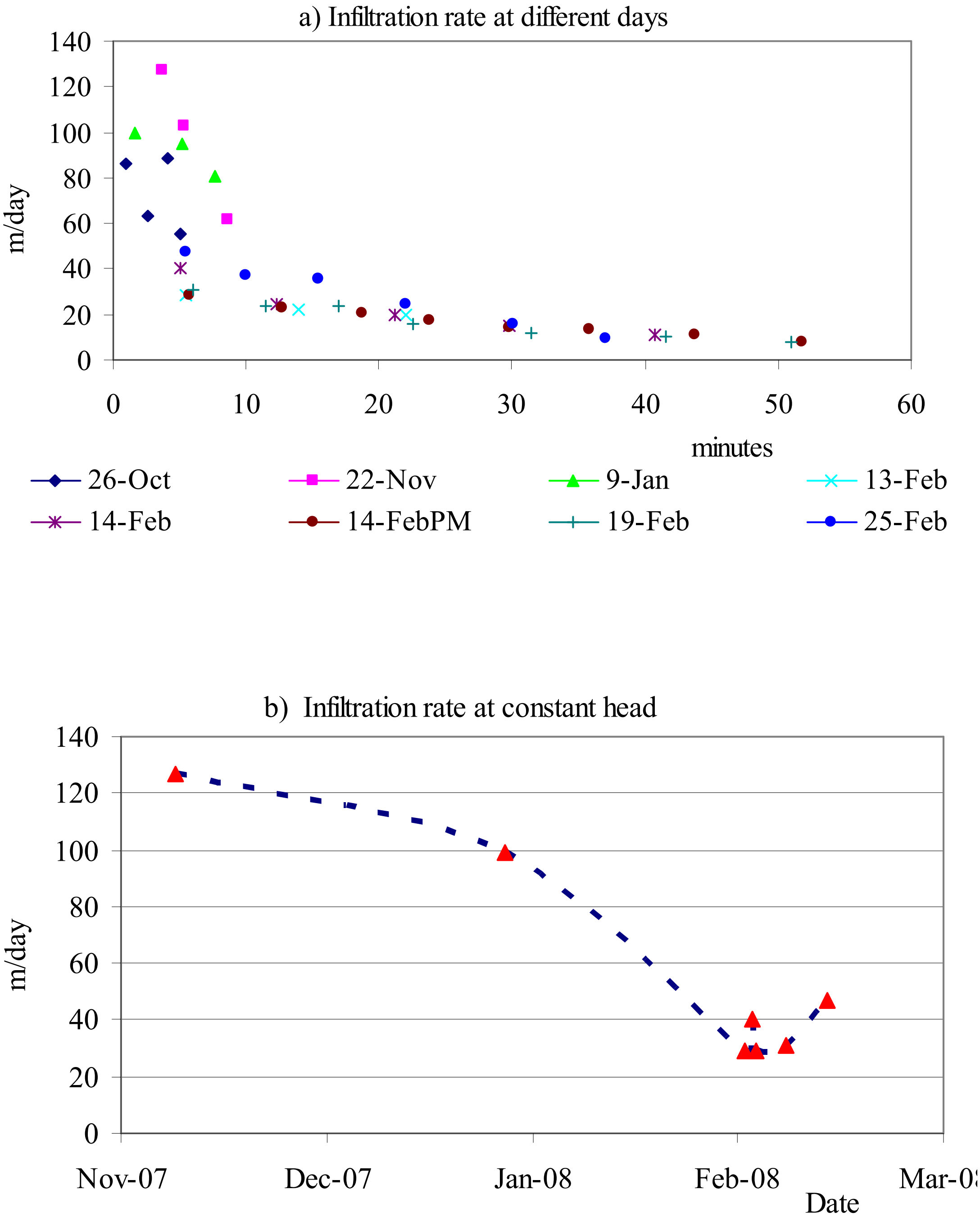


Fig. 4.2 Infiltration rate at recharge pit in the pilot house

Infiltration rates were also measured at a constant head of 90 cm along the experiment period, and the infiltration rate fluctuated between more than 100 m/day at the beginning of the season in November until January and reached steady state values from 25 to 37 m/day in February (fig.4.2b). The steady state infiltration rate values is shown in Table 4.4

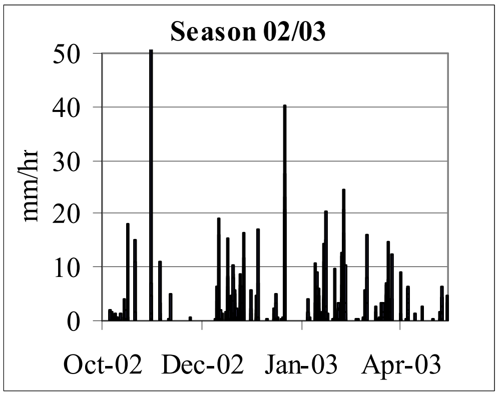
From the analyses of rain intensity and storm heads fallen on the roof, 85% of rain (186 mm out of 221 mm) fell with intensities less than 10 mm/hour, and consequently, onsite infiltration pits could be designed on this basis. Using the same infiltration facility, one-meter diameter infiltration pit is enough to catch rain coming from 100 m^2 of the roof or yard area where RWH is implemented. In this case, most of the rainfall (85%) with intensities less than 10 mm/hour will be onsite recharged to the aquifer. In extreme rain intensities exceeding 10 mm/hour, excess rain will be flooded to the street, where it is caught through urban street catchment system or collected in the central stormwater lagoons.

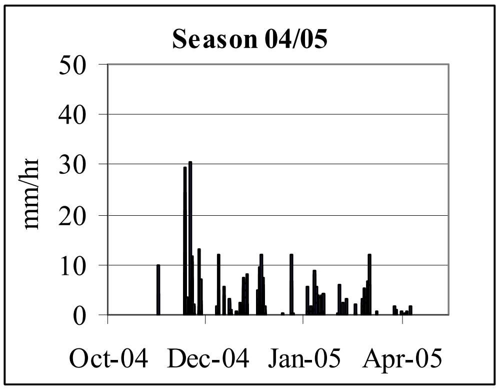
Table 4.4 Measured infiltration rate

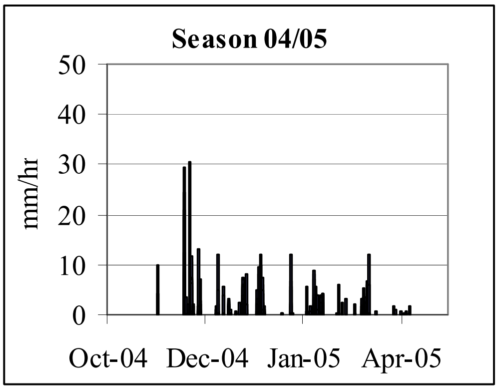
Date of test	13.02.08	14.02.08 6:00 AM	14.02.08 6:00 PM	19.02.08	25.02.08
Infiltration rate m/day	25.5	30	26	26.5	36.8
Average			30 m/day		

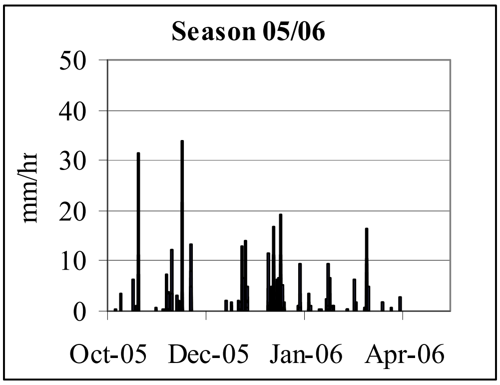
4.3.5 Infiltration Capabilities based on Rain Intensities in Gaza

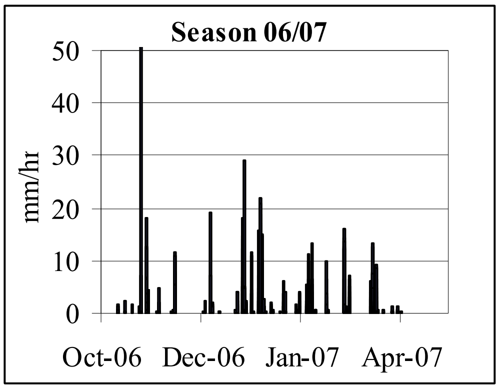
Rainfall intensity data were available at the meteorological station in Gaza city which were interpreted to compare them with the rain intensity data measured at the pilot house roof which is situated in the middle of the Gaza Strip. The rain intensity data available in Gaza city were found for five rainy seasons from 2002/2003 until 2006/2007. The hourly intensities were based on 15 minutes duration. These hourly intensities for the five rainy seasons are shown in (fig. 4.3), where most of the rainfall fell in intensities less than 10 mm/hour. The annual average rainfall in Gaza is higher than that in the middle area where pilot house roof is. The annual averages of rainfall in Gaza and middle area are 437 mm and 349 mm respectively (MoA 2008).











* Based on raw data of PMD 2007

Fig. 4.3 Rain intensities at Gaza city in rain seasons 2002/2003 until 2006/2007*

From the statistics of the rain intensities in Gaza city, onsite rainfall harvesting could be in the range between 85% as in season 2006/2007 and 94% as in season 2003/2004 (table 4.5). If the total rainfall will be harvested onsite, more infiltration pits are needed, and this may not be tolerable for the house owner to allow for the construction of RWH unit around his house. For a typical house in Gaza of an area of up to 300 m^2, construction of three (1.0 m diameter) infiltration pits could be tolerable for the house owner to catch 80-90% of rooftop rainwater.

Table 4.5 Rainfall exceeding 10 mm/hr (15 min. duration)*

Season	Total Rain	Rain with more than 10 mm/hr	# of events	Excess from pits (mm)	Onsite harvesting mm	% harvesting
S 02/03	556.7	162.2	38	67.2	489.5	88
S 03/04	410.9	81.0	22	26	384.9	94
S 04/05	265.1	55.2	13	22.7	242.4	91
S 05/06	240.5	67.4	17	24.9	215.6	90
S 06/07	420.5	164.5	41	62	358.5	85

** Based on raw data of PMD 2007*

With simple calculations, it could be reached that an infiltration pit of 0.8 m^2 area having an infiltration rate of 30 m/d (i.e. 1.25 m/hour) can absorb rain intensity of 10 mm/hour for a roof area of 100 m^2 without storage facility according to the following equation:

*Infiltration area needed = (roof area * rainfall intensity)/ infiltration rate*

Based on that, RWH system could be designed for each house with one circular infiltration pit with a diameter of one meter for every 100 m^2 of the roof area to harvest 90% of rooftop rainwater. According to the experiment carried out on the pilot house roof, it was reached that one infiltration pit of 1.0 m diameter can harvest 90% of rainwater fallen on 100 m^2 of roof area without the need of storage facility. The RWH capacity may decrease in southern Gaza Strip or increase in the north, where rainfall and rain intensity decrease and increase respectively. To harvest the whole amount of rainfall fallen on the roofs, then storage facility or more infiltration pits are needed.

4.4 Quality of Pilot Roof and Road Rainwater

Using rainwater harvesting has been used for drinking purposes long time ago. However due to human interference in the environment, the harvested water became unsafe for direct drinking, in particular with focus on heavy metals, where Arsenic contaminated aquifers affect about 1-2% of the worlds population, and it is generally bounded to iron Fe(III) minerals (Hohmann et al. 2010).

The chemical constituents of rooftop rainwater are relatively good comparable to the quality levels of drinking water according to WHO guidelines (GRDC 2007). The quality of rooftop rainfall collected from the pilot house in Gaza proved to be suitable for artificial recharge of groundwater (Paper III) and close to the drinking water standards in terms of major anions and cations as shown in table 5. PH value tends to acidity in the pure rainfall (6.57) while it becomes alkaline in the collected rooftop water (7.48) due to dissolution of roof sediments. Chloride and nitrate average values were 100 and 14.9 mg/l respectively which are much less than WHO standards (250 mg/l) for chloride and (50 mg/l) for nitrate.

According to the scientific researches done on the first flush, it became a scientific fact to consider the first flush as the first 10 mm of the rainfall (K.R.G.2007). However, in the semiarid region such as Gaza Strip, where rainstorms are separated by dry periods, and in this case first flush is applicable to each rainstorm. When diverting 10 mm of each storm, this will significantly decrease the amounts of roof and yards rainwater that could be utilized. So it is recommended to clean of the roof and yards periodically instead of diverting the first flush for each rainstorm.

Although rainwater from well maintained roof catchments is usually clean, rainwater from ground catchment systems is not recommended for drinking (FAKT 2011). Chronic intake of arsenic causes severe health problems like cancer and skin diseases such as black foot disease (Kapler et. al. 2010). To protect water quality, good system design and operation and maintenance are essential. When the collected rooftop rainwater is intended to be artificially infiltrated to the aquifer, this gives the chance for infiltrated water to be treated during its passage in the soil aquifer matrix. The treatment can be physical, chemical and biological including filtration, sorption, transformation and degradation. Adsorption and surface precipitation are the most important processes related to soil and groundwater (Lindberg 1990 & Ahuja 2008), where adsorption is the main process in the removal of heavy metal in addition to chemical precipitation (Papers III). Rainwater and surface water have very low and undetectable limits of Arsenic less than 1µg/l to 2 µg/l, and the aquifers which are replenished by rainwater and surface water have arsenic contents with the acceptable levels (Ahuja 2008). From experimental measures, organic matters are degraded during soil infiltration, and removal reached 60% for TOC and 70% for COD (Lehtola et al. 1996).

Moreover, heavy metals such as Zn and Pb could be treated through simple and sustainable technology through the use of addition of carbon and sulphate sources in the infiltrating rainwater if soil is conditioned with sulphate reducing bacteria SRB (Rafida and Sallis 2011) according to the following general reactions:

$$\text{Organic matter} + SO_4^{2-} \xrightarrow{(SRB)} S^{2-} + H_2O + CO_2$$

$$S^{2-} + 2H^+ \rightarrow H_2S \text{ (Hydrogen Sulfide)}$$

Then hydrogen sulphide gas combines with metals forming metallic sulphides such as ferrous sulphide (FeS) and zinc sulphides (ZnS) which are not soluble and precipitating in the infiltrating media.

In the pilot house roof, it was found also that inorganic constituents were also less than those in urban road stormwater and close to the Palestinian standards of drinking water quality found in (PWA 2000) as shown in table 4.6. The chemical analyses including major ions, organic and inorganic carbon and heavy metals are shown in Appendix D. The quality of the roof rainwater is much better than that of road stormwater. Moreover, the quality of the tap water which supply the pilot house from public water supply is brackish with chloride concentration exceeded 1000 mg/l.

Table 4.6 Roof and road rainwater chemical analyses

Chemical constituent	Pure Rainfall	Rooftop rain	Urban road rain	Tap water	Palestinian drinking Standard
PH	6.6	7.5	7.5	7.3	6.5-8.5
EC (µS/cm)	108	463	5944	5920	
TDS (mg/l)	72	309	3963	3947	1500
Chloride Cl^-(mg/l)	35	100	2192	1378	600
Sulfate- $SO4^{-2}$ (mg/l)	5	51	323	678	400
Nitrate- NO_3^- (mg/l)	3	15	12	155	70
Calcium-Ca^{+2} (mg/l)	5	19	72	193	100-200
Magnesium- Mg^{+2} (mg/l)	8	17	169	89	150
Potassium K^+ (mg/l)	2	3	59	14	12
Sodium Na^+ (mg/l)	24	57	1167	1052	200
Total alkalinity (mg/l)	22	30	117	260	400
HCO_3^- (mg/l)	12	36	143	317	
CO_3^{-2}	11	0	0	0	
Hardness as $CaCO_3$ (mg/l)	51	118	876	849	600
Zinc Zn (µg/l)	70.9	148.8	74.6	111.5	5000
Iron Fe (µg/l)	65.2	235.9	595.5	258.6	500
Aluminum Al (µg/l)	600	500	1021	500	200
Copper Cu (µg/l)	11.4	8.7	44.8	5.8	1000
Lead Pb (µg/l)	< 3 µg	3.8	29.9	< 3 µg	10
Cadmium Cd (µg/l)	< 2 µg	< 2 µg	< 2 µg	< 2 µg	3
Chromium Cr (µg/l)	< 2 µg	21.0	5.1	23.8	50

The heavy metals concentration of rooftop rainwater is acceptable for recharging the aquifer, since their chemical constituents were better than those of the Palestinian standards for drinking water except for Aluminum and TDS. In all cases, harvested rainwater is not preferred to be used directly for drinking. Based on international experience, carbon was found in the organic content in the runoff water, but with addition of little sulphate sources, the removal of heavy metal could reach more than 80% (Rafida and Sallis 2011).

The organic matter comes during rain runoff on roofs or during precipitation from polluted air, and it is measured in terms of BOD, COD or TOC. Heavy metals such as copper (Cu), lead (Pb), zinc (Zn), arsenic (As), chromium (Cr), and Cadmium (Cd) found in urban stormwater runoff may come from sources of metals in stormwater including automobiles, painting materials, motor oil, construction materials, and deposits from factories (Pocono Northeast 2007). However, the organic matter measured in the pilot rooftop rainwater was less than that measured in road runoff in Gaza. TOC was less than 5 mg/l in rooftop rainwater, while it ranged from 10 to 40 mg/l in the samples taken from urban road stormwater. According to (Tal &Blanc 1998), organic matter could be removed through soil aquifer treatment, where their removal reached 90% for COD and BOD in similar cases in Shafdan area north from Gaza Strip.

Heavy metals and other organic contents could be removed through soil aquifer treatment in the normal infiltration pits in Gaza. However the quality of urban stormwater is less, but it is close to the Palestinian standards except for lead, aluminum and iron, and consequently more treatment is needed if they are intended to be used for drinking purposes.

4.5 Socioeconomic Survey and Questionnaires

There are similarities in dealing with water resources management and their problems among different countries. However, when dealing with socioeconomic issues, they depend on local contexts, where public awareness to the problem differs from one region to another.

The public in the Gaza Strip as the study region was interviewed at two levels, water professionals or water experts and local people who own their houses. The following sections discuss the results raised from the analysis of the questionnaires.

4.5.1 Water professionals

The results of the water professionals' questionnaires showed that there is a need to adopt RWH as a new water resource, where 73% of professionals ranked RWH as important to very important. The professionals were not satisfied about the water services supplied to people with only 10% ranking their satisfaction of water quality as good. However, concerning water quantity supplied to people, 43% ranked the quantity as good showing that there is sufficient water quantity but of bad quality. This shows that the water utility service provider prioritizes supplying the required quantities of water although the water quality is below international and Palestinian standards.

Concerning the use of harvested rainwater either from rooftop or road runoff, no single professional recommended its use for drinking, and only one professional recommended it for domestic non-drinking water. Most of them recommended the use of harvested rainwater for artificially recharging the aquifer (13 professionals), where water undergoes purification through infiltration in the soil. Only six professionals recommended its use for irrigation.

When professionals were asked about the appropriate technology for different residential zones having different types of buildings, they preferred onsite RWH in individual houses of all types of buildings except those in refugee camps due to the lack of available land. Onsite RWH for individual houses was ranked as the highest for houses with private gardens, houses without private gardens, houses in tower buildings, and houses in rural areas. However, the option of RWH in central collection lagoons in refugee camps was preferred by the professionals. Fig.4.4 shows the types of RWH system preferred by water professionals to be adopted in different types of residential zones in the Gaza Strip.

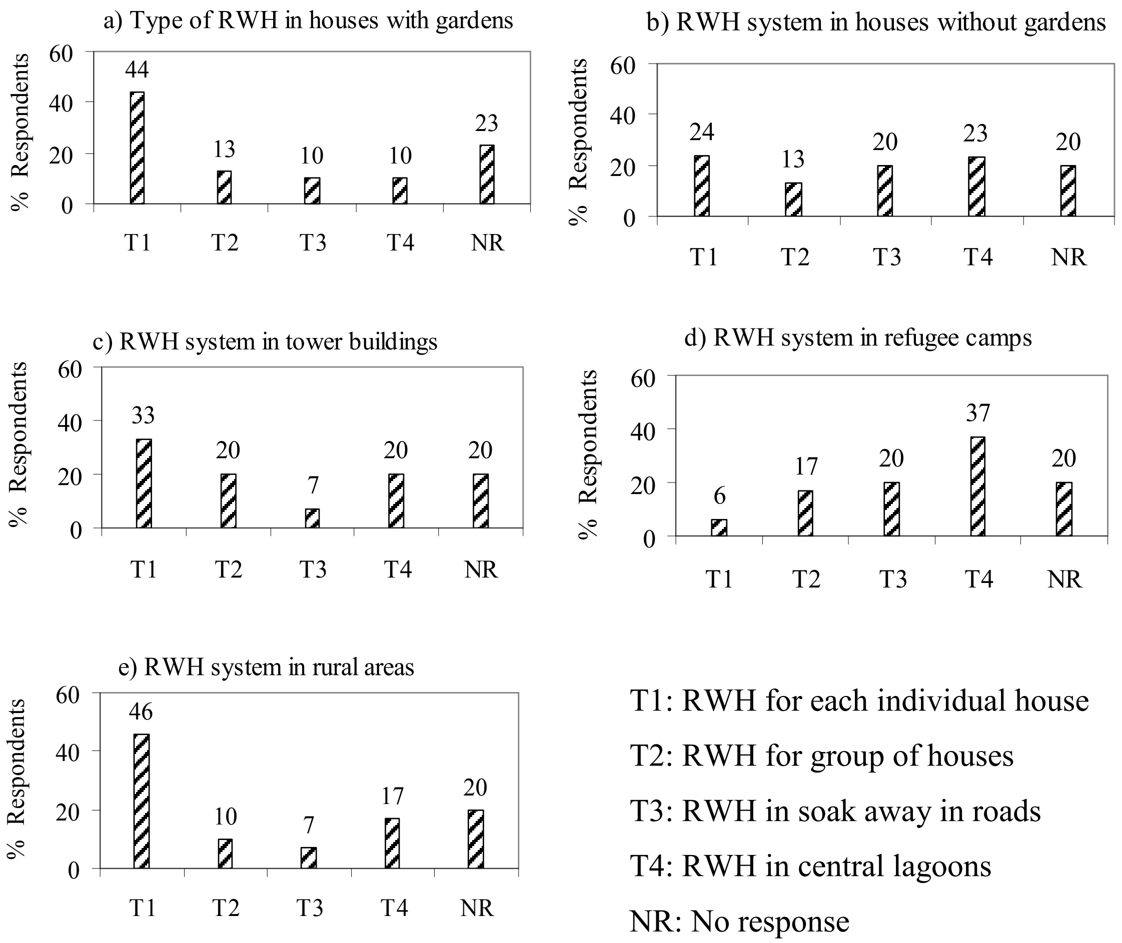


Fig. 4.4 Types of RWH systems preferred by professionals

RWH can be implemented by the government, local people or international and national non-governmental organizations. There were 50% of the respondents who encouraged this responsibility to be shared between government and house owners. Only 3% of respondents thought that this responsibility should lie on the government, and 20% thought that this responsibility should lie on house owners (fig. 4.5a). If RWH implementation is to be shared between house owners and government, the question arises as how this will be practically applied. Four scenarios were suggested to the professionals; 1) public awareness, 2) that RWH be a pre-requisite for any new construction, 3) that RWH be a pre-requisite for municipal services such as water and electricity supply and 4) enforcement using all possible means including force. The preferred scenario was the second option, where 44% of respondents ranked selected this option (fig. 4.5b).

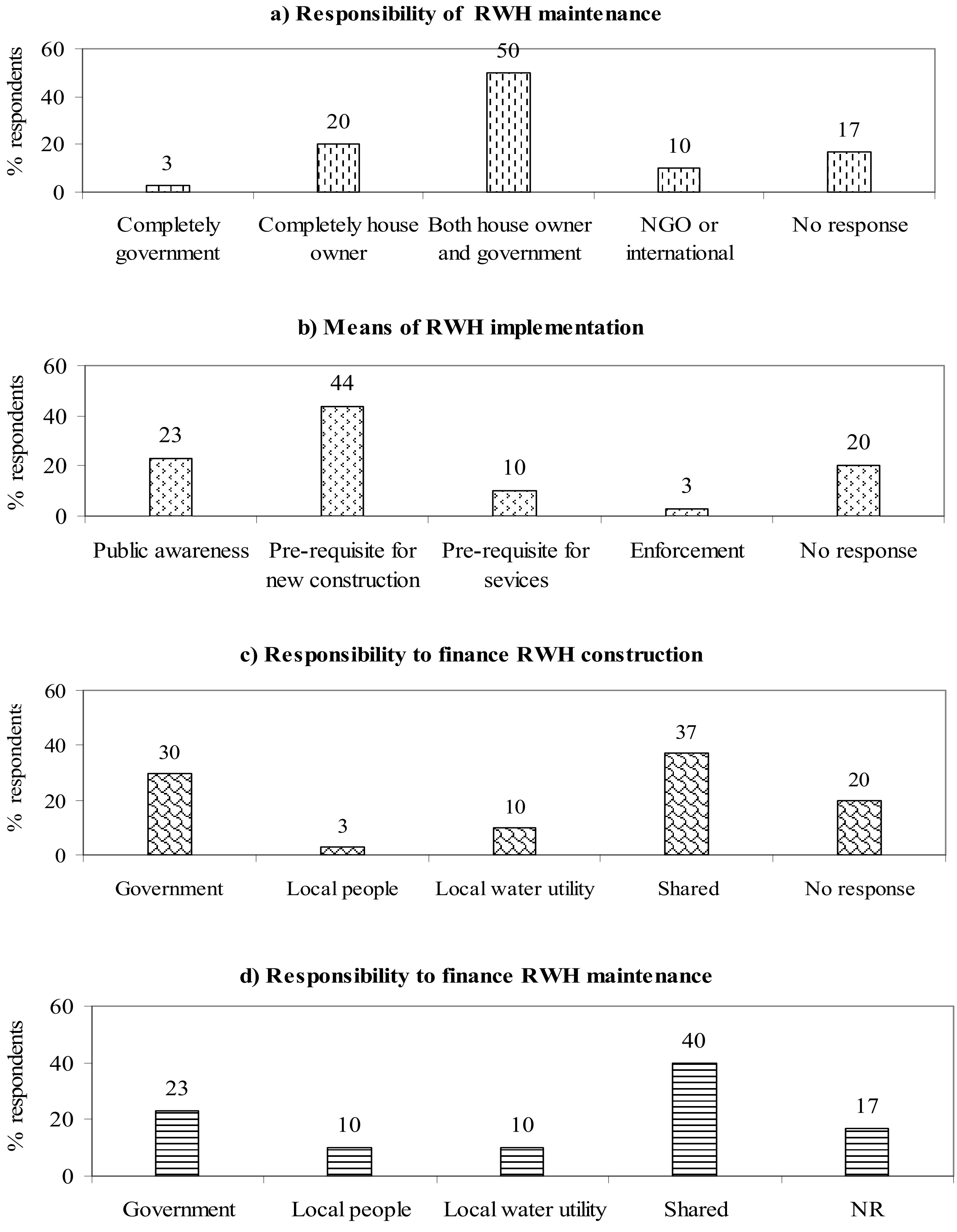


Fig. 4.5 Implementation and finance of RWH system

If the house owner allows implementation of a RWH system at his/her house, the issue of how to finance the RWH system arises given that there is poor economic situation prevailing in the Gaza Strip for both local people and government. There were 37% of respondents who stated that both government and local people should share in the construction costs, and 30% of respondents stated that government alone should bear the costs. These were the two preferred options. For other options, there were only 10% of respondents who stated that RWH financing should be beared by local utilities, and only 3% of respondents stated that RWH should be financed by local people, and this is the least preferred option (fig. 4.5 c).

Similar results were found for maintenance costs with shared financial responsibility between government and local people getting the highest rank of 40%, and governmental responsibility got the second highest rank 23% (fig. 4.5d).

4.5.2 House owners

From questionnaires completed by 137 house owners, it was found that 50 % of people depend on water vendors for drinking water purposes, and 18 % depend on in-house desalination units. Therefore, only 32% use municipal water for drinking. However, for domestic and non-drinking use, 75% of people depend on the municipal public water supply. Regarding the satisfaction of respondents to the water services, there were 63% of respondents who rated the quantity of water as good and 37% rated it as poor.

However regarding water quality, only 49% of respondents rated it as good, and 51% rated it as poor. This means that the local people share the water professionals with the same satisfaction of water quantity, but they are not satisfied with water quality of the public water supply but in different scale. During interviews with respondents, both water professionals and house owners showed their well awareness of the water resources scarcity and the great benefit of RWH as a new water resource.

The awareness of local people for the need of RWH was tested in the questionnaire about their opinion on the necessity of rainwater harvesting. There were 68% who ranked the need of RWH as very necessary, 19% of respondents said that it was necessary and 11.5 % of them ranked it as possible. Only 1.5 % of respondents said that there is no need for RWH. The willingness of house owners to allocate an area for RWH inside the perimeter wall of their own house was good whereas only 23 %

were unwilling to allocate an area for this purpose. Moreover, 43 % of respondents were willing to adopt RWH, of which 23 % are willing to allocate an area exceeding four meters squares, and 20% were willing to allocate an area from two to four meters square. The remaining respondents (34%) answered that they would want it, but they have no area available inside their perimeter wall. This leads that 77 % of respondents encourage implementation of this new technique in the Gaza Strip (fig. 4.6 a).

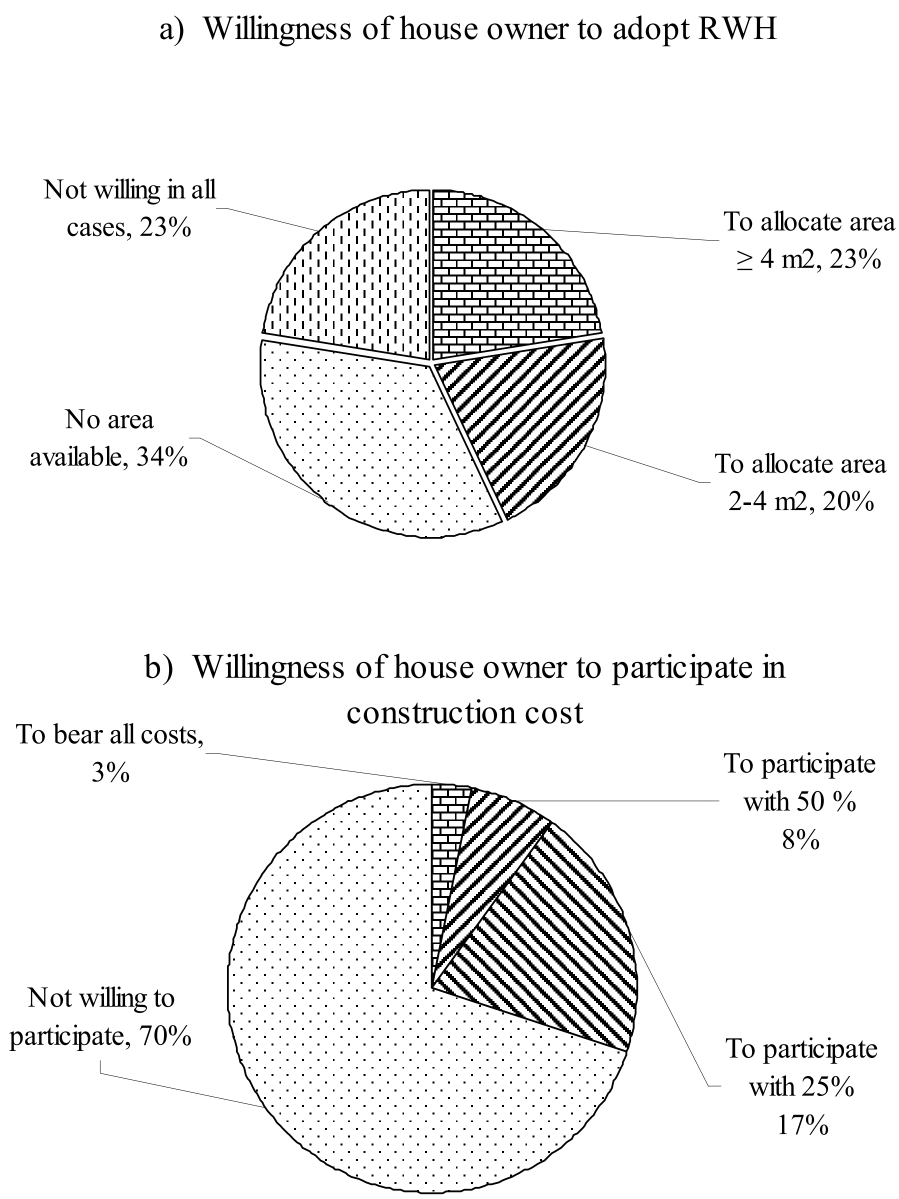


Fig. 4.6 Willingness of house owner to adopt RWH at house

The local people were asked about their willingness to contribute financially to the construction costs, which was 800 USD for 300 m^2 roof area, 1000 USD for 500 m^2 roof area and 1500 USD for 1000 m^2 roof area 70%, where these costs were derived from the cost of RWH pilot roof made in the Gaza Strip. Although they are well aware of the water scarcity, the respondents replied that they were unwilling to participate in the construction cost of RWH units. Only 3% of respondents were willing to bear all cost, 8% were ready to participate with 50 % of the costs, and 17% were ready to participate with 25% of the costs (fig. 4.6 b). This could be explained by the poor economic situation of the local people.

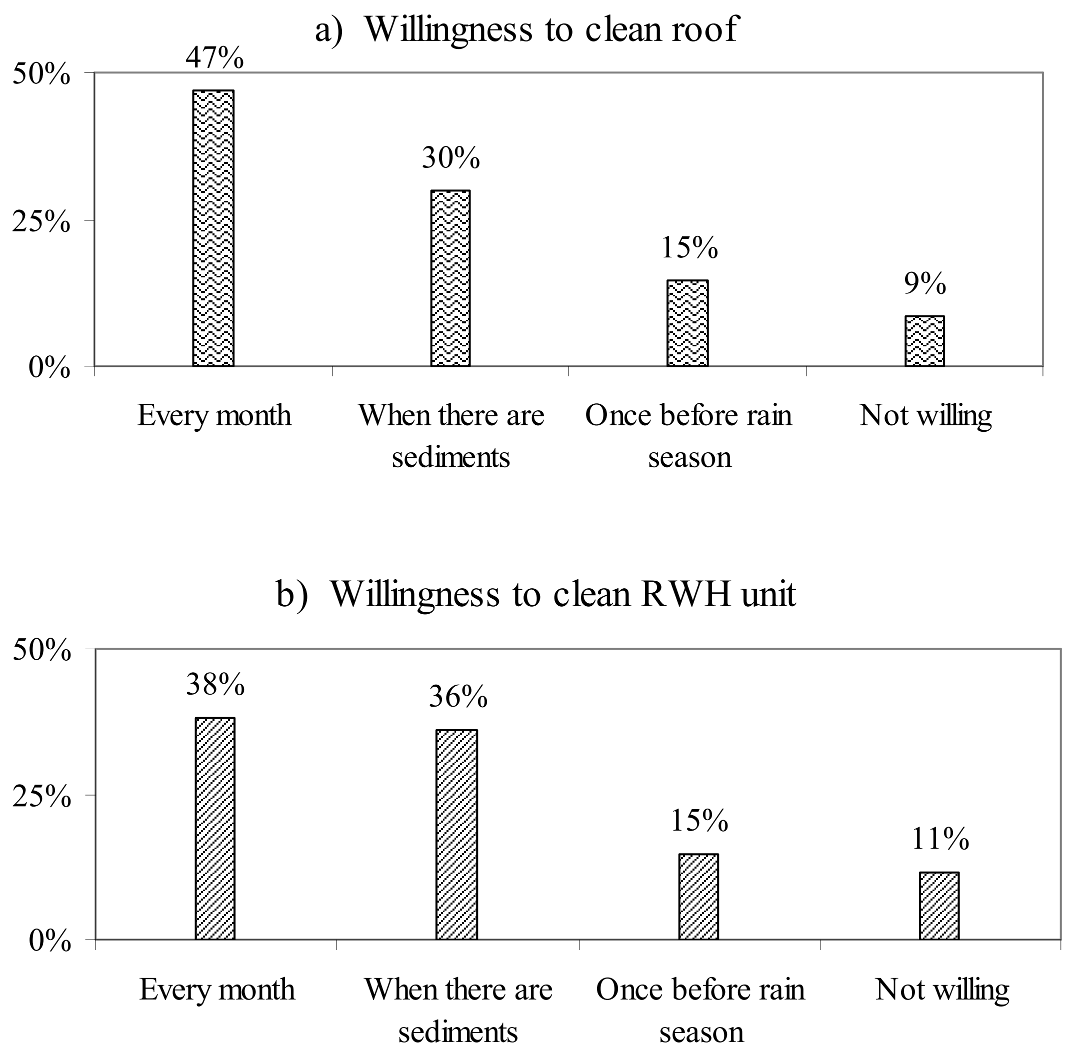
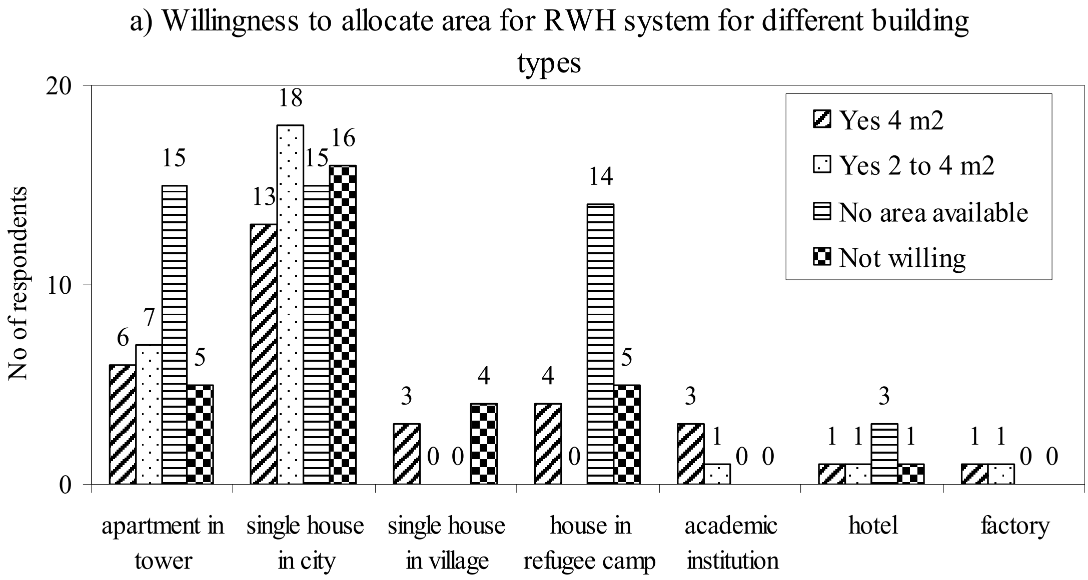


Fig. 4.7 Willingness of house owner to carry out RWH unit maintenance

Different types of houses were found in the Gaza Strip. The most problematical type with respect to RWH feasibility was houses in the refugee camps, where there was very little free available land, and houses are close to each other. This makes onsite RWH inside houses very difficult or even impossible. On the other hand, RWH system onsite is more appropriate for houses with private gardens. The third important factor in making this new technique successful is the awareness of the people who are generally familiar with the water scarcity problem in the Gaza Strip.

On the other hand, respondents stated that they would be very happy to do maintenance of a RWH unit, if they were implemented and financed by another party e.g. government. There were 91% of respondents who stated that they would be willing to clean their roofs in order to receive clean rainwater. Out of them, 47% would be ready to clean their roofs every month, 30 % will clean the roofs, when they observe sediments, and 15% are ready to clean once a year before the start of the rainy season (fig. 4.7a). Similar results were obtained concerning the maintenance of the RWH unit, where 89% of respondents stated they were ready to clean the RWH unit at least once before the wet season (fig. 4.7b).

Responses to allocate area for RWH differed depending on the building types located in different zones of the Gaza Strip. It is noticeable that the third choice, which states that there is no available land beside the house, dominated in the zones of apartment towers and refugee camps. However, for single houses located in cities, where there is available land, half of the respondents stated their willingness to allocate an area over two meters squares (fig. 4.8 a), although this does not imply willingness to participate in the financing of a RWH unit. In all building types, the majority of people were found to be unwilling to participate in financing RWH units (fig. 4.8b).



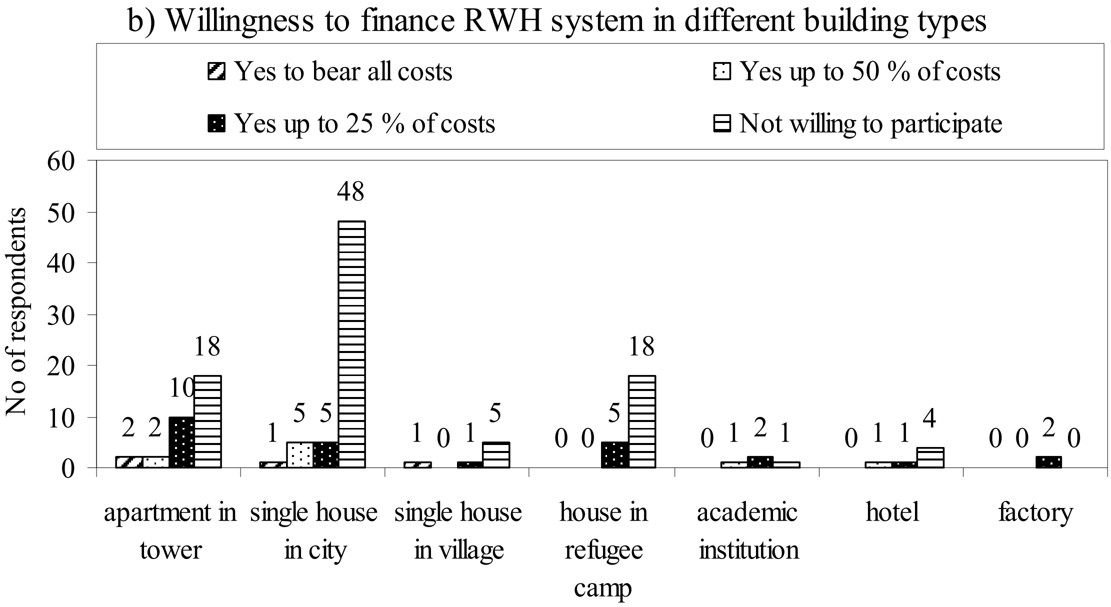


Fig. 4.8 Willingness to adopt and finance RWH

Concerning use of harvested rainwater, the respondents showed high interest in direct benefit from it through direct reuse for domestic purposes in their houses e.g. toilet flushing and washing to get direct benefit of it, where this option got 40% of respondents (fig.4.9). Due to the severe water problem local people face especially in water quality, some of the respondents showed their interest in RWH reuse for drinking purposes (13 %), if the authorities take care of its treatment to be suitable for drinking. For infiltration of harvested rainwater besides house or in a nearby allocated area and then recovering it from operating water wells, only 23% of respondents encouraged this option. This shows that people are very interested to directly use what they harvest. For irrigation of gardens, 23% of respondents encouraged this option for safety use. However, unlike house owners most of the water experts as discussed earlier encouraged indirect use of harvested rainwater through artificial recharge and recovery from water wells to give chance for water treatment through infiltration.

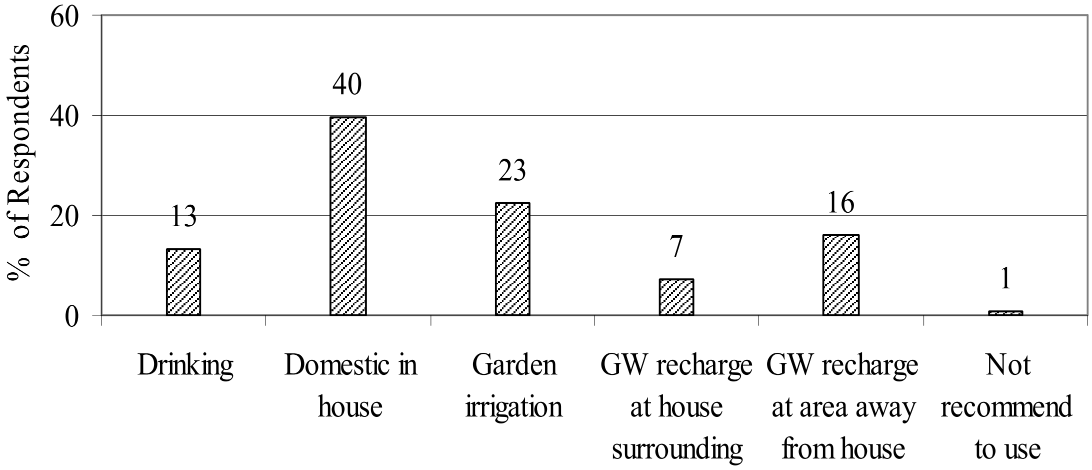


Fig. 4.9 Use of harvested rainwater

4.6 Impact of Effluent Recharge on Groundwater

Although artificial recharge of effluent has more potential water quantities than those from RWH, it has its positive and negative impacts on the aquifer. These impacts were discussed in detail (Paper IV).

4.6.1 Positive Impacts

Throughout the application of effluent to the infiltration basins of the pilot project implemented for five years (2000-2005) in Gaza, positive impact was noticed on the groundwater level, which increased during the years of artificial infiltration. There was clear rise in the groundwater level in the monitored wells. An example showing this rise is shown in (fig 4.10). Moreover, nitrate level decreased in the groundwater due to dilution with the effluent having less concentration of NO_3^- than that of the native groundwater. Denitrification and nitrification processes, occurred in the biological treatment decreased the level of NO_3^- concentration in the effluent, and consequently its impact was clearly noticed in the nitrate level of the monitored groundwater.

4.6.2 Negative Impacts

The treated effluent has been physically and biologically treated, and high concentration of Cl, and Boron were found in the effluent, since they are conservative matters. This had its negative impact on the native groundwater, where chloride and boron levels were increasing throughout the years of artificial recharge. Figure 4.11 shows clearly the rise in the salinity i.e. chloride levels in one of the monitored wells (R-270).

To be suitable for aquifer recharge, more treatment of the effluent is needed. Boron and chloride levels could be decreased through advanced chemical treatment which is relatively expensive to have it at this stage. To avoid, aquifer recharge by reclaimed wastewater, the later could be pumped directly to the farms in the irrigation networks. This is common in many parts of the world where water is scarce. The risk of this scenario depends on many factors such as pollution level of source water coming from the treatment efficiency of the wastewater treatment plant, water contact with the crops and the amount of food consumed by human. However, irrigating crops directly from reclaimed wastewater could cause enteric human diseases transmitted to the consumers of the crops, where the degree of risk depends on the culture of food preparation done by each group of people who live in the same country (Hamilton et al 2006). When the vegetables are cooked at high temperature, their risk is less than that when they are eaten fresh. It is clear that the existing treatment of wastewater in Gaza is not suitable for irrigation, and consequently more treatment is needed to reach the acceptable levels for different crops. Treatment through SAT or even sand filters were not able to reduce the chloride and Boron levels. Compared to stormwater harvesting, reuse of wastewater effluent needs more post treatment before it can be reused.

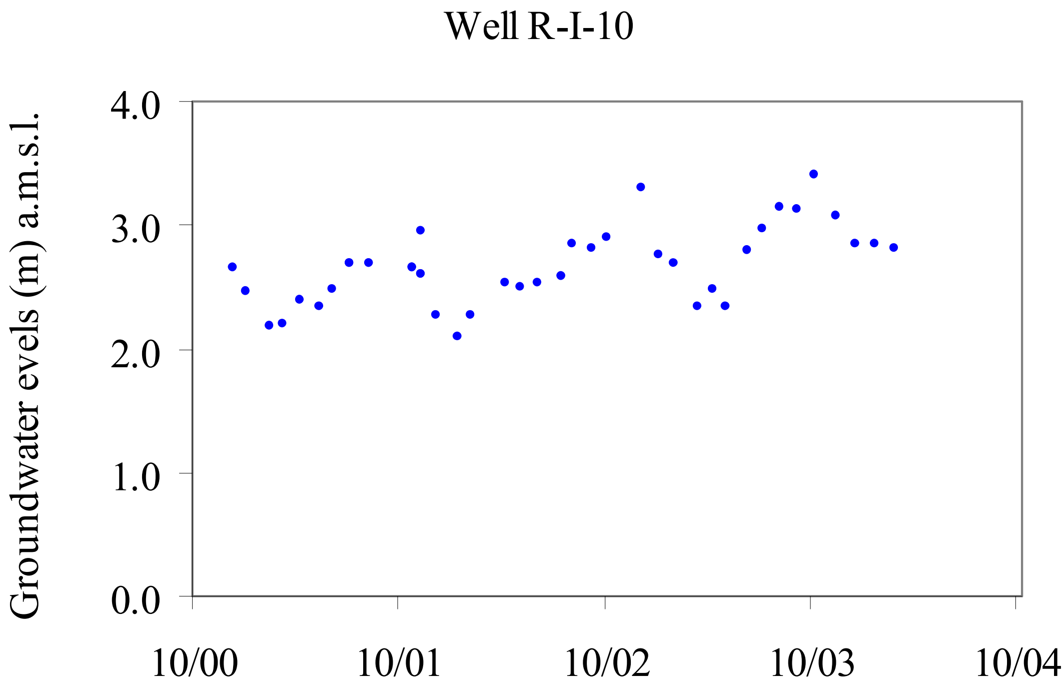


Fig. 4.10 Impact of effluent recharge on groundwater level

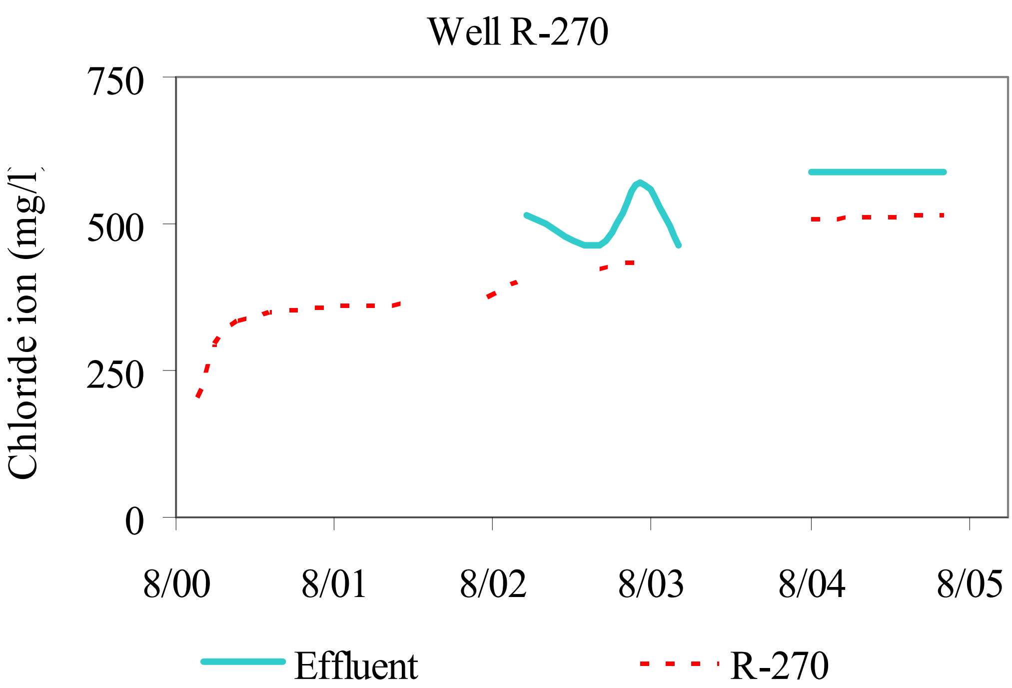


Fig. 4.11 Impact of effluent on groundwater salinity

5. Conclusions and Recommendations

Conventional water resources are not enough to fulfill the increasing water demand which led to deterioration of the quality and quantity of the groundwater system in the Gaza Strip. Consequently new non-conventional water recourses are seeked such as desalination, reuse of treated wastewater and harvesting of stormwater. Desalination is constrained by its high investment and operation costs and deficit of available electricity needed to operate the desalination plants.

Wastewater reuse is still in its early stages, where the treatment level does not meet the Palestinian standards for recharge and direct reuse, where more advanced treatment is needed, if it is recharged to avoid negative impact on the native groundwater (KfW 2005). From the assessment of the pilot project carried out in Gaza to recharge the aquifer with treated wastewater effluent, there were positive impacts by decreasing nitrate level in aquifer and increasing the groundwater level in the local area. However, there were also negative impacts on the chloride and boron level of the native groundwater which endangers human and agricultural lives. At this stage, where treatment of effluent is not enough, recharging the aquifer with stormwater is more attractive in terms of water quality. Harvesting of stormwater which come from roofs, yards and paved surfaces has less amounts of water than those of planned desalination and wastewater reuse, but storm water is cleaner, and less treatment is needed before infiltration to the aquifer.

Significant quantities of stormwater are wasted as runoff to the sea and through evaporation after being collected in low depressions, while water resources in the Gaza Strip are suffering from water scarcity. The deficit in the water resources budget had its impacts on the declination of groundwater levels and deterioration of groundwater quality which led to bad public water supply services quantitatively and qualitatively. New non-conventional water resources are consequently seeked to bridge the gab in the water resources budget. In addition to seawater desalination and reuse of reclaimed wastewater, rainwater harvesting is one of these non-conventional water resources. It should be considered as a resource that provides benefits such as groundwater recharge (Pocono Northeast 2007). The Gaza Strip has a limited area of

365 km^2 and mostly is urban areas, where 78% of stormwater come from urban areas which amount to 22 Mm^3 every year (Paper I). Collection of stormwater in central lagoons has been experienced in the Gaza Strip and proved to be non-efficient means in rainwater harvesting due to loss of control in the rainy season. Onsite rainwater harvesting through artificial recharge of rooftop rainwater around the houses or through infiltration structure for recharging road rainwater will decrease the load on the central rainwater lagoons and optimize harvesting of stormwater. Managing stormwater in different parts of the city in isolation from each other has the advantage of decreasing the peak flow in the main stormwater system (VANR 2002). The quantities collected from roofs and yards belong to buildings in the Gaza Strip was estimated at 5.2 Mm^3 every year which form 23% of the total urban stormwater runoff.

From the pilot house concrete roof, it was reached that the average rooftop runoff coefficient was 0.74 for the measured rainy season (2007/2008). The first rain event was mostly absorbed by the dry rooftop after long dry and hot summer. The harvested quantities of rooftop rainwater depend mainly on event storm head, which in turn depends on rain intensity and duration. To harvest all the rooftop rainwater, storage tank is needed in addition to full control of house owner in filling and draining of the storage tank to the infiltration pits located in the corridor of the house. This could be difficult to implement at the beginning of adoption of rainwater harvesting system. However, direct drainage from house rooftop to the infiltration pits showed that each 1.0 m diameter circular infiltration pit is enough to harvest 90% of the rainwater flowing from 100 m^2 rooftop area, and this is recommended to harvest the rainwater at the beginning, since little input from the house owner is required.

Rain runoff from roofs and yards increases with the increase of rainfall intensity, and the runoff coefficient could reach more than (0.9). However, when intensity is low, the runoff coefficient may reach less than (0.4). Unlike the value of runoff coefficient of buildings listed in hydrology literature, this coefficient has been weighted to have an average value of (0.74) at the pilot concrete roof house in Gaza. The rain runoff from roofs and yards forms about 23% of the total runoff from the whole urban areas in the Gaza Strip. This percentage has a value 5.16 Mm^3 and could be artificially recharged to the aquifer through infiltration pits around the houses themselves or in the yards of schools and other public buildings. To utilize this option, it was estimated that each 100 m^2 of roof or yard area needs 0.8 m^2 infiltration area, i.e. 1.0 m diam. circular infiltration pit is enough to harvest 90% of rooftop stormwater onsite around the house.

Large scale projects of rainfall harvesting proved to be non- efficient in the Gaza Strip due over load in the rainy season. Onsite rainwater harvesting will decrease the load on the large scale storm water collection lagoons and facilitates its recharge in controlled spread basins. So, it is highly recommended to work on the two levels of storm water harvesting onsite RWH and offsite RWH. This has two advantages, firstly it will decrease the flooding in the streets which work as conveyors of storm water, and secondly it will maximize the quantities of storm water that recharge the aquifer. If the soil around the houses is not permeable, such infiltration pits could be done by replacing the impermeable soils with sand or other permeable materials. The infiltration rate of local sand reaches eight meters every day, if it is kept clean.

From the water quality analyses, the collected rooftop rainwater showed high water quality levels that are close to the drinking water standards. This has previously indicated by international researches (Vanderzalm et al. 2007). However, during the long dry period, a lot of pollution could be transported by nature and human means and settle on the roof. So, in addition to cleaning of the roof before the start of the rainy season, it is recommended to divert the first flush of rooftop rainwater or rainfall fallen in the first 15 minutes of the rainy season without harvesting.

The water quality of rooftop and yard runoff is relatively clean compared to WHO drinking water standards, if the rainfall collection systems are frequently cleaned. It is recommended to divert only the first 10 mm first flush from the first rainstorm, since they are expected to have significant amount of chemical and biological pollutants, otherwise the roofs and yards are cleaned occasionally in the rest of the rainy season.

The first flush is defined as the first 10 mm falling after the dry period, where at least 80% of pollution load is transported in the first flush (Soller et al. 2005 and Kim et al. 2005). The RWH system has to be cleaned every period from accumulation of tree leaves, garbage that could pass in the pipes and reach the infiltration pits. For more treatment, simple and sustainable technology could be introduced here through addition of sulphate and carbon sources with soil conditioning of sulphate reducing bacteria. The chemical reactions lead to production of hydrogen sulphide gas, which in turn react with heavy metals such as Zn and Pb forming insoluble metal sulphides e.g. ZnS and PbS (Rafida and Sallis 2011).

There has been an increasing public awareness for the need of RWH, and that could be adopted as a new water resource. Adopting RWH in the Gaza Strip can be divided into three systems. Firstly, onsite infiltration of harvested rainwater in houses having available land around the house (this could be found in the cities, hotels, factories and rural areas), with the maintenance of RWH units and rooftop carried out by the house owners themselves, where an agreement between the authorities and house owner could be made. This system has proved to be efficient in other countries e.g. New Delhi, India, where the maintenance of RWH systems must be carried out every six months before and after the monsoon to prevent clogging in the system (New Delhi I.P 2006). Secondly, district infiltration of RWH where harvested rainwater from houses in a district is diverted to a small size infiltration basin. In this case, maintenance of the RWH system is done by local authorities, but the cleaning of rooftop remains the responsibility of the house owner. Public awareness is an effective way to inform local people regarding this. Thirdly, for areas where no open areas are available, or they are far away from the houses, rainwater could be directed to either soak away in public roads or a central lagoon which would receive less water quantities, if the preceding methods were implemented.

According to the experience of water professionals in the Gaza Strip, making RWH as a pre-requisite for new construction is the most practical way to ensure onsite harvesting of rainwater. In New Delhi, rainwater harvesting systems were made mandatory in all new buildings with an area exceeding 100 m^2. Some subsides are provided by the government, and monitoring of the implementation of the system and imposing of penalties are the responsibilities of the government (New Delhi I.P 2006). Also, it is important that the people should make some voluntary contribution towards the construction, monitoring and maintenance of the RWH system with encouragement in the form of incentives and subsidies from the responsible authorities. When actions are required by specific communities to protect groundwater resources, incentives should be considered, and how they could be provided. There is a need for raising awareness campaigns, giving examples of RWH systems and training to encourage uptake of RWH. Without the participation of people in the development of RWH projects, these projects will fail (FAO 2010). The people should be involved in all phases of the project, planning, implementation and evaluation. It is preferable that the people participate in the construction and maintenance of the system with the support of the local authorities. Such participation by the people during the operation of the system should be received as feed back to the responsible authorities through evaluation campaign carried out every year which may include problems encountered and suggestions for improvements.

All parties should participate in rainwater harvesting including water institutions, governmental bodies, local utilities and the public. Awareness is needed at the first stage, and in particular schools, where most of the inhabitants of the Gaza Strip are young. The law and governmental interference are necessary during implementation, since obeying the rules has positive impact on public awareness at the first stage of RWH management. Financial aids are needed at the beginning to promote house owners adoption of the onsite RWH systems at their houses.

6. References

Ahuja, Satinder 2008. The Problem of Arsenic Contamination of Groundwater. In Arsenic Contamination of Groundwater: Mechanism, Analysis and remediation. John Wiley & Sons, Inc. 2008. ISBN: 878-0-470-14447-3, p18

Al-Agha, M. and El-Nakhala, H. Hydrochemical facies of groundwater in the Gaza Strip, Palestine. Hydrological Sciences-Journal-des Sciences Hydrologiques, 49(3) June 2004, Taylor and Francis Publisher, London, pp359- 371

Al-Kharabsheh, A. 1995. Possibilities of Artificial Groundwater Recharge in the Azraq Basin: Potential Surface Water Utilization of Five Representative Catchment Areas. Lehr-und Forschungsbereich Hydrogeologie und Umwelt der Universität Würzburg. ISSN 09309-3757, p 36

Al Sheikh, R., Jung, H. And Koegler, T. Diagnosis of Limitations in Operational Capacity of Sea Water Desalination Plants in Gaza Strip. Proceedings of the LNCV international forum “Food Security under Water Scarcity in the Middle East: Problems and Solutions”. Como, Italy 24-27 November 2004, p298

Al Yaqobi, A. and Hamdan, S. 2005. Constraints facing water resources management in the Gaza Strip. International conference on water values and rights, Ramalla, Palestine, 2-4 May 2005.

Aish, A. Water quality evaluation of small scale desalination plants in the Gaza Strip, Palestine. Fourteen Int. Water Technology Conference Proceedings, 21-23 March 2010, Cairo, Egypt, pp 153-168

Baalousha, H. 2006. Desalination status in the Gaza Strip and its environmental impact. Desalination Journal 196 (2006), Elsevier, p5

Bagoma, David, Loiskandl, Willibald and Jung, Helmut. Water Manageent, Rainwater Harvesting and Predictive Variables in Rural Housholds. Springer Science+Business Media B.V. 2010, Water Resour Manage 24:3333-3348

Bhattacharya, A. and Rane, O. 2007. Harvesting rains: catch water where it falls. Rooftop rainwater recharge. Journal of Environment, centre for civil society. http://www.ccsindia.org/ccsindia/policy/enviro/ studies on 5 Jul 07, p427

Brontowiyono, Widodo 2008. Sustainable water resources management with special reference to rainwater harvesting- case study of KartaMan Tul, Java, Indonesia, PhD dissertation, University of Karlsruhe, pp 53&202

Bruins, Hendrik J., Akong'a, Joshuo, Rutten, Marcel M.E.M. and Kressel, Gideon M. 2005. Drought planning and rainwater harvesting for arid-zone pastoralists: the Turkana, the Maasai, and the Negev Bedouin. Water efficiency II. Rural areas and agriculture, Arid Lands. No 57, May-June 2005. http://ag.arizona.edu/oals/ALN/aln57/bruins.html.

Burke, J. and Moench, M. 2000. Groundwater and Society. Resources, Tensions and Opportunities. Themes in groundwater management for the twenty-first century. United Nations publications, New York, October 2000. ISBN 92-1-104485-5, p132

CGWB 2008. Central Groundwater Board. Success Stories of Rainwater Harvesting and Artificial Recharge of Groundwater in NCT, Delhi. Ministry of Water Resources, New Delhi, pp 2-4 **http://cgwb.gov.in/GroundWater/AR/Success%20stories_RWH_Delhi.pdf**

Chave, P., Howard, G., Bakir,P., Appleyard, S. and Hoque B. Policy and legal systems to protect groundwater. In Protecting Groundwater for Health. Managing the Quality of Drinking-Water Sources, World Health Organization, IWA Publishing, London, 2006, pp 537-562. ISBN: 13:9781843390794

Choukr-Allah, Redouane 2011. Innovative Wastewater Treatment and Reuse Technologies to Southern Mediterranean Countries. The Handbook of Environmental Chemistry. Springer- Verlag Berlin Heidelberg 2011, p30

CMWU 2010. Coastal municipal water utility in the Gaza Strip databases, December 2010.

Drewes, J. and Jekel, M. 1996. Reuse of Advanced Treated Sewage Effluent for Groundwater Recharge. Proceedings of an International Symposium on Artificial Recharge of Groundwater, Helsinki, Finland, June 3-5, 1996, p165

FAKT 2011. Consultant for Management, Training and Technologies with cooperation with UNEP, Margraf Publishers and International Rainwater Catchment Systems Association (IRCSA). http://www.rainwater-toolkit.net/index.php

FAO 2010. Socio-economic factors and project management. http://www.fao.org/docrep/u3160e/u3160e00.HTM , on 12 Apr.2010.

GDRC 2007. Rainwater Harvesting and Utilization. An Environmentally Sound Approach for Sustainable- Urban Water Management: An Introductory Guide for Decision-Makers. Global Development Research Center. http://www.gdrc.org/uem/water/rainwater/ rainwaterguide.pdf. Accessed on 3 July 07.

GDRC 2008. Global Development Research Center. Rainwater Harvesting and Utilization. http://www.gdrc.org/uem/ water/rainwater/rainwater/introduction. html. Accessed on 2 November 2008.

Hamdan 1999. Potential Artificial Recharge of Groundwater in the Coastal Region of Palestine. Msc. Thesis report Series 1999-22. Stockholm, Sweden, p 14

Hamdan S. and Muheisen M. 2003. Rainfall and Groundwater in the Gaza Strip. Palestinian Water Authority, Gaza, July 2003, p4

Hamilton, A., Stagnitti, F., Premier, R and Boland, A. Is the risk of illness through consuming vegetables irrigated with reclaimed wastewater different for different population groups. Water Science & Technology, 5th Water Congress: Integrated Water Management and Environmental Impacts, International Water Association, Beijing, China 10-14 September 2006, pp 379-386

Hohmann, C., Zhu, Y.G., Morin, G. and Kappler, A. Immobilisation of arsenic in paddy soil by iron (II)- oxidizing bacteria.Grundwasser für die Zukunft. Tagung der Fachcektion Hydrogeologie in der DGG (FH-DGG), 12-16 Mai 2010, Tübingen. Schriftenreihe der Deutschen Gesellschaft für Geowisenschaften, Heft 67, p30

Howard, P., Chave, P., Bakir, P. and Hoque, B. Socioeconomic, Institutional and Legal Aspect in Groundwater Assessment and Protection. In Protecting Groundwater for Health. Managing the Quality of Drinking-Water Sources, World Health Organization, IWA Publishing, London, 2006, pp 139-155. ISBN: 13:9781843390794

Huang, R., Zhang, J., Ma, L., Jianh, A., Kong, X.J., Li, X.K. and Bao, L. Efficiencies of residual organic pollutants removal from secondery effluent by switching of coagulation-air flotation- filtration processes. Water Science & Technology, 5th Water Congress: Integrated Water Management and Environmental Impacts, International Water Association, Beijing, China 10-14 September 2006, pp 215-222

Huq Imamul, S.M. 2008. Fate of Arsenic in Irrigation Water and Its Potential Impact on the Food Chain. In Arsenic Contamination of Groundwater: Mechanism, Analysis and remediation. John Wiley & Sons, Inc. 2008. ISBN: 878-0-470-14447-3. Pp29-30

Kappler, A., Hohmann, C., Behrens, S., Vögelin, A. and Berg, M. Characterization of microbial communities and iron minerals in household sand filters used to remove arsenic from groundwater in Vietnam. Tagung der Fachcektion Hydrogeologie in der DGG (FH-DGG), 12-16 Mai 2010, Tübingen. Schriftenreihe der Deutschen Gesellschaft für Geowisenschaften, Heft 67, p60

Karim, M.R. Microbial contamination and associated health burden of rainwater harvesting in Bangladesh. IWA Publishing 2010. Water Science and Technology-WST: 2129-2135

Karim, Md., Shelly, A. and Biswas, M. People Perception and Acceptance of Rainwater Harvesting in A Coastal Area in Bangladesh. Proceedings of the twelfth international conference on rainwater catchment systems, New Delhi, India. November 2005, pp 6-9

Kiely, G. 1996. Environmental Engineering, International edition 1998. McGraw Hill, Boston. P 199. ISBN: 0-7-116424-3

Kim, L., Kayhanian, M., Zoh, K. and Stenstorm, M. 2005. Modeling of highway stormwater runoff, Kim, L., Kayhanianb, M. Zohc, K. and Stenstromd, M.K. Science of the Total Environment 348 (2005), Elsevier 1–18, pp 2-3,16

KfW 2005. Sludge and Effluent Reuse Study for Gaza Central Area. Kreditanstalt für Wiederaufbau in cooperation with Coastal Municipal Water Utility and Palestinian Water Authority. Inception Report Background and Problem Analysis, April 2005, pp 6.3 and 7.2

Kumara, G.G. Ajith and Wickramasinghe, N.I, 2003. Community perception on rainwater harvesting – Sri Lanka. 29th WEDC International Conference. Towards The Millennium Development Goals. Abuja, Nigeria 2003.

Lehtola, M., Miettinn, I., Vartiainen, T. and Martikainen, P. 1996. Changes in Microbiology and Water Chemistry During Slow Sand Filtration. Proceedings of an International Symposium on Artificial Recharge of Groundwater, Helsinki, Finland, June 3-5, 1996, p201

Lindberg, Johan 1999. Ecological Engineering for Treatment of Contaminated Groundwater- Two Examples. PhD thesis. Stockholm, Sweden1999, p9

Melloul, A., Albert, J. and Collin, M. Lithological mapping of the unsaturated zone of a porous media aquifer to delineate hydrogeological characteristic areas: Application to Israel's coastal aquifer. African Journal of Agricultural Research Vol. 1 (3), October 2006, p50

Metcalf & Eddy 2000. Coastal aquifer management program. Integrated aquifer management plan, volume I, task 3. Gaza, p 23

MoA 2008. Palestinian Ministry of Agriculture, Soil and Irrigation Directorate. Annual rainfall quantities in Gaza Strip. Gaza, 2008.

PCBS, Palestinian Central Bureau of Statistics 2009. Population, Housing and Establishment Cencus 2007. Main Indicators by Locality Type, Ramalla, Palestine, pp 60-64

Nilsson, P. 1990. Infiltration of wastewater, an applied study on treatment of wastewater by soil infiltration. Doctoral dissertation, report no. 1002, Lund, Sweden.

New Delhi I.P 2006. Evaluation Study of the Scheme of Rainwater Harvesting. Planning Department. I.P. Estate, New Delhi- 110002. New Delhi. July 2006. http://delhiplanning.nic.in/Reports/RWH.pdf, on 11 Apr. 2010.

NWP 2000. National Water Plan, Final Copy- Palestinian Water Authority, Gaza and West Bank, December 2000.

Osaka/Shiga 1997. Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean. UNEP International Environmental Technology Centre, IETC Technical Publication Series by, Osaka/Shiga, Japan, 1997. **http://www.oas.org/dsd/publications/unit/oea59e/ch10.htm**. Accessed on 30 March 2011.

PMD 2007. Palestinian Meteorological Department, Ministry of Transport, rainfall databases, Gaza, Palestine.

Pocono Northeast 2007, Resource Conservation and Development Council, Stormwater Management Handbook, http://www. stormwaterresourcesfor municipalities.com. Accessed on 15 May 2007, pp4-7

PWA 2000. Palestinian Drinking Water Standards in the Gaza Strip. Palestinian Water Authority, Gaza, July 2000, pp 4-6

PWA 2005. Rainfall and groundwater in the Gaza Strip report, the Palestinian Water Authority, Gaza, p 3

PWA 2006. Agricultural and Municipal water demand in Gaza Strip, the Palestinian Water Authority, Gaza, May 2006.

PWA 2007. Rainfall Data in Gaza Strip. Strategic Planning Directorate, Palestinian Water Authority, Gaza, June 2007, pp 8-9

Qin, Hong, Burian, Steven J. and Edwards, Findlay G. 1995. GIS-Based BMP Planning Tool for Stormwater Quality Management. University of Utah and University of Arkansas, October 2004, p51

Rafida, A.I. and Sallis, P.J. 2011. Removal of Heavy Metals in Vertical Flow Biofilters Conditioned with Sulphate Reducing Bacteria. Environmental Engineering Group, School of Civil Engineering and Geosciences, University of Newcastle, UK. http://public. balanceco2.com/WaterCatchment/pdffiles/Theme-5-Part 2/Rafida-A I.pdf. Accessed on 4 Apr. 2011.

Salem, M. 1963. Geology of groundwater in the area between El-Arish and Gaza. Msc. Thesis, Cairo University, Cairo Egypt, p 21

Seiler, K.P and Gat, J.R. 2007. Groundwater Recharge from run-off infiltration and percolation. Springer, Dordrecht, the Netherlands, 2007. ISBN: 978-4020-5305-4, pp173-174.

Siriwardene, N.R., Deletic, A. and Fletcher T.D. Clogging of stormwater gravel infiltration systems and filters: Insights from a laboratory study. Elsevier. Science Direct. Water Research 41 (2007): 1433-1440

Soller, J., Stephenson, J., Olivieri, K., Downing, J. and Olivieri A. 2005. Evaluation of seasonal scale first flush pollutant loading and implications for urban runoff management, Sollera, J., Stephensona, J., Olivieria, K. Downing, J. and Olivieria, A. Journal of Environmental Management 76 (2005) 309–318, Elsevier 2005

Tal, N. and Blanc, R. 1998. Wastewater treatment and groundwater recharge for reuse in irrigation: Dan Region reclamation project, Shafdan. Proceedings of international symposium on artificial recharge of groundwater-TISAR 98, Amsterdam, 21-25 Sep. 1998, p103

Vanderzalm, J., Dillon P., Marvanic, S. and Page, B. 2007. Over 100 years of drinking stormwater treated through MAR: Assessing the risks of stormwater recharge on the quality of the Blue Lake. In: Proceedings of International Symposium on Managed Aquifer recharge, Oct. 28- Nov. 2, 2007. ISBN: 0-9788283-9-9, Phoenix, Arizona.

VANR 2002, Vermot Agency for National Resources, the Vermot Stormwater Management Manual, volume II- technical guidance, August 2002, USA.

WRAP 1994. Water Resources Action Program-Palestine. Palestinian Water Resources. A Rapid Interdisciplinary Sector Review and Issues Paper., Jerusalem 1994, p4

Yassin, M., Tubail, K. and Al-Dadah, J. Towards strategies for pollution control on the use of wastewater effluent in sustainable agriculture in the Gaza Strip. World Review of Science, Technology and Sustainable Development, Vol. 5, No. 1, 2008, Inderscience Enterprises Ltd., pp 66-78

Published Papers

Paper I

Stormwater availability in the Gaza Strip, Palestine.

Hamdan, S., Troeger, U. and Nassar, A., 2007. Int. J. Environment and Health, Vol. 1, No. 4, 2007. Inderscience Enterprises Ltd: 580-594.

Stormwater availability in the Gaza Strip, Palestine

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Abstract: Stormwater harvesting has become an important water resource. The rational runoff formula has been applied using GIS as a tool to estimate runoff amounts from different landuse categories. These amounts have been estimated to be 37 Mm^3 in the existing landuse and will reach 43 Mm^3 for planned landuse, i.e. urban development expansion. Continuous urbanisation will result in more wastage of rainfall that could be used for replenishment of groundwater. The Gaza Strip was divided into seven geographic zones, the potential amounts of rainfall runoff in each zone were estimated, and accordingly, conveying infrastructures and infiltration systems are identified. Of course, this will add a new resource to the water budget, which will suffer from a deficit estimated to be 100 Mm^3 per year by the year 2020. This and other non-conventional resources will together bridge the gap between supply and demand.

Keywords: Gaza Strip; groundwater recharge; landuse; Palestine; stormwater; water budget.

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1 Introduction

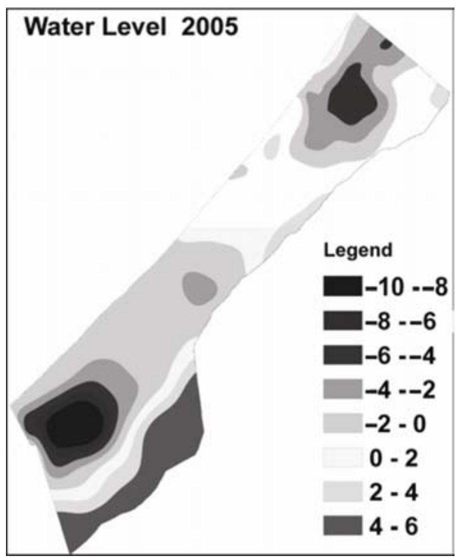
The Gaza Strip lies at the eastern edge of the Mediterranean, its climate is characterised as semi-arid region and it is a part of one of the scarce water countries. It had a population of 1.47 million people in the year 2005 (PCBS, 2006) living in 365 km^2 area. Because it is separated from the West Bank geographically, its water resources are managed separately; its aquifer is a part of the coastal aquifer whereas the West Bank shares with other three mountain aquifers. A location map is shown in Figure 1. Therefore, water resources in each part of Palestine are managed separately to fulfil the growing demand due to increasing population and social–economic development.

Figure 1 Location map

Groundwater is the only water resource that is used to serve the people in the Gaza Strip. This water resource has been much exploited in the last three decades due to over abstraction (Al Yaqobi and Hamdan, 2005). The renewable amount of water from rainfall that replenishes the aquifer is much less than the water demand, which has been increased due to increasing population. The per capita consumption is 138 l every day for both domestic needs. The population increased from 1,167,359 in the year 2000 to 1,515,924 in the year 2005, which increased domestic water demand from 57 Mm^3 in year 2000 to 75 Mm^3 in year 2005 (Mushtaha and Al Dadah, 2006). The deteriorated water quality in terms of chloride and nitrate concentrations was reflected in the water services that are supplied in the public water supply system through 22 local municipalities distributed in five governorates in the Gaza Strip.

The area of the Gaza Strip is limited, where agricultural sector occupies about 184 km^2, which amounts to about 50% of the total area of the Strip (Hamdan and Jaber, 2001). The former settlements are now under Palestinian control and mostly they are sand dunes. Some of these areas are governed by municipalities and facing danger of urbanisation and consequently decrease in the catchment areas as shown in the landuse map in Figure 5 later.

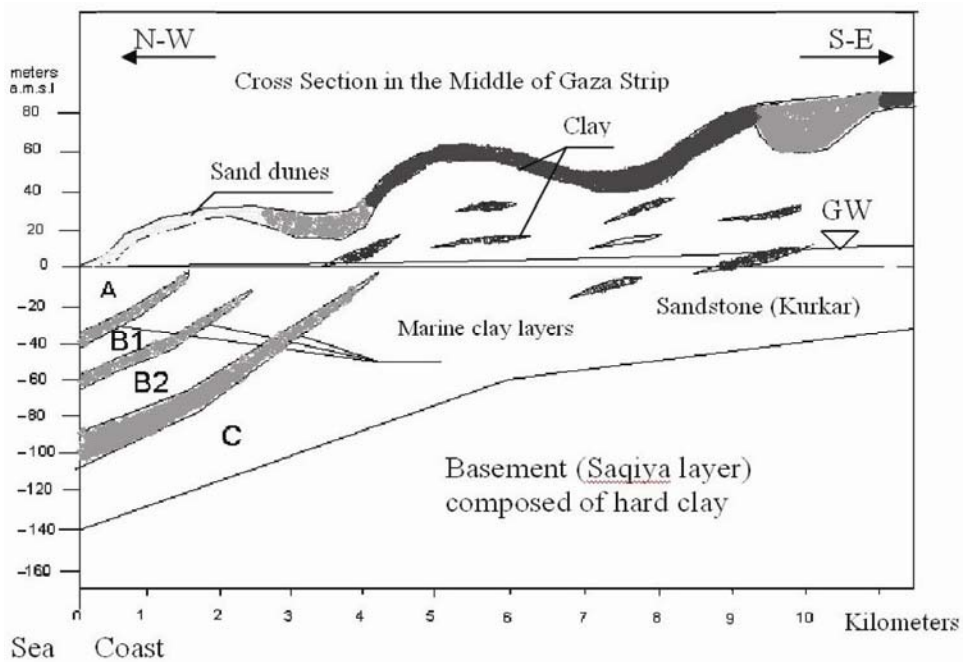
Figure 2 Groundwater levels in Gaza Strip



As priority in the Palestinian policy, stormwater harvesting is considered as a major part of every large-scale project implemented, e.g. roads, port, industrial estate, etc. There will be local infiltration sites in each project. However, large-scale infiltration schemes were considered in the last ten years as a major component of the water resources management in Palestine in general and in the Gaza Strip, in particular.

Artificial recharge became a priority after the Israeli disengagement from the Gaza Strip. Most of the disengaged areas are sand dunes. The measured infiltration rate of surface water of these sand dunes is about 50 m every day (Hamdan, 1999). The sand dunes are the top part of Pleistocene marine sand and sandstone, which is inter-bedded with clayey layers making three or four sub-aquifers (Figure 3).

Figure 3 Cross section in the coastal aquifer



Source: Melloul and Israel (1991).

2 Methodology

The data of measured rainfall quantities fallen on Gaza Strip for the past 32 years since the season 1973/1974 until the season 2005/2006 have been interpreted. Excel sheets were done for making statistics to find out the mean annual rainfall in each station for the whole period. First, the bulk amounts of rainfall were quantified in all zones of the Gaza Strip to see rainfall availability in the area (Figure 4). The response of groundwater to natural infiltration of rainfall and abstraction of groundwater was evaluated. The water level in the two water wells was evaluated. These two agricultural water wells were selected as one well located in a zone in the north (well A/107), and the second is located in a zone in the south (well L/47) with depth from ground surface to groundwater 60 and 68 m, respectively. The locations of these wells are shown in the landuse map in Figure 5.

Quantification of potential stormwater in Gaza Strip was based on applying the rational formula for runoff and the different land uses in the Gaza Strip were derived from the aerial photos. Each rain station represents local zone of the Strip where it is located. The areas of these zones represented by stations were calculated based on Thiessen polygon method using Geographic Information System (GIS). The study area was divided into seven zones Z-1 until Z-7. GIS was used to calculate the area of each landuse in each zone. The main features used to calculate the runoff were based on the landuse map and soil map to find description of the areas that correspond to that in Table 1 (Kiely, 1996).

Figure 4 Bulk rainfall quantities fallen in Gaza Strip

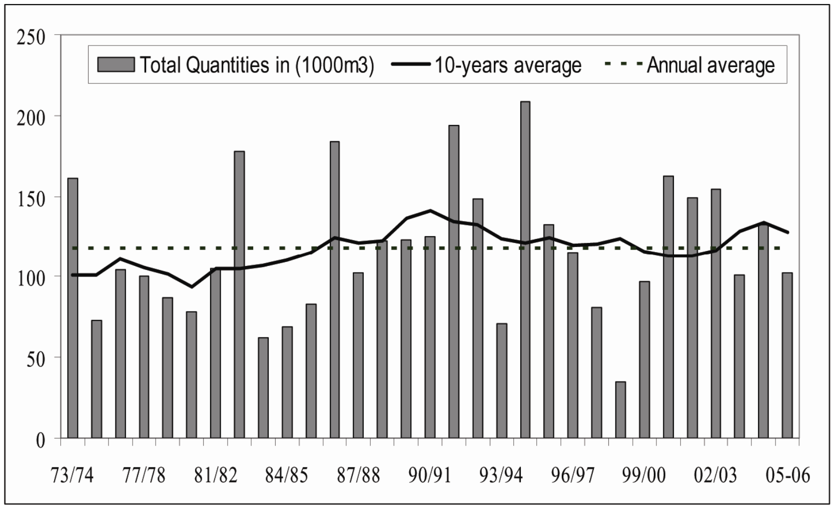
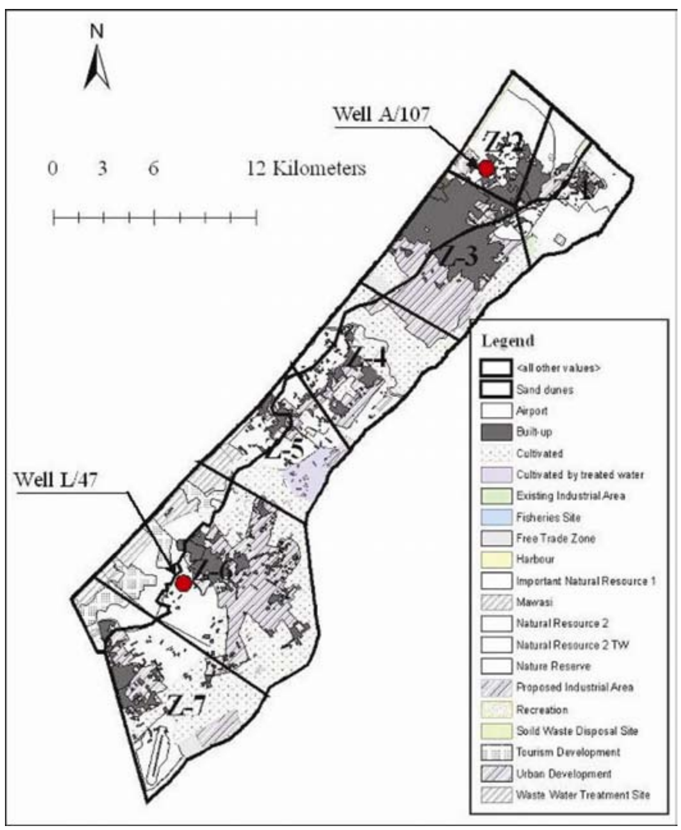


Figure 5 Studied zones and landuse (see online version for colours)



Source: PWA (2006).

Then, the estimated average annual amount of stormwater in each zone was based on the rational runoff formula created from the empirical method referred to Mulvancy (1851), Kuichling (1889) and Lloyd-Davis (1906) in Kiely (1996). According to (Kiely, 1996),

$$Q = CIA \tag{1}$$

where Q, runoff quantity (L^3); I, rain intensity (L/T); A, catchment area (L^2).

The total amount of surface runoff, which forms the stormwater in Gaza, is calculated as the summation of the quantities in all zones:

$$Q = \sum Q_{Z1} + Q_{Z2} +, \ldots, + Q_{Zm}. \tag{2}$$

For each zone, the estimated stormwater was calculated from the following formula, which is based on the above-mentioned rational formula:

$$Q_{Zm} = I_m * \sum C_{Km} * A_{Km} \tag{3}$$

where Q_{Zm}, quantity of stormwater in zone number m (L^3/T), I_m, mean annual rainfall in rain station representing zone number m (L/T); C_{Km}, runoff coefficient of land surface of landuse category (K) in zone m (dimensionless); A_{Km}, area of landuse category (K) in zone m (L^2).

The potential stormwater was estimated for both the existing landuse and future planned landuse. So, the runoff coefficient (C) differs for some landuse categories in the two cases. The planned land uses, which lay over sand dunes in the west of Gaza Strip, have been considered of zero runoff.

3 Rainfall and groundwater response

Rainfall is measured in the Gaza Strip at 12 rain gauge stations distributed spatially at the whole area and representing all zones from north to south. The average rain head fluctuates from 200 mm per year in the south of Gaza Strip to about 450 mm per year in the north. The bulk quantities were calculated based on Thiessen polygon method. These quantities are fluctuating from one year to another. In the last ten years, the bad rainy season was in 1998/1999 where the bulk amount was <40 Mm^3, while in the seasons 2001/2002 and 2003/2004, these amounts exceeded 160 Mm^3 (see Figure 3). As an average, rainfall fallen on Gaza Strip as a bulk quantity is estimated to be about 114.1 Mm^3 per annum (PWA, 2005). The net annual recharge was estimated to be 46 Mm^3 every year and it was also 62 and 65 Mm^3 in the seasons 2001/2002 and 2002/2003 consecutively (Hamdan and Muhaisen, 2003).

The quantity and quality of groundwater is affected by the quantity and quality of in- and out-flowing water from the groundwater system. Rainfall replenishes the aquifer with an average annual amount of 40.8 Mm^3 (PWA, 2005) as a part of the total supply to the aquifer (107.9 Mm^3). The total abstracted water from the aquifer amounts to 162.1 Mm^3 every year (CAMP, 2000).

3.1 Response to rainfall

Groundwater level fluctuations due to rain infiltration depend mainly upon the soil type, land use and rain intensity. In the north (Beit Lahia) one well was selected (A/107) as an indicator to it, while well (L/47) represents the south of Gaza Strip (Khan Younis). Water level of both the wells showed response to rainfall. Figures 6a and 7a show the distribution of rainfall in three consecutive years in the north and the south, respectively, while Figures 6b and 7b show the response of groundwater levels in monitored water wells that are located in the same areas represented by the measured rain stations.

In November 2004, at the beginning of rainy season, water level was measured to be −0.581 amsl and increased to −2.001 amsl in March 2005, which is the end of the rainy season giving a total increase of groundwater level of + 0.58 m. In the water well L/47 representing the south in Khan Younis area, the water level was −5.1 amsl in November 2004 and increased to −4.3 amsl in March 2005 giving an increase of + 0.8 m. These examples give an indication that the groundwater system has fast response to rainfall and this encourage harvesting all of urban stormwater as one of the most important sources in Gaza.

Figure 6a Rainfall in north Gaza

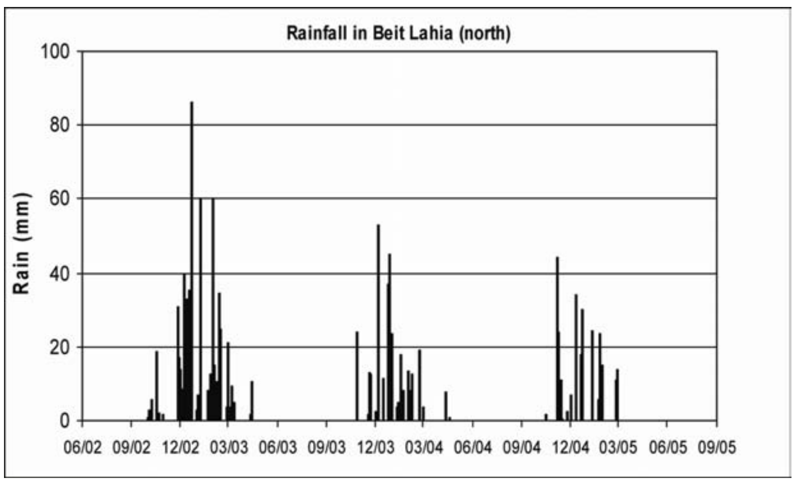


Figure 6b Response of groundwater level in well (A/107)

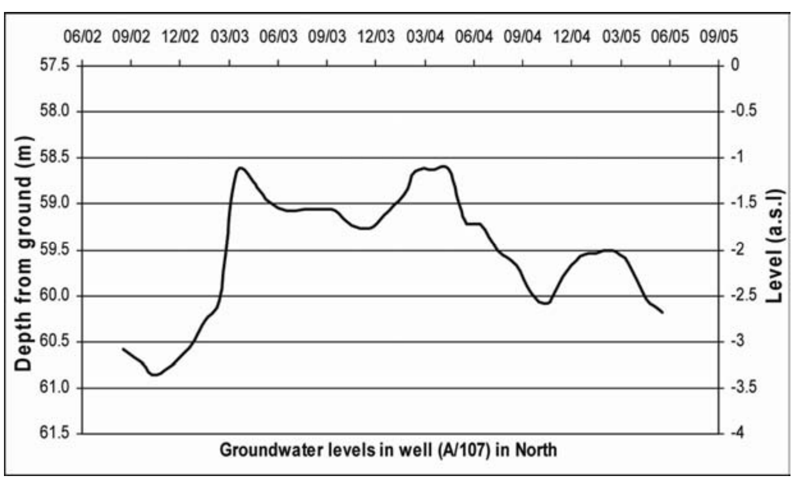


Figure 7a Rainfall in south Gaza

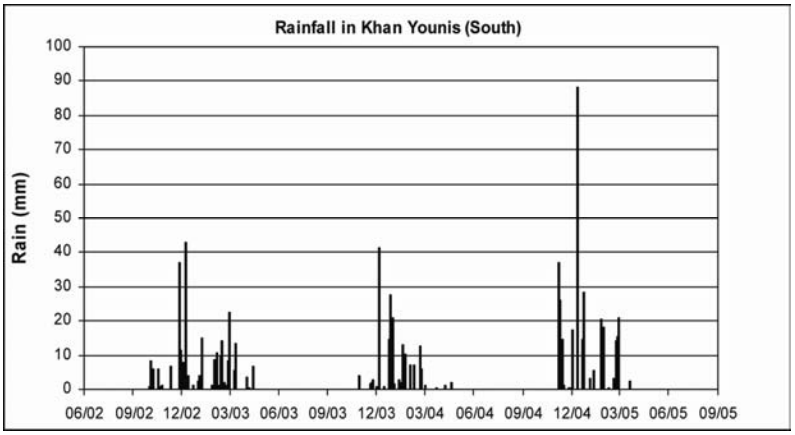
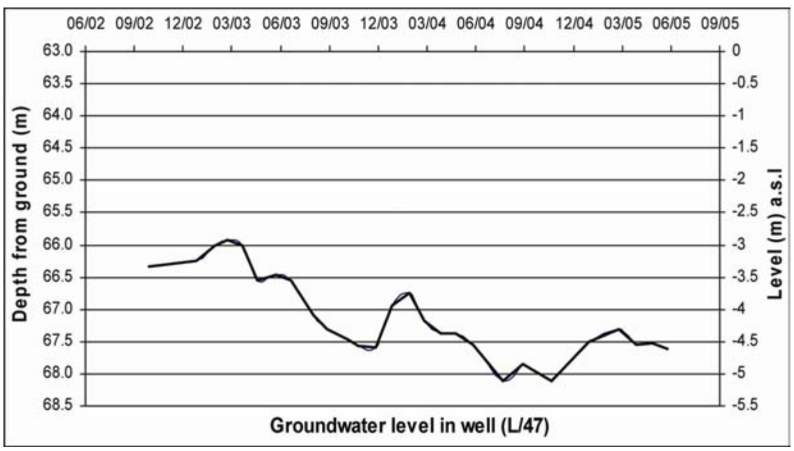


Figure 7b Response of groundwater level in well (L/47)



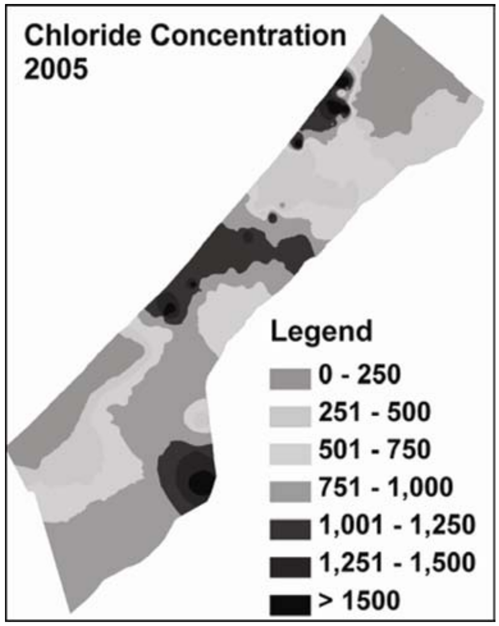
3.2 Response to abstraction

The in-flows to aquifer are estimated to be 107.9 Mm^3 every year coming from natural infiltration, irrigation return flow, percolation pits of wastewater and artificial recharge of stormwater in the year 2005 (CAMP, 2000). The total demand is estimated to be 162.1 Mm^3 in the year 2005 to fulfil the domestic, industrial and agricultural needs (Mushtaha and Al Dadah, 2006). The gap between total demand and total supply gives us a total deficit in the water budget in year 2005 of about 54.2 Mm^3.

The accumulating deficit every year led to continuous decrease in the groundwater levels that became few metres below the mean sea levels especially in the south in Khan Younis and Rafah, where groundwater levels reached <5m below sea level (see Figure 2). The quality of the groundwater was also deteriorated, where chloride level (salinity) increased in water pumped from almost all the water wells either for domestic or agricultural uses. The chloride concentration all over the Gaza Strip is shown in

Figure 8 The fresh zone is still available in the north of Gaza due to high rainfall amount (450 mm per year) compared to the south (200 mm per year). In some areas, salinity reached more than 1,500 mg l^{-1} as chloride ion.

Figure 8 Chloride contents in Gaza aquifer



According to the groundwater numerical model for the Gaza Strip in Qahman and Larabi (2006) if the situation continues in the same manner, seawater intrusion with total dissolved solids concentration of 2,000 mg l^{-1} at the base of sub-aquifer (*A*) will move 1.5 km in the year 2020 in the northern part of Gaza (Qahman and Larabi, 2006). This will affect the quality of domestic wells used for public water supply based on the quality data of domestic wells (PWA, 2004). The WHO standard for chloride is 250 mg l^{-1} and the Palestinian standard is 600 mg l^{-1}. Results indicated that out of 99 monitored domestic wells, only 42 wells comply with the WHO standards and only 65 comply with the Palestinian standard (PWA, 2004).

4 Quantification of potential stormwater

The potential quantities of stormwater runoff are based on the land use of the Gaza Strip. A detailed map of land use was derived from an aerial photo made in the year 2003 as shown in Figure 5. The landuse includes both existing and planned uses, so values of runoff were calculated twice, one for the existing and the second for the planned uses as shown in Table 1.

Table 1 Runoff coefficient of existing and planned land uses

Planed landuse	*C of planned landuse*	*Existing landuse*	*C of Existing landuse*
Airport	0.8	Airport	0.8
Built-up areas	0.865	Built-up areas	0.865
Cultivated	0.15	Cultivated	0.15
Cultivated by wastewater	0.15	Cultivated	0.15
Existing industrial area	0.865	Existing industrial area	0.865
Fisheries site	0.865	Fisheries site	0.865
Free trade zone	0.865	cultivated	0.15
Harbour	0.865	Harbour	0.865
Natural resources 1–3	0.075[a]	Important natural resource 1	0.075[a]
Mawasi	0.075[a]	Mawasi	0.075[a]
Natural reserve	0.075[a]	Natural reserve	0.075[a]
Proposed industrial areas	0.865	cultivated	0.15
Recreation	0.075[a]	Recreation	0.075[a]
Solid waste disposal site	0	Solid waste disposal site	0
Tourism development	0.325	Natural reserve	0.075[a]
Urban development	0.865	Cultivated	0.15[a]
Wastewater treatment site	0	Cultivated	0.15

[a]Runoff coefficient of these land uses that lie over sand dunes were set as zero except for urban development land uses for planned phase.

The urban and industrial development, harbour, free trade zone and tourism development are still not on ground but planned to be. Their land uses at the moment are agricultural and natural reserve areas. The runoff coefficient in each land use was taken as the average value of the range of coefficient. For example, for urban areas, which are composed of roofs and streets, the range of runoff coefficient in Kiely (1996) was 0.78–0.95. For this category available in Gaza Strip, the runoff coefficient was taken as 0.865. Also, for areas with top soil of clay, the runoff coefficient was taken as 0.15 which is the average of the range given by Kiely (1996) which is 0.13–0.17. Moreover, urban development is now open agricultural area with runoff coefficient of 0.15 as clayey soil, while it will be a built-up area of runoff coefficient of 0.865 in the future. The studied zones Z1 until Z7 with landuse are shown in Figure 5. However, the stormwater was calculated for both planned and existing land uses.

So, the runoff coefficient is applied to calculate the runoff quantities as stormwater in both urban and suburban areas for each zone in the Gaza Strip. ArcGIS produced the areas of the polygons of land uses. The summation of overall quantities is summarised in section of Results. In these tables, the area of urban development lay over sand dunes have not been deducted when calculating the stormwater runoff for planned phase since these surfaces will be built-up areas.

5 Results

In the urban areas, the total amount of runoff for the whole Strip at the existing land use was found to be 22.2 Mm^3 per year as collected stormwater runoff. After the built-up areas increase according the planned landuse, where the urban development will be built-up area, and consequently the amount of the stormwater will increase to 36.7 Mm^3 per year as shown in Table 2.

Table 2 Stormwater quantities from urban areas

Zone number	*Stormwater from planned urban areas (m^3)*	*Stormwater from existing urban areas (m^3)*
Z-1	3,241,240	1,930,223
Z-2	1,988,748	1,592,089
Z-3	13,285,452	7,631,877
Z-4	3,994,871	3,849,240
Z-5	1,544,591	996,727
Z-6	8,218,917	3,418,421
Z-7	4,398,217	2,755,369
Total in m^3	36,672,035	22,173,946
Total in Mm^3	36.672	22.174

Table 3 summarises the stormwater quantities produced from suburban areas. The stormwater comes from cultivated areas, reserve areas, natural resources (sand dunes) and recreation areas will increase also from 5.7 Mm^3 per year in existing phase to 5.9 Mm^3 per year in planned phase, where some cultivated areas in the existing situation will change to tourism areas. The overall quantities of stormwater are now 27.8 Mm^3 per year and will increase to 42.6 Mm^3 per year when planned landuse is implemented as shown in Table 4.

Table 3 Stormwater quantities from suburban areas

Zone number	*Stormwater from planned suburban areas (m^3)*	*Stormwater from existing suburban areas (m^3)*
Z-1	574,864	574,864
Z-2	151,014	43,558
Z-3	479,256	464,203
Z-4	1,177,727	1,197,542
Z-5	862,053	861,795
Z-6	1,607,179	1,577,813
Z-7	1,073,181	945,729
Total in m^3	5,925,274	5,665,504
Total in Mm^3	5.925	5.666

Tables 2–4 show the summary of calculations in all Thiessen polygon zones from Z1 until Z7. The total amounts were also shown in these tables.

Table 4 Stormwater quantities from the whole areas

Zone number	*Stormwater of all planned landuse (m^3)*	*Stormwater of all existing landuse (m^3)*
Z-1	3,816,104	2,505,088
Z-2	2,139,761	1,635,648
Z-3	13,764,709	8,096080
Z-4	5,172,599	5,046,782
Z-5	2,406,643	1,858,521
Z-6	9,826,095	4,996,234
Z-7	5,471,398	3,701,098
Total in m^3	42,597,309	27,839,450
Total in Mm^3	42.597	27.839

6 Discussion

Palestinian Water Authority (PWA) has identified the resource of stormwater harvesting as an important resource to bridge the gap between water resources demand and supply. Its strategy was to maximise rainwater recharge as far as practical by recharging runoff from large surface areas and introduction of flood alleviation measures at the source (PWA, 2000). The stormwater will be increased due to urbanisation and runoff water will increase. So, some stormwater facilities were proposed by the stormwater master plan to mitigate floods and harvest the collected stormwater. The initial amounts of artificial stormwater recharge are estimated to be 4.25 Mm^3 per year at 2005 and will increase to reach only 7.1 Mm^3 per year in the year 2020 (CAMP, 2000), where this forms only 30% of stormwater coming from urban areas (22.2 Mm^3 per year).

From the results shown in Tables 2 and 3, there are runoff waters of about 27.8 Mm^3 per year and this will increase to about 42.6 Mm^3 per year when the planned landuse is implemented in the coming decade. Until now, this runoff is still used partially in different projects of rainwater harvesting in the Gaza Strip, and some projects faced difficulties in implementation.

There are projects for stormwater collection, but they serve flood mitigation measures only, without harvesting it for recharging the aquifer. Most of this water is pumped to the sea. Stormwater harvesting became a priority issue firstly to mitigate flooding and secondly, to add to the existing limited water resources.

6.1 Implemented projects

Since the mid-1990s, large projects were identified in the Gaza Strip. One large project was executed in Gaza city, the second one was done in North governorate while the third one was made in a city in the south of the Gaza Strip. Other small schemes were executed also to act as local infiltration for different sites in the Gaza Strip. The first project was constructed in 1995 to collect runoff from Gaza city and water was artificially recharged to groundwater through injection wells. Owing to lack of experience and control, these wells were not operated well, and the collected water has to be pumped to the sea or evaporated in the lagoon. The level of water reached several metres in the rainy events, and the estimated in-flow water to the lagoons is about 7 Mm^3 every year, which is wasted to the sea (PWA, 2006). The infiltration from the lagoon bottom is very little since the bed soil is silty clay and does not allow water to infiltrate. It only mitigated the winter flooding from which Gaza city suffered for many years, while the second goal is still not achieved. If the collected amount is recharged to the aquifer, this will decrease the existing water deficit by about 13%, i.e. 7 Mm^3 per year out of total deficit of 54 Mm^3 per year (CAMP, 2000).

The second project was implemented in 1999 North Gaza to collect the stormwater from Jabalia Camp, which also suffered a lot from flooding. The stormwater is collected as surface runoff on the streets and directed to a pool, and then pumped to designed infiltration basins close to the existing wastewater treatment plant in the north. The estimated amount of stormwater collected at that pool is about 2 Mm^3 per year (Sida, 1999).

A third large project was implemented partially in a city in the south of Gaza Strip. All the urban stormwater collected from city is directed as surface runoff to constructed pipes and box culvert through constructed gullies. The collected water is directed by gravity through the main box culvert to a large infiltration area of about 10 ha. The water quantity flowing to the basin was estimated to be about 4 Mm^3 every year (PWA, 2006). It was supposed to construct gabions surrounding the basin and drilling of boreholes to increase the infiltration capacity of the basin. However, these activities were hindered due to political situation at that time in the year 2001, since it was close to an Israeli settlement.

Other three small infiltration basins were constructed to allow water infiltrating from local areas around. One basin is Waqf reservoir in Gaza city, while the other two basins are located in Khan Younis area and called playground and Samasma basins. The large and small infiltration basins could provide about 14 Mm^3, which amounts about 60% of potential urban runoff every year when they are operated in their capacities which is the target of PWA in its strategy. This will decrease the deficit of 54.2 Mm^3 per year by about 26%. The remaining deficit in the water budget is supposed to be bridged through large-scale seawater desalination and reuse of treated wastewater through infiltration and direct use in agricultural uses. Therefore, stormwater management will have an important role together with desalination and wastewater reuse to enhance groundwater system in the Gaza Strip.

6.2 Constraints

Management of the existing infiltration basins is facing many difficulties due to the lack of other infrastructure. In the project in the southern city (Khan Younis), most of the city is not served by a sewerage system and all the people are using local percolation pits to dispose wastewater. Due to unstable political atmosphere, there is no perfect control on misuse of existing stormwater infrastructure, where local people connect their percolation pits on the stormwater pipes and take environmental risks on the quality of infiltrated water. Many actions are taken by the municipality to stop this behaviour of local people, but the control is not perfect.

In Beit Lahia (north Gaza), infiltration basins are used for stormwater infiltration in the rainy season. In summer season where there is no rainfall, these basins are used for infiltration of treated wastewater coming from the existing neighbouring wastewater treatment plant to mitigate flooding of wastewater in the wastewater lagoon and collapse of lagoon shoulders. According to the water strategy, the recharged treated wastewater should be pumped through recovery wells and pumped for agricultural uses. On the other hand, when stormwater is artificially recharged to the aquifer, the pumped water could be used for domestic purposes. This activity hindered the function of the infiltration basins, for which they were constructed.

In the third large-scale project, in Sheikh Radwan pool, most of the collected water is wasted to the sea through direct pumping from the lagoons. It was designed to recharge the aquifer through injection wells, which were never operated. These large amounts of water should be pumped to suitable infiltration basins.

7 Conclusions and recommendations

Urban stormwater harvesting is an important water resource that plays a significant role in enhancement of water resources management in Palestine, in general and in the Gaza Strip in particular. It has a potential input of about 22 Mm^3 every year from urban areas only and about 28 Mm^3 per year as runoff from the whole Gaza Strip in its current landuse. This will help in bridging of about 60% of existing water deficit in the water budget.

These amounts of stormwater in the Gaza Strip will reach about 37 Mm^3 per year from planned urban areas. The amount of runoff of the completely planned area is calculated to be about 43 Mm^3. When urban expansion is implemented as planned, the natural infiltration of rainfall to the aquifer will decrease, and these amounts of runoff are good resources to be utilised.

So, more stormwater harvesting projects are needed to help in decreasing the water deficit in the water resources budget. Some large-scale stormwater harvesting projects were constructed in north and south of Gaza Strip, but there was not perfect control to avoid risky behaviours of the local people that hinder the function of these projects. Some small infiltration schemes were implemented too to allow local infiltration from nearby areas.

The natural recharge of rainfall is about 40% of the total bulk rain quantities fallen on the Gaza Strip with an average of 117 Mm^3 every year. The rest of water that flows to the sea or evaporated could be harvested through the constructed infiltration basins.

Owing to the existing deficit in the water budget, the groundwater quality was deteriorated and salinity reached more than 1,500 mg l^{-1} as chloride ion. Moreover, the groundwater levels were declined continuously and reach a level of 5 m below sea levels. If no action is taken in resources management, the groundwater system will reach a point, where remediation becomes very difficult. Therefore, stormwater harvesting together with other new resources such as large-scale desalination and reuse of wastewater will bridge the gap in the water deficit and protect the groundwater system and will be used in a sustainable state.

References

Al Yaqoubi, A.S. and Hamdan, S.M. (2005) 'Constraints facing water resources management in the Gaza Strip', *International Conference on Water Values and Rights*, Ramalla, Palestine.

CAMP (2000) *Coastal Aquifer Management Program – Palestinian Water Authority*, Gaza, pp.3–26.

Hamdan, S. (1999) 'Potential artificial recharge of groundwater in the coastal region in Palestine', *Thesis Report*, MSc Thesis, Department of Civil and Environmental Engineering, KTH, Stockholm.

Hamdan, S. and Jaber, I. (2001) 'Environmental criteria for urban expasion in the Gaza Strip', *Architects Association Conference, Tripoli, Libya*. Arabic Version: 4.

Hamdan, S. and Muhaisen, M. (2003) *Rainfall and Groundwater in the Gaza Strip Report*. Gaza.

Kiely, G. (1996) *Environmental Engineering*, Mulvancy 1851, Kuichling 1889 and Lioyd-Davis 1906 in G. Kiely (Ed.) (pp.187–199). Boston, MA: McGraw Hill. ISBN 0-07-116424-3.

Melloul, A. and Israel, N. (1991) 'Hydrological Atlas of Israel', *Southern coast-Gaza Strip*, Water Department, Ministry of Agriculture. Jerusalem (in Hebrew).

Mushtaha, A. and Al Dadah, J. (2006) *Agricultural and Municipal Water Demand in Gaza Governorates for 2005, Gaza* (p.11).

PCBS (2006) *Palestinian Central Beauru of Statistics, Palestine* (Arabic Version) (p.13).

PWA (2000) *National Water Plan, Final Copy – Palestinian Water Authority*, Gaza, West Bank.

PWA (2004) *Water Quality Assessment of Drinking Wells in the Gaza Strip*, Gaza.

PWA (2005) *Rainfall and Groundwater in the Gaza Strip Report*, Gaza (pp.3–7).

PWA (2006) 'GIS based water databases', *Palestinan Water Authority, Gaza*.

Qahman, K. and Larabi, A. (2006) 'Evaluation of numerical modelling of seawater intrusion in the Gaza aquifer (Palestine)', *Hydrogeology Journal*, Vol. 14, pp.713–728.

Swedish International Development Agency (SIDA) (1999) 'Stormwater and sewerage project northern Gaza', *Additional Studies. Final Report*, p.58.

Paper II

A literature based study of stormwater harvesting as a new water resource.

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A literature based study of stormwater harvesting as a new water resource

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ABSTRACT

Rainwater harvesting is an important new water resource that participates in bridging the deficit in the water resources in water scarce countries. It is not a new technology but it has been practiced in many countries for many years. From a quantitative point of view it makes a positive contribution to the water resources balance. However, the quality of this new water resource was under the subject of this study in addition to the historical and international experiences carried out in stormwater management. Rainwater harvested from rooftops was noted to be much cleaner than that coming from urban stormwater runoff. The water quality parameters in stormwater were examined with a focus on heavy metals such as Cd, Zn, Pb and Cu which are released in low pH values. Fortunately, heavy metals like other ionic bounds and metal oxide bounds are removed by precipitation or co-precipitation at high values of pH.

Key words | groundwater quality, heavy metals, rainwater harvesting, water resources

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INTRODUCTION

Increasing water demand as a result of population growth and industrialisation with limited water resources called for the need to manage water resources efficiently. Continuous urbanisation as natural output of population growth and industrialisation pressed the water resources in two dimensions, firstly increasing water demand and secondly decreasing the natural infiltration of rainfall to the underground aquifer. New water resources should be looked for. Among them are seawater desalination, domestic wastewater reuse and rainwater harvesting. The first option needs energy and it is feasible to be used in remote and very arid regions, where the energy needed to convey freshwater from distant areas is larger than the energy used to desalinate water. In some cases, political concern rejects this option on the account of commercial concern. The second option as reuse of treated domestic wastewater is a good option to fulfil the agricultural water demand, and this needs high level of wastewater treatment especially when treated wastewater is used directly for irrigating farms without undergoing soil aquifer treatment processes through artificial recharge of groundwater. The third option is rainwater harvesting which proved to have good water quality close to WHO drinking water standards.

Rainwater harvesting is basically a system of collecting rainwater from rooftops and yards in addition to urban stormwater coming from the remote catchments areas and the streets, and storing it as it is for later uses or artificially recharging it to replenish the groundwater basins. The rainwater harvesting level varies from household level to large-scale water harvesting projects. The quality of harvested rainfall is different from one place to another depending on the weathering conditions, traffic load on the streets, atmospheric pollution, the agricultural activities in the open catchments areas and other anthropogenic factors induced by humans e.g. waste and industrial activities, in addition to pollution occurred in the conveying system itself including water storage tanks and pipe networks. More attention of quality is considered when rainfall is collected in storage and redistributed for people for drinking purposes.

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Rooftops rainwater is relatively clean and easily accessible and stored in the aquifer through simple infiltration pits or trenches excavated for this purpose. In addition to conserving water resources, on-site rooftop rainwater harvesting minimizes local erosion and flooding contaminants mobility from pollution source to many places through stormwater runoff. This system has been practised in many countries since long time ago. Recently, rooftop rainwater harvesting is even used in water-rich countries e.g. Europe to irrigate gardens and minimize street flooding. In arid regions rainwater is used to fulfil domestic water demand.

Rainwater harvesting has been known for thousand of years in arid and semi-arid regions. It has been practiced in different areas in the Middle East, North Africa, Mexico and southwest USA (Rice 2004). Its history in Asia traced to about the 9th or 10th Century (GDRC 2008), where in rural areas of South and South-east Asia, they made small-scale collection of rainwater from roofs and simple dam constructions. Rainwater harvesting for water supply had been perfected in ancient times in different cultures. It is not a new concept for water resources management. It has been made by human activities for a long time, first known 3,000 years ago (RHG 2008). Human beings made the agricultural terracing of hills and water storage behind dams. It is also reported that 2000 years ago the Romanian builder Vitruvius created rain water collection plants (Borneff *et al.* 1996). The so called Atrium collected rain water flowing from the roofs into an overground and underground water basin that looks like bottle with small opening which was easily locked to protect water from external pollution. The world's largest (4000 m^3) single cistern was built under the rule of the Emperor Justinian and still today attracts tourists in Istanbul (Borneff *et al.* 1996). Also, in Palestine rainwater collection systems were known to have existed some 4,000 years ago in the semi-arid and arid regions of the Negev desert, which receives less than 150 mm of rainfall annually (Norhaiza 2004).

For example, in Thailand, rainwater collection from the eaves of roofs or via simple gutters into traditional jars and pots has been practiced for 2000 years (Prempridi & Chatuthasry 1982). Recently, about 40,000 well storage tanks in China were constructed in the period between 1970 and 1974 to store rainwater and stormwater runoff in ponds which are lined with red clay to minimize seepage (UNEP 1982). Rainwater harvesting was achieved through artificially recharging it to groundwater, with the construction of unlined canals that leak water to subsurface (Seiler & Gat 2007).

With the advance of technology, rainwater harvesting was developed to centralized systems of water collection, with pipes and collective communal systems. Stormwater management becomes a key factor in the planning of any new infrastructure to serve both flood mitigation and new water resource harvesting. Previous methods of stormwater runoff were to protect houses from flooding. Road runoff was overcome through draining it to a mixed system to convey sewage and stormwater to treatment plants. However, and after inducing the concept of rainwater harvesting, separate system of for stormwater pipe network was used to utilize this water, especially in the scarce-water countries, which are mostly exist in arid and semi-arid regions. These regions were classified (by Gerson *et al.* 1985) according to the annual precipitation as follow:

- Semi arid 400–250 mm/yr
- Moderately arid 250–150 mm/yr
- Arid 150–80 mm/yr
- Extremely arid $<$80 mm/yr

PLANNING CRITERIA

For planning of any stormwater harvesting system either for large catchments areas runoff or for rooftop, many factors should be considered in the design and implementation phases. These factors are related to rainfall, catchment's area type, topography, soil and formation, buildings and groundwater.

Rainfall

The quantity and quality of fallen rainfall are the key factors on the quality of running runoff over both roofs and roads. The total quantity of rainfall in each rainstorm, the rainfall intensity, return period and duration are used mainly in the design of the storage volume needed to absorb the collected stormwater. Rain showers, which tend to be local, strong and of short duration, are found in some countries mainly in tropical and arid zones (Seiler & Gat 2007). Rain showers are also found in middle east countries, for example, the maximum rainfall intensity in Negev exceeded 200 mm/hr measured in October 1979 in Mitzpe Ramon rain station (Lange 1999), although this area is classified as semi-arid region. The quality of fallen rainfall is a key factor especially in countries with high air pollution, and this could be found in Europe which has mostly acid rainfall with pH less than 5. In USA, Texas, pH was measured to be between 4.6 to 5.6 (TWDB 1997). In South America too, where bio-fuel is used and sugar canes are burnt, high organic carbon in the air is dissolved in the fallen rainfall, and consequently high concentration of organic carbon is encountered in the water runoff (Coelho *et al.* 2008). The risk of low pH comes from mobilization of metals in the solvent water (GDRC 2008).

Buildings

The building sizes, ages, location and layout when they are crowded, scattered or remote are key factors for estimating the runoff water comes from their roof. The quality of the running rain water over the roof is affected by the roof type if it is concrete, or covered by bitumen sheets, or clay tiles. For example, it was found that lead concentration in rain runoff from concrete roof was 1 μg/l, while it was 10 to 100 μg/l in runoff from clay tiles roofs (Bullermann *et al.* 1990). The use of the roof and its periodic cleaning will highly affect the quality of rooftop rainwater. The paved yards that belong to large building such as schools, universities, hospitals play a significant part in rooftop rainwater harvesting. Moreover, the roof type affects the value of pH which is a key factor in chemical precipitation of pollutants in stormwater runoff. When rainfall collides with concrete roof, for example, pH increases and running stormwater tends to be more alkaline which is a good media for heavy metal compounds precipitation (Bullermann *et al.* 1990).

Open catchments areas

The water runoff flowing on the streets come from streets themselves, the buildings in the cities or received from remote catchment's areas with different land uses. The soil cover and topography affects the runoff coefficient and consequently the overall quantities of received runoff at the plant. If these areas are used for agriculture, the water chemistry is affected by eutrificants e.g. nitrogen and phosphor in addition to pesticides. The water is expected to be highly polluted if it passes industrial zones or streets with bad controlled wastewater network, where sewage manholes are flooded in winter season and stormwater runoff is mixed with raw wastewater. Advanced techniques could be used including collection of runoff with drain pipes and storage of collected water which are suitable for agricultural purposes (GDRC 2008). Storage of collected runoff will protect this water from animal and bird drops. In case of using the stored water for artificial recharge of aquifer, it will also be purified through soil filtration in addition to biochemical processes.

Soil type

When deciding to divert the collected runoff to infiltration basins to replenish the groundwater system, the soil and underneath formation are the controlling factors. The infiltration capacity of the topsoil and its vulnerability to quick clogging has to be avoided. In some areas with suitable soil, infiltration spread basins are the cheapest and practical. However, in areas with non-permeable soil such as clay, boreholes are drilled to penetrate the latter areas until reaching the permeable formation. These boreholes are filled with coarse material e.g. sand and are called then sand piles. The soil type also plays an important role in the purification of the collected stormwater in the removal of organic matters and bacteriological pollution in addition to the sorption of heave metals in suitable pH values of the percolating water. The high permeable soils have the advantage of infiltration large quantities of stormwater, but on the account of pollutant removal. These types of soils such as soil and gravel have low pollutant removal/sorption ability and consequently lead to impaired use of the groundwater for domestic purposes. The sorption process occur in the saturated zone, where clay and silt proved to be efficient in removal of stormwater pollutants (Lee *et al.* 1998). So, continuous monitoring of both soil and ground water is needed to control both infiltration capacity and water treatment in the stormwater infiltration basins.

Groundwater system

When implementing artificial recharge of groundwater, three main aspects are considered which are quantities of recharged water, its quality and the hydraulic parameters of the receiving groundwater system. Most aquifers have larger horizontal dimensions than their depth, and the ratio between aquifer depth and its extension fluctuates between 1:1,000 to 1:10,000 in arid areas (Seiler & Gat 2007). This means that the impact of recharge has local effect on groundwater, and consequently most of the recharged water could be abstracted again from recovery wells around the infiltration zones.

Also, the groundwater table should be at sufficient depth from the floor of the infiltration system to give the chance of water purification in the unsaturated zone. As the treatment is affected by the soil it passes before reaching the groundwater, the quality of the ground water could be affected by the received percolating water, and consequently the groundwater has to be frequently monitored. The use of the groundwater in the zone of infiltration if it is used for drinking or agricultural purposes are important in designing the required special monitoring program for continuous testing of the impact of stormwater harvesting on the groundwater system in both quantitative and qualitative aspects. The local use of groundwater decides if the stormwater infiltration at that area is acceptable or not. For each use, such criteria are of concern. For drinking purposes, for example poisons, iron, hardness, dissolved solids and aesthetic are important. For irrigation purposes, boron, alkalinity, sodium-calcium ratio and dissolved solids are controlling (TWDB 1997). It is necessary to drill recovery wells around the infiltration zone to abstract the infiltrated water and distribute it based on its quality and fitness to different water purposes.

QUANTITATIVE ASPECT

The main goal of on-site stormwater harvesting is to decrease the quantities of stormwater running in the large-scale projects, and here the best management practices (BMP) is good to be introduced. According to (VANR 2002*b*) BMP as been defined as:

> Best Management Practices is to manage stormwater in different parts of the city in isolation from each other. BMP has the advantage of decreasing the peak flow in the main stormwater system.

Artificial recharge of groundwater was induced by humans in earlier times through making agricultural terracing in the hills and retaining of flood water after sand dams. Artificial recharge was made either unintentionally or intentionally. The first type is classified as incidental artificial recharge of groundwater and the second type as forced artificial recharge (Seiler & Gat 2007). Incidental recharge comes from the infiltration of irrigation water as return flow to the aquifer which comes through non efficient irrigation systems. Also, the seepage of wastewater percolation pits and unlined septic tanks is considered as incidental artificial recharge. The leakage of water from public water supply networks, which is considered as losses in the network, is recharging the groundwater. The infiltration of water at the bottom and sides of irrigation canals connecting the water source to the farms are also other example of this type. What meant by artificial recharge in most of literature is the second type which is the forced artificial recharge of groundwater and called in other researches as managed aquifer recharge. In this case, the water is directed from the source to injection wells or infiltration basins for storage goals, or pumped from groundwater wells besides river banks purification of river water.

The clogging of infiltration basins could be from suspended solids or fungi and bacteria in the soil where they surround themselves with netlike structures (Nilsson 1990). So, periodic scraping of infiltration basin bottom is necessary.

QUALITATIVE ASPECT

Dealing with stormwater harvesting, the water quality is of the most important rather than its quantity. It should be looked on the stormwater catchment to which extent it participates in stormwater pollution. In some extreme pollutant sources such as industrial areas and fuel station, these areas are likely to be more controlled and their stormwater runoff pretreated or diverted away to sewage networks before mixing with the main stormwater collecting system, and treated all the year as first flush stormwater that should always be diverted away from the stormwater harvesting system. The pollution sources were well classified by (VANR 2002*a*) as hot spot areas or not as shown in Table 1. The quality parameters are found to be in different degrees based on the land uses and activities in the catchments areas which are mainly discussed in following sections as rooftop rainwater catchments areas and road runoff stormwater.

Quality parameters

The quality of stormwater is influenced by the by different factors, air pollutants, roofs, yards and streets over which they are drained. Their storage and conveying media play an important role in the quality of collected stormwater.

Major cations and anions

It is meant here the major cations excluding heavy such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and Mn^{2+} and major anions in particular, NO_2^-, NO_3^-, Cl^- and SO_4^-. Sodium chloride is influenced by seawater. Low pH value is expected in industrial countries with acid rain due to large quantities of gas emissions such as carbon dioxide.

Organic matters

Organic matter content in stormwater depends mainly on the local conditions and frequent cleaning of the catchments area either roofs, roads or open areas. Its main sources come from leaves, organic materials and wastewater leakage which are difficult to quantify. Organic matter is found in the form of many constituents such as organic acids, fats, amino acids, proteins, carbohydrates and others all containing carbon. So it is difficult to measure all organic matters, and it was common in scientific researches in this field to measure BOD, COD and TOC as indicators of organic matter in water. The organic matter is normally degraded in the unsaturated zone where they are adsorbed to soil particles. The temperature has little effect on treatment efficiency except for close to freezing point (Nilsson 1990). However the organic matter removal is highly dependent on soil material, the hydraulic load of the infiltration basin, the organic load in the water and the depth of unsaturated zone. The percent removal will decrease with high hydraulic load, and increases with increase of organic load and unsaturated depth. From field experiment reported by (Canter & Knox 1985), it was found that the treatment efficiency of organic matter in the mixed soil and clay at 1.5 m below the infiltration basin is summarized in Table 2.

Table 1 | Land uses and activities to be considered in stormwater harvesting*

Hot spot land uses and activities	Non hotspot land uses and activities
Vehicle salvage yards and recycling facilities	Residential streets and rural highways
Vehicle fueling stations	Residential development
Vehicle service and maintenance facilities	Institutional development
Vehicle and equipment cleaning facilities	Office developments
Fleet storage areas (bus, truck, etc.)	Non-industrial rooftops
Industrial sites	
Outdoor liquid container storage	
Outdoor loading/unloading facilities	
Public works storage areas	
Facilities that generate or store hazardous materials	
Commercial container nursery	

*VANR (2002*a*).

Table 2 | Organic matter removal through infiltration*

Parameter	Min. load (mg/l)	Removal efficiency (%)	Max. load (mg/l)	Removal efficiency (%)
BOD	140	80	666	87
COD	240	76	2,026	93
DOC (Dissolved Carbon)	24	71	190	91

*Based on Canter & Knox (1985).

The treatment of organic matter in stormwater is the same. Also, to get indication of their contents, the parameters commonly recognized are biological oxygen demand (BOD_5), chemical oxygen demand (COD) and total organic carbon (TOC) which became an easy method to obtain a rapid and reliable statement about the organic load of the water sample. Dissolved organic carbon (DOC) has also become internationally recognized which does not include the carbon is suspended particles as the case of TOC.

The organic matter in rain runoff over roofs depends mainly on the local cleaning and the roof material itself. According to Bullermann *et al.* (1990), it was found that COD in the flowing rainfall runoff over roofs in Germany depends mainly on the roof type itself. It had average values of COD of 22 mg/l, 38 mg/l and 88 mg/l in flowing rainfall runoff over roofs of tiles, concrete and bitumen respectively. In the same research TOC had the same trend among the three types of roofs. The average values of TOC were 6.4 mg/l, 11.0 mg/l and 27.4 mg/l in flowing rainfall over the roofs of tiles, concrete and bitumen respectively, and this gave TOC:COD ratio of about 1:3 which is obtained normally in wastewater. On the other hand, availability of organic matter has its advantages in the precipitation and co-precipitation of heavy metals. The organic matter will be degraded using oxygen from Mn oxides, Fe oxides, SO_4^{2-} and CO_2 (Song & Müller 1999). Since organic matter is expected to be low in stormwater, the removal efficiency is expected to be 70%–80%.

However, the bacteriological contamination is expected to be found in all types of stormwater collected either from rooftop or from road runoff. The allowable limits of total coliform and faecal coliform were set by WHO to be zero in drinking water. From analyses of number of collected rainwater samples, their values have exceeded the WHO values in terms of total coliform and faecal coliform (Norhaiza 2004; GDRC 2007). The bacteriological pollution is expected to be removed totally through the soil aquifer treatment processes associated with the artificial recharge in the infiltration basins.

Heavy metals

The reduction of SO_4^{2-} during the degradation of organic matter leads to production of HS^-, and iron, copper, cadmium, lead and zinc are which precipitated according to the following equations:

$$Cu^{2+} + HS^- \rightarrow CuS + H^+ \quad (1)$$

$$Fe^{2+} + HS^- \rightarrow FeS + H^+ \quad (2)$$

$$Cd^{2+} + HS^- \rightarrow CdS \downarrow + H^+ \quad (3)$$

$$Pb^{2+} + HS^- \rightarrow PbS \downarrow + H^+ \quad (4)$$

$$Zn^{2+} + HS^- \rightarrow ZnS \downarrow + H^+ \quad (5)$$

A significant release of heavy metals (Cd, Zn, Pb, and Cu) during the oxidation of anoxic sediments occurs only at low pH values below 4.5. Above this pH value, dissolved heavy metals are absorbed onto Fe and Mn oxides surfaces. So, pH value is a key factor for the mobility of heavy metals in both infiltrating water and in the soil at the bottom of the infiltration basins. Pb and Cd could be absorbed on other particles such as Fe/Mn oxides and clay minerals, and consequently Pb and Cd in pore water would be too low to be detected. In contrast, at low values of pH heavy metals are released due to oxidation of sulfides. In contrast, at low values of pH, heavy metals are released due to oxidation of sulfides (Song & Müller 1999) according to the following equation:

$$FeS + 9/4O_2 + 5/2H_2O \rightarrow Fe(OH)_3 + SO_4^{2-} + 2H^+ \quad (6)$$

Cadmium. Cadmium is commonly associated with Zinc in carbonate and sulfide. It is transported by air current as a pollutant. Soil conditions like temperature, pH, humus, clay materials, and hydrous oxides of iron, manganese and aluminium are significant for the circulation processes of cadmium. Cadmium exists in the earth crust at average values of 0.11 ppm (Låg 1991). Beyond the threshold point when pH exceeds seven, cadmium like all metal ions is adsorbed to soil or sediments. It is widely used by humans in medical products, shavers, drills and hand saw, and cadmium phosphors are used also in TV tubes, x-ray screens fluorescent lamps and others (Moore & Ramamoorthy 1983). Cadmium is precipitated in high value of pH according to the Equation (3) earlier mentioned. The allowable level of cadmium in drinking water was set by WHO as 3 μg/l due to its high toxicity. Some studies showed that there is relationship between exposure to cadmium and cancer incidence (Kjellström *et al.* 1979), where its toxicity comes through accumulation of cadmium in organs and having long half-life (10–30) years.

Lead. Lead is mainly used in batteries and produced during the combustion of fuel in automobiles which is absorbed by humans. Lead compounds such as halides, sulfates, phosphates and hydroxides are insoluble and with low toxicity in aquatic systems and there is strong association of lead with urban airborne particulates since 50% of the total inorganic lead is absorbed by humans (Moore & Ramamoorthy 1983). Lead is also precipitated in high value of pH and existence of organic matters according to the Equation (4).

Chromium. Chromium is widely used by humans in manufacturing stainless steel, pointing water pipes and chrome plated metals. Two forms of chromium are found: hexavalent (Cr^{+6}) and trivalent (Cr^{+3}). The first form is more toxic than the second one because of the high rate of adsorption through intestinal tracts of the hexavalent. Fortunately, stomach acidity reduces (Cr^{+6}) to much less toxic (Cr^{+3}) form whose gastrointestinal absorption is less than 1%. So, chromium is considered as less toxic than other heavy metals such as cadmium, copper, lead, nickel and zinc. However, according to Sittig (1980) epidemiological studies have shown relationship between exposure to chromates and cancer incidence.

Copper. It is widely spread in its free state and in sulfides, arsenide, chlorides and carbonates. It is used mainly in electrical installation, plumping and souvenirs. It is found also in compounds with organic and inorganic matters. It forms complexes with hard bases like carbonate, nitrate, sulfate, chloride, ammonia and hydroxides (Moore & Ramamoorthy 1983). Copper is precipitated in high pH according to the Equation (1).

Zinc. Zinc is found mainly in carbonate rocks and within dolomite and calcite minerals. It is widely used in galvanizing iron and water pipes since it is corrosion resistant material. It is also used in roof of corrugated steel sheets, automobile, office equipment, heating and ventilation ducts. Zinc is also precipitated in high pH according to the Equation (5).

Quality of pure rainfall

During precipitation there are inorganic acid compounds resulting from solution of air carbon dioxide and nitrogen oxides in addition to other organic compounds. This decreases the pH value of the fallen rainfall to different extents depending on the place and the air pollution from industrial gas emissions. The dust and aerosols available in the air are washes down with rainfall. In some countries where bio-fuel is used, dissolved carbon is observed clearly in the rainfall. In Brazilian where sugar cane burnt, the air is heavily polluted by organic carbon which is dissolved in falling rainfall.

The dissolved organic carbon (DOC) in fallen rainfall was measures in the state of Sao Paulo in south east of Brazilian by Coelho *et al.* (2008) in three years' research (2004–2006), in which sugar canes are heavily burnt. There was clear influence on the DOC value in the falling rainfall which also 0.95 mg/l to 3.1 mg/l in non-harvesting period, while in harvesting period it increased to the range 1.6 mg/l to 5.09 mg/l. In other countries like Germany, industrial emission is the source of dissolved inorganic carbon resulting in low values of rainfall pH. According to Borneff *et al.* (1996)

Table 3 | Rainfall quality in cities in Germany*

Parameter	Unit	Analysis result
pH	–	5.1
Electrical Conductivity	μS/cm	49.8
Ca++	mg/l	1.1
Mg++	mg/l	0.2
NO_3^-	mg/l	4.7
Cl^-	mg/l	2.9
SO_4^-	mg/l	9.6
Cd	μg/l	0.4
Cr	μg/l	0.9
Pb	μg/l	5.3
Zn	μg/l	25.7

*Borneff *et al.* (1996).

water samples were taken from different cities in Germany in the period 1974 until 1994. The results are summarized in Table 3.

Quality of urban stormwater

Stormwater harvesting could be distinguished into two main types; rooftop rainwater or runoff including the yards of the houses, and the rain runoff flowing over the open areas i.e. catchments areas, where part of water either partially infiltrates or evaporates and the rest flow over the roads to depressions in form of valleys and lagoons. In this study, the first type of runoff water is recognized as rooftop rainwater, and the second type is recognized as the road runoff water.

Rooftop rainwater

It was reported that pathogen levels in roof water are usually lower than those recorded in stormwater, with pathogens mainly sourced from faeces of birds and small animals (AEPHC 2008). However, the rainwater quality is affected after its running over the roof. The degree of influence depends mainly on the roof type. Roof water takes contents of sulfate, nitrate and heavy metals e.g. lead, cadmium, copper and zinc in addition to organic contents. High heavy metals concentrations are found in the industrial areas, where the quality depends on roof type and its location, if it is residential, industrial or commercial places. The pollution depends also on the age of the concrete and bitumen roofs. The metals and depositions are more in concrete than those in water running over tiles. However the concentrations of metals could not reach or be almost around the standards of the drinking water.

The accumulating deposited dusts on the roofs, yards and streets during the dry period are also participating in changing the quality of the running stormwater. As a consequence of dry deposition on the roof, precipitations can be polluted in notable amount including organic and inorganic matters. Such pollutants like aromatic hydrocarbons, organically bound halogen compounds and heavy metals arrive with the water drops in the atmosphere, and adsorbed by the roofs which are washed away by rainfall (Rott 1994).

The most common roofs are: (i) concrete roofs (ii) tile roofs, (iii) bitumen roofs, (iv) asbestos roofs and (v) metal roofs. Each roof type has its advantages and disadvantages.

(i) The concrete roofs which include alkaline material calcium carbonate and the dust particles accumulated at the roof in addition to some depositions come directly from the roof itself as a result of its weathering. Also they are good environment for depositions with degree depending on their ages. This will change the quality of the flowing rainfall and increase the pH value, and this has positive effect on removing heavy metals. This increases the adsorption of lead and cadmium compounds with the dust particles in high pH values. For example it was found from researches in Germany that the concentration of lead in the water flowing over concrete roof less than 1 μg/l while it mostly fluctuated from 10 to 100 μg/ in water flowing over clay tiles roofs (Bullermann *et al.* 1990).

(ii) Tile roofs which are smooth surfaces roofs including inclined clay tiles and horizontal tile. Consequently, their influence on the quality of running rainfall is little (Rott 1994).

(iii) Bitumen roofs which contain oil products. It is suspected to lead to cancer for long skin contact in addition to unpleasant smell and a yellowish coloring of the roof runoff (Michaelidis & Young 1983). In laying the strips of bitumen on roofs, they contain quartz gravel and sand, which in turn play an important role in adsorption of heavy metals in the existence of high pH values, and consequently these roofs could be utilized for rainwater harvesting.

(iv) Asbestos contain materials with known negative environmental impact. It has toxic dust which enters directly to the human body (Rott 1994). It is not recommended to harvest rainwater for drinking purposes.

(v) Metal roofs can increase metal contents in the roof rainwater such as corrugated steel sheets which are manufactured from galvanized steel or coated with chromium.

Road runoff water

Road runoff which flow over the catchments areas which are commercial, industrial, residential and agricultural in addition to the streets themselves catch with it different types of pollutants to the collection area. The potential sources of pollution could be from the mineral oil products e.g. fuel and lubricants, fertilizers and pesticides used in the agricultural areas indicated in nutrients matters such as nitrogen phosphorus and heavy metals. Potential sources of heavy metals in the street rain runoff come from automobile tires and the mud deposited on the street. Other chemical constituents, such organics, pesticides, petroleum hydrocarbons, oil and grease, etc., pathogenic organisms, such as bacteria, viruses and protozoan parasites are found in road runoff (Lee *et al.* 1998). A research done on the content of heavy metal in both automobiles tires and runoff sediments deposited on the streets was done in the city of Heidelberg in Germany, and these values are shown in Table 4 based on (Metzler 1984).

The high pollution of road runoff sediments comes normally from its adsorption of heavy metal in the runoff water itself in high values of pH. So, the main pollution of road rain runoff comes from traffic, as fuel consumption oil and lubricants products and in some cases as a result of road accidents. In some researches carried out in Germany in the seventiesit was found that road runoff was mainly polluted mainly by chloride (108 mg/l), cadmium (6 μg/l), lead (202 μg/l), zinc (360 μg/l) and iron (3.42 mg/l) as weighted average (Krauth 1979). Other heavy metals come mainly from traffic and the dry deposits during the dry period.

Table 4 | Content of heavy metals in automobile tires and street mud*

Metal	Unit	Tire material	Street runoff sediments
Lead	mg/kg	10–100	43–4,500
Cadmium	mg/kg	1–5	–
Zinc	mg/kg	10–12	52–3,600
Copper	mg/kg	–	9–727

*Based on Metzler (1984).

INTERNATIONAL EXPERIENCES

Rainwater harvesting has been practiced recently in many areas in many countries and achieved success of the results in their integrated water resources management. Some international experiences in, but not limited to some countries are discussed in the following sections.

Australia

In Mount Gambier city of with area of 27 km^2 population of 23,000 people in south east corner of South Australia use recharged storm water coming from 300 catchment's drainage areas and recharged through 500 boreholes in unconfined karstic limestone aquifer since 100 years. Recharged stormwater is pumped then for public water supply after it was treated through recharging it to the aquifer and recovering it back. From the risk assessment organic chemical hazards study carried out at this city it was reached that the aquifer treatment was good and enough so that recovered water could be used for drinking purposes (Vanderzalm *et al.* 2007).

Bangladesh

The rainwater is collected in house storage tanks and used later for drinking and cooking. Its use is increasing amongst local people. Water quality testing has shown that water can be preserved for four to five months without bacterial contamination (GDRC 2007). The tanks used for this purpose ranged from 500 to 3,200 litres.

Figure 1 | Rainwater Harvesting in Potsdamer Platz-Berlin after (Kintat 2002).

Germany

In Berlin, rainwater utilization systems were introduced in 1998 as part of a large scale urban development at Potsdamer Platz, to control urban flooding, save city water and create a better microclimate (Figure 1). Rainwater is collected from rooftops of total area of 32,000 m^2 of 19 buildings and stored in a 3,500 m^3 rainwater basement tank (GDRC 2007). Then this water is reused for garden, toilet flushing and car washing. It saved about 2,430 m^3 per year from the municipal potable water supply since 1998 until now.

In other cities, Süßenmüle and Karlsruhe, the quality of stormwater coming from roofs proved to be clean. As in many other countries, a decision for example has been taken by Karsruhe city planning to use the draining roof rainwater on-site at houses where it will improve the groundwater and clean the soil after the clean results of roof water quality which is shown in Table 5 (Maier *et al.* 2004). The city planning decided to separate the roof rainwater away from the city stormwater collection system either separate systems or mixed system with sewage.

In other two areas, Darmstadt and Kassel in Germany, the four main heavy metals were measured for their averages in the overflowing rainwater over both inclined clay tiles roofs and concrete roofs. A comparison between both roofs' waters shown in Table 6, which is based on Bullermann *et al.* (1990).

Table 5 | Heavy metals in roof water in the German cities Süßenmüle and Karsruhe

	Maximam conzentration	
	Station Süßenmühle	Station Karlsruhe
Iron (µg/l)	30	418
Copper (µg/l)	17	117
Zinc (µg/l)	127	482
Lead (µg/l/l)	57	14
Cadmium (µg/l)	30	–

Greece

In Kefalonia island in the municipality of Erisos in northern Greece has a total area of 78 km^2 are harvesting rainwater in 23 ferroconcrete rainwater storage tanks constructed in 1970s and located at the bottom of cement-paved hill slopes serving as catchment areas fluctuating from 600 m^2 to 3,000 m^2 (Sazakli *et al.* 2007). The collected rainwater is then distributed by local authorities to household as pure collected rain or mixed with groundwater. The water quality was good according to chemical analyses but not suitable for drinking in terms of biological pollution which needs to be treated (Sazakli *et al.* 2007). The heavy metals of these samples are summarized in Table 7. The average pH of the runoff water was 8.31 and this helps in the removal of the remaining metals.

Japan

In Sumida City, the Ryogoku Kokugikan Arena is utilizing rainwater on a large scale. The rooftop with area of 8,400 m^2, rainwater is collected and drained into a 1,000 m^3 underground storage tank and used for toilet flushing and air conditioning (GDRC 2997). Later about 750 private and public buildings in Tokyo have introduced rainwater collection and utilization systems.

Table 6 | Heavy metals in water runoff over concrete and clay tile roofs

Metal	Unit	Concrete roof	Inclined clay tile roof
Fe	µg/l	60	30
Pb	µg/l	50	30
Cd	µg/l	1	1
Zn	mg/l	1.6	1.6

Table 7 | Average values of metals in Kefalonia, Greece in 2002–2005*

Parameter	Average in Runoff in Kefalonia, Greece
pH	8.31
Iron (μg/l)	11
Copper (μg/l)	<2.5
Zinc (μg/l)	10
Lead (μg/l/l)	<2
Cadmium (μg/l)	0.05
Chromium	<1.3

*Sazakli *et al.* (2007).

Palestine

In Palestine, rainwater collection system was known since 4,000 years ago in the semi-arid and arid regions of the Negev desert (Norhaiza 2004). Recently, many projects have been constructed for rainwater harvesting based on large-scale projects that collect urban road runoff into central collection pools and later diverted to artificial groundwater recharge system. The largest one was constructed in the seventies in Gaza city to drain catchment area of 1,850 hectares to collection pool locally recognized as Sheikh Radwan reservoir (Figure 2) and then recharging to aquifer through four large injection wells located in the collection pool itself. However these wells were not enough, and most of the collected water is pumped to the sea. Two other stormwater collection systems were constructed in North Gaza and in Khan Younis in south of Gaza Strip, providing infiltration to the aquifer. Unfortunately some wastewater is mixed in the winter season with the stormwater runoff which should be mitigated. In the remote areas in villages of West Bank, in Palestine, rainwater is collected in the winter season and in underground storage tanks and reused again for domestic purposes.

Figure 2 | Stormwater collection pool in Gaza, Palestine (23 Jan. 2008).

USA

US Virgin Islands, is an island city which is 4.8 km wide and 19 km long. It has an annual rainfall in the range of 1,020 to 1,520 mm. A rainwater utilization system is a mandatory requirement for a residential building permit. Each house must have a catchment area of 112 m^2 and a storage tank with 45 m^3 capacity (GDRC 2007), where rainfall is diverted to a storage tank below the house so that collected water is used later for non potable purposes. Another example is the National Volcano Park in Hawaii, where rainwater collection system includes the rooftop of a building with an area of 0.4 hectares and ground catchment area of more than two hectares. Water is directed to ground water tanks with 3,800 m^3 capacity. A water treatment and pumping plant was built to provide users with good quality water. The collected water is used to supply 1,000 workers and residents of the park in addition to 10,000 visitors per day. In an other case rainwater is harvested in desert in south central Idaho in north west USA for the purpose of wildlife drinking in this desert with precipitation 125 to 250 mm per year (Rice 2004).

CONCLUSION AND RECOMMENDATION

In the case of treated wastewater with higher values of organic matter, the removal efficiency is high and could exceed 90%, and as shown in studies carried out it was found that at an infiltration rate of 0.1 m/day, and BOD concentration of 1–5 mg/l, the latter removal was complete (Nilsson 1990). This value of organic matter is expected to be found in stormwater of both urban runoff and rooftop rainwater. Besides soil type of infiltration basin, the hydraulic load of infiltration system is an important factor, where organic removal is decreased by increasing infiltration. So infiltration rate should be maintained at am optimum rate concluded from continuous monitoring of the groundwater around the infiltration facilities.

The water law in most countries does not promote the rainwater harvesting system as one of the strategic water resources despite the growing demand for water. Rainwater harvesting is practised commonly in remote areas especially in the villages, where connecting water pipes are not economically feasible or even impossible; rainwater harvesting was a must for their survival. Rainwater harvesting will enter its efficient practice after legal regulations are set in the country. This will need to change the ordinances of issuing licences of new constructions to have rainwater harvesting system in each building and utility such as playgrounds, parks or any other type of yards. The system could be implemented through the initiative of the people since they are aware of the scarce water problem in their country. In some cities like Hyderabad and Chennai, they have rainwater harvesting regulations incorporated in the city municipal bye-laws (Hartung & Patschull 2008). This approach should be incorporated into bye-laws for all new constructions and yards including all residential, institutional and commercial utilities.

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REFERENCES

AEPHC 2008 (Australian Environment Protection and Heritage Council). Australian Guidelines for Water Recycling Stormwater Harvesting and Reuse. May 2008.

Borneff, M., Mannschott, P., Erdinger, L., Kirsch, F., Okpara, J. & Sonntag, H. G. 1996 *Risikobewertung der Nutzung von Regen- und Dachablaufwasser, Literaturstudie*. Landesanstalt für Umweltschutz Baden-Württemberg. ISBN: 3-88251-225-3. Karlsruhe 1996. p. 12.

Bullermann, M., Busweiler, U., Klein, U., Rexroth, R. & Sell-Foro, W. 1990 *Regenwasser in Privaten und Öffentlichen Gebäuden. –Qualitative und quantitative Aspekte, technische Anlagen*. Darmstadt July 1990. ISBN: 3-923419-33-3. pp. 73–115.

Canter, L. W. & Knox, R. C. 1985 Septic tank system effects on groundwater quality . Cited in: Nilsson, P. (ed) Infiltration of Wastewater, an Applied Study on Treatment of Wastewater by Soil Infiltration. Doctoral Dissertation, report No. 1002, Lund, Sweden 1990, p. 30.

Coelho, C. H., Francisco, J. G. & Nogueira, R. F. P. 2008 Dissolved organic carbon in rainwater from areas heavily impacted by sugar cane burning. *Atmospheric Environment Journal* **42**, 7115–7121.

GDRC 2007 Rainwater Harvesting and Utilization. An Environmentally Sound Approach for Sustainable- Urban Water Management: An Introductory Guide for Decision-Makers. Global Development Research Center. http://www.gdrc.org/uem/water/rainwater/rainwaterguide.pdf (Accessed on 3 July 07).

GDRC 2008 http://www.gdrc.org/üm/water/rainwater/introduction.html (Accessed on 2 Nov. 2008).

Gerson, R., Amit, R., & Grossman, S. 1985 Dust availability in desert terrain. A study in deserts of Israel and the Sinai. Institute of Earth Sciences. The Hebrew University of Jerusalem, Israel. In: Lange, J. 1999. A non-calibrated rainfall-runoff model for large arid catchment, Nahal, Zin, Israel. Institut für Hydrologie der Universität Freiburg i.Br. 1999. ISBN 0945-1609.

Hartung, H. & Patschull, C. 2008 http://www.water-2001.de/datenbank /571531674.53269.31/Hartung-et-al-legal_aspects.doc (Accessed On 25 October 2008).

Kintat, S. 2002 Regenwasser und Reinigungkonzept. Universität Weimer, Germany. http://www.uni-weimar.de/architektur/oekologisches_bauen/11projekte/2002berlinexkurs/Exkursion2002_10_PotsdamerPlatz-wasser.pdf (Accessed on 8 Dec. 2008).

Kjellström, T., Friberg, L. & Rahnster, B. 1979 Mortality and cancer morbidity among cadmium-exposed workers. *Environmental Health Perspectives* **28**: 199–204. In: Moore, J. W. & Ramamoorthy, S. (eds) 1983. *Heavy Metals in Natural Water. Applied Monitoring and Impact Assessment*. Springer-Verlag, New York, Berlin, Heidelberg, Tokyo. ISBN: 0-387-90885-4. pp. 29–50.

Krauth, K. 1979 Beschaffenheit von Straßenoberflächenwasser. Beeinflussung der Gewässergüte durch die Regenabflüsse von Straßen. Siedlungswasserwirtschaftliches Kolloquium. pp. 3–14.

Lange, J. 1999 A non-calibrated rainfall-runoff model for large arid catchment, Nahal, Zin, Israel. Institut für Hydrologie der Universität Freiburg i.Br. 1999. ISBN 0945-1609.

Låg, J. 1991 Human and animal health in relation to circulation processes of selenium and cadmium. The Norwegian Academy of Science and Letters. International Symposium 31 May–1 June 1990. pp. 18, 37.

Lee, G. F., Jones-Lee, A. & Taylor, S. 1998 Development of Appropriate Stormwater Infiltration BMPs: Part I. Potential Water Quality Impacts, Monitoring and Efficacy Evaluation. Presented on Ground Water Protection Council 98 Annual Forum, September, 1998 http://www.water-research.net/Waterlibrary/runoffeq/stmwt_infil.pdf

Maier, D., Maier, M. & Sacre, C. 2004 Nutzen und Risiken der Vwewandung von Dachablaufwasser im Haushalt. In Bauthema 01. Regenwassernuzung. Fraunhofer IRB Verlag, 2004, Stuttgart. pp. 47, 57.

Metzler, D. 1984 Grundlagen für die Planung und Gestaltung von Anlagen zur zentralen Versickerung von Regenwasser aus öffentliche Kanalisationsanlagen. Dissertation des Doktorgrades der Naturwissenschaften der Justus-Liebig Unversität Gießen, Gießen, 1984. pp. 10–11.

Michaelidis, G. & Young, R. 1983 Design and Maintenance of rainwater harvesting systems. Water Resources Journal (Bangok), Dez. 1983. pp. 35–42. In: Bullermann, M., Busweiler, U., Klein, U., Rexroth, R. & Sell-Foro, W. (eds) *Regenwasser in Privaten und Öffentlichen Gebäuden. –Qualitative und quantitative Aspekte, technische Anlagen*. Darmstadt July 1990. ISBN: 3-923419-33-3. pp. 73–115.

Moore, J. W. & Ramamoorthy, S. 1983 *Heavy Metals in Natural Water. Applied Monitoring and Impact Assessment*. Springer-Verlag. New York, Berlin, Heidelberg, Tokyo. ISBN: 0-387-90885-4. pp. 29–83.

Nilsson, P. 1990 Infiltration of wastewater, an applied study on treatment of wastewater by soil infiltration. Doctoral Dissertation, report No. 1002, Lund, Sweden 1990. pp. 27–30, 93, 172.

Norhaiza, N. 2004 Rainwater Harvesting System. School of Civil and Environmental Engineering, University College of Engineering and Technology, Kuantan, Pahang. http://cee.ump.edu.my/article.cfm?id = 1584 (Accessed on 1st Nov. 2008).

Prempridi, T. & Chatuthasry, C. 1982 An Introduction to rainwater harvesting. In GDRC 2008. RC 2008. http://www.gdrc.org/üm/water/rainwater/introduction.html (Accessed on 2 Nov. 2008).

RHG 2008 Rain Water Harvesting Guide, http://www.rain-barrel.net/rainwater-collection.html (Accessed On 1st November 2008).

Rice, W. E. 2004 Desert water harvesting to benefit wildlife: a simple, cheap and durable sub-surface water harvester for remote locations. *Environmental Monitoring and Assessment* **99**, 251–257.

Rott, U. 1994 Erstellung einer Literaturstudie zum Thema Regen- und Grauwassernutzung. Institut für Siedlungswasserbah, Wassergüte-und Abfallwirtschaft der Universität Stuttgart. November 1994. pp. 13–19.

Sazakli, E., Alexopulos, A. & Leotsinidis, M. 2007 Rainwater harvesting quality assessment and utilization in Kefalonia Island, Greece. In: Water Research Journal 41 Science Direct, Elsevier 2007. pp. 2039–2047.

Seiler, K. P. & Gat, J. R. 2007 Groundwater Recharge from run-off infiltration and percolation. Springer, Dordrecht, The Netherlands, 2007. ISBN: 978-4020-5305-4. pp. 64–66.

Sittig, M. 1980 Priority toxic pollutants. Health impacts and allowable limits. Noyes Data Corporation, New Jersey. In: Moore, J. W. & Ramamoorthy, S. (1983) *Heavy metals in natural water. Applied Monitoring and Impact Assessment*. Springer-Verlag. New York, Berlin, Heidelberg, Tokyo. ISBN: 0-387-90885-4. pp. 69–73.

Song, Y. & Müller, G. 1999 Sediment- Water Interaction in Anoxic Freshwater Sediments. *Mobility of Heavy Metals and Nutrients*. Springer-Verlag, Berlin, Heidelberg, New York 1999. ISBN: 3-540-65022-9. pp. 57–73.

TWDB 1997 Texas Water Development Board in Cooperation with the Center for Maximum Potential Building Systems, 2nd edition, 1997, Austin, Texas, p. 4.

UNEP 1982 Rain and storm water harvesting in rural areas, Tycooly International Publishing Ltd., Dublin. In GDRC 2008. http://www.gdrc.org/üm/water/rainwater/introduction.html (Accessed on 2 Nov. 2008).

Vanderzalm, J., Dillon, P., Marvanic, S. & Page, B. 2007 Over 100 of drinking stormwater treated through MAR: Assessing the risks of stormwater recharge on the quality of the Blue Lake. In: *Proceedings of International Symposium on Managed Aquifer recharge, Oct. 28–Nov. 2, 2007*. ISBN: 0-9788283-9-9, Phoenix, Arizona. pp. 615–619.

VANR 2002*a* Vermont Agency of Natural Resources. *The Vermont Stormwater Management Manual, Volume II- Stormwater* Treatment Standards. April 2002, USA. pp. 2-3–2-7.

VANR 2002*b* Vermont Agency of Natural Resources, *the Vermont Stormwater Management Manual, Volume II–Technical Guidance*. August 2002, USA. p. 7.

Paper III

Quality risks of stormwater harvesting in Gaza.

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Quality Risks of Stormwater Harvesting in Gaza

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ABSTRACT

Rainfall harvesting for artificial recharge is an option to address water scarcity in Gaza, which has an average annual rainfall of 350 mm and will also reduce urban flooding. Continuous urban expansion has increased runoff and decreased natural infiltration in open areas. This study examines the quality of collected storm water from rooftop and streets to mitigate any risk reveals. Collection of stormwater runoff from rooftops and diverting it into local infiltration systems for artificial recharge to groundwater will also decrease road flooding in the city. The quality of harvested rooftop stormwater runoff in Gaza has proved to be suitable for artificial recharge and meets drinking water standards. The harvested stormwater has low concentrations of chloride and nitrate and as groundwater recharge will improve the quality of the existing brackish groundwater. The risk of heavy metal contamination of groundwater is low, since the measured pH in all rainwater runoff was close to 7.0. This reduces the risk of solution and mobilization of heavy metals in the infiltrating water.

Key words: Rainwater harvesting, water resources, water quality, groundwater, health

INTRODUCTION

Rainwater harvesting is an ancient technology for augmenting water resources. Its use in both Palestine and Greece dates back 4000 years, when residences were built with cisterns and paved yards to capture rainwater (UNESCO, 2000). In South East Asia rainwater harvesting can be traced back to the 9th or 10th Centuries, when small-scale collection of rainwater from roofs and simple brush dam constructions were common in rural areas and it has long been used in the Loess Plateau region of China (GDRC, 2008). Recently, in Sri Lanka rooftop rainwater is used for drinking purposes in the dry zones after pollution of their water with iron and fluoride, but it was limited in wet zones of Sri Lanka (Kumara *et al*., 2003).

In Gaza there is an urgent need to re-introduce this technology. The Gaza strip is a semi-arid region with a total area of 365 km^2. Topographically and geologically, Gaza overlies four elongate depressions that alternate with ridges which are composed mainly of calcareous sandstone (Salem, 1963). The low-lying ground in these depressions floods frequently, leading to closure of the main roads for several months every year. Annual precipitation in Gaza ranges from 200 mm in the South to 450 mm in the North, which falls in around 40 rainy days between October and March. Ongoing urbanization has led to an increase in the built-up area at the expense of natural areas, which has led to two problems related to stormwater. Firstly, urbanization has caused a decrease in natural rainfall recharge to the aquifer. This is critical at a time when Gaza suffers from an overall annual water resources budget deficit of 50 Mm^3. Secondly, the ever-increasing urban runoff accumulates in the low lying land of the cities and causes flooding, which has to be pumped by portable pumps to the sea. As well as the economic and human cost involved in managing flooding, this represents a waste of an essential water resource. Construction of large scale stormwater collection projects has been shown not to be economically feasible and previous studies have recommended constructing stormwater reservoirs close to groundwater infiltration (artificial recharge) sites to decrease the costs of pumping and conveying water (Sogreah, 1998). Studies for stormwater harvesting planning recommended capturing stormwater locally and coordination with local authorities in order to decrease stormwater runoff (Metcalf and Eddy Consultant Co., 2000; Sogreah, 1998).

On-site harvesting of rooftop stormwater runoff will decrease the load on existing large scale stormwater collection projects. It is also cleaner than collecting runoff after it has reached street stormwater collection systems and been mixed with urban pollutants. Collected rooftop runoff tends to exhibit quality levels that are generally comparable to the World Health Organization (WHO) guideline values for drinking water (GDRC, 2007). By contrast, heavy metals, especially copper, lead and zinc, are common pollutants found in urban road runoff, according to the U.S. EPA's Nationwide Urban Runoff (Engstrom, 2004). The quality of rooftop runoff depends mainly on the roof type (Bullermann *et al.*, 1990). In Gaza, most of the roofs are concrete. Other factors affecting the quality of rooftop runoff are the roof cover; guttering; down pipes; leakage of domestic water stored in roof tanks; dry season deposition on rooftops; and aerosols in the air which are deposited with rainfall. In Gaza, the first flush of these aerosols is associated with the first rainstorm after each dry period. This pattern is common in countries with intermittent rainfall events. Some pollutants come from chemical interaction between the rainwater and the roof material and the physical washing off or erosion of material on the roof. Other factors, such as grazing birds and small animals on roofs, can cause large amounts of pollution. In these cases, it is necessary to clean any roofs used for stormwater harvesting before the start of each rainy season. Where roofs have been cleaned, stormwater harvested from them is typically very clean and where this is recharged to the ground, it can contribute to improved groundwater quality in polluted areas. This practice has been followed in other scarce water countries, such as India (UNESCO/IHP, 2005):

- The best quality runoff water in urban areas is from rooftops and increasingly initiatives (e.g., government buildings in India) are being made to direct this water immediately to groundwater recharge through infiltration galleries, wells and boreholes. This not only replenishes urban aquifers that are often over-exploited, but also introduces good quality water into often-polluted groundwater

Other measures for local treatment, such as bio-retention or primary treatment, may be necessary before runoff water is infiltrated to groundwater. A simple bio-retention unit may be practical for treating and purifying stormwater as it flows through a soil matrix (VANR, 2002).

To adopt rainwater harvesting, Water should have low concentrations of heavy metals due to their risk on human health. Researchers indicated positive correlations between high concentration of trace metals in drinking water and human risk causing dangerous diseases such as cancer, infant death and cardiovascular syndrome (Ziadat, 2005). Because of the large size and intensity of rainfall events in Gaza, on only about 40 rainy days during the year, the existing large scale rainwater harvesting projects do not have the capacity to absorb the volume of collected water. The pollutant loads depend on the dry period and rainfall intensity. Most of the heavy metals are transported by the first flush. The concentration of heavy metals in first flush samples is dependent on dry period and size of rainfall with observed ranges, where maximum value exceeds 10 times the minimum value for Zn, Cu and Pb (Alo *et al.*, 2007). On-site infiltration of rooftop stormwater runoff will decrease the load on these large scale projects, so that they are better able to manage the volumes of road runoff to the large scale infiltration basins. Any rooftop stormwater harvesting system used for artificial groundwater recharge, however, must ensure a high enough quality of the water collected, after it had been filtered through infiltration processes, without dangerous pollutants and with pH values that are not low enough to mobilise heavy metals downward to the aquifer. With low pH value, there is a potential health effect of acute and chronic exposure to pollutants as impact of acid deposition on drinking water quality (El-Gammal *et al.*, 2008). This study examines the quality of collected storm water from rooftop and streets to mitigate any risk reveals.

MATERIALS AND METHODS

An experiment was carried out for a single house in the middle of the Gaza Strip in the rainy season from October 2007 until April 2008. The storm water falling on the whole roof was collected through three inch pipes, which delivered through a single outlet to a storage tank. Water samples were taken from the tank during each rain storm that exceeded five millimeters depth. Samples were taken at the start and the end of each storm event. Totally, 17 water samples were taken from rooftop rainwater. Additionally, during each storm event samples of road runoff were taken from the two main large scale stormwater collection pools in Gaza city, locally called Asqola (ASQ) and Sheikh Radwan (SHR), where five samples were taken from each site, i.e., 10 samples were taken to examine road runoff water quality. Also, four water samples taken from pure rainfall and one sample from the tap water that may affects the salts contents of rooftop rainwater, where storage water tanks are found on the roof.

The water samples were preserved and sent for laboratory analysis. For major ion analysis, the American standard method was used. For Total Organic Carbon (TOC) analysis, the Tekmar Dohrmann method was used. An atomic absorption spectrometer (novAA 400) was used to analyse concentrations of the following heavy metals: cadmium (Cd), iron (Fe), lead (Pb), copper (Cu), chromium (Cr), zinc (Zn) and aluminum (Al). For high metal concentrations which were Zn, Fe, Cu and Al, the flame method was used. However, the graphical method was used for low metal concentrations which were Cu, Pb, Cd and Cr. The data have been interpreted and compared with national, regional and international standards for both drinking water and water used for artificial recharge of groundwater.

RESULTS AND DISCUSSION

The quality of rooftop stormwater and urban road stormwater runoff in terms of heavy metal, other inorganic and organic constituents is discussed here.

Organic compounds: Total Organic Carbon (TOC) was used to indicate the levels of organic compounds. The TOC was less than 5 mg L^{-1} in all samples of rooftop stormwater runoff, which is close to what was seen in pure rainfall (Fig. 1). By comparison, values of TOC measured in rooftop stormwater runoff in Germany were higher, at 11.0 mg L^{-1} from concrete roofs and 27.4 mg L^{-1} from bitumen roofs (Bullermann *et al.*, 1990). However, TOC in urban road stormwater runoff in

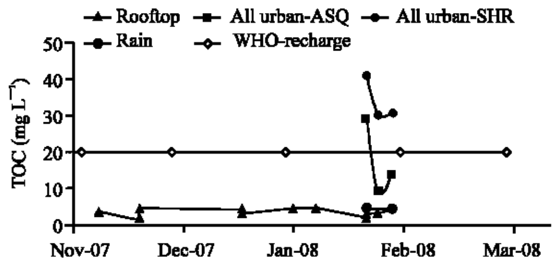

Fig. 1: Total organic carbon in stormwater in Gaza

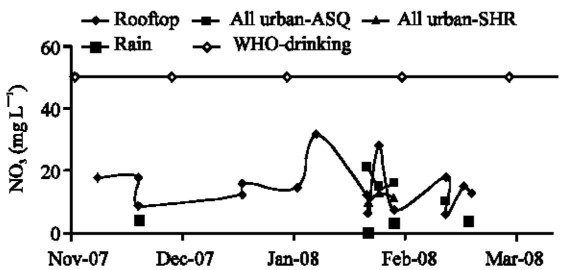

Fig. 2: Nitrate concentration in stormwater in Gaza

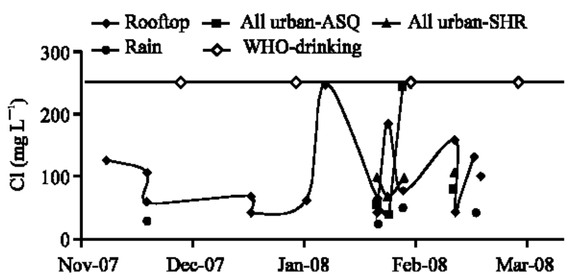

Fig. 3: Chloride concentration in stormwater in Gaza

Gaza ranged from 10 to 40 mg L^{-1}, which can be explained by mixing with organic compounds as water flows over roads, or by the presence of some wastewater overflowing from manholes and mixing with rainfall runoff. During artificial recharge, organic compounds are expected to be consumed during infiltration through the soil, since the groundwater table is at least 20 m below the ground surface across most of the Gaza Strip. Other organic indicators such as BOD_5 and COD have been shown to be removed through Soil Aquifer Treatment (SAT) in more than 90% of cases.

Inorganic compounds: The water quality results for rainfall, rooftop rainfall runoff, road rainfall runoff and tap water at the experimental house site are shown in Fig. 1-9. The experimental house site at which roof rainfall samples were taken has a domestic water reservoir which is typical of those in the Gaza Strip. When the rooftop domestic water reservoir floods during the dry and wet periods, the quality of collected rooftop stormwater runoff will be influenced to a certain extent. Sodium and chloride concentrations were very high in tap water and this has increased their concentrations in rooftop rainwater to a limited degree. Chromium concentrations in tap water were higher than in any of the runoff samples and are derived from the old municipal water supply pipes.

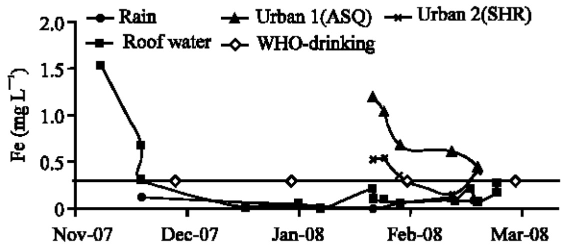

Fig. 4: Iron concentration in stormwater in Gaza

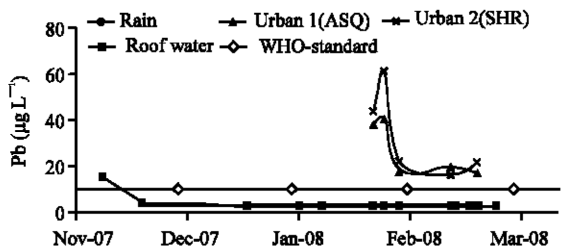

Fig. 5: Lead concentration in stormwater in Gaza

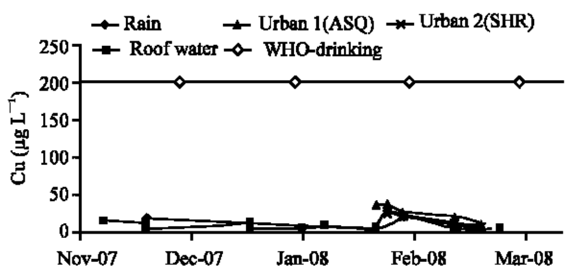

Fig. 6: Copper concentration in stormwater in Gaza

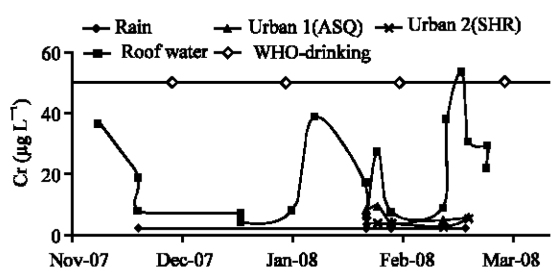

Fig. 7: Chromium concentration in stormwater in Gaza

The mobility of heavy metals is dependent on pH. The pH of the pure rainfall samples collected in Gaza is less than 7.0 due to the solution of CO_2 and the consequent increase in acidity in falling rainfall, which reduces the pH to an average value of 6.57. Naturally, rainwater tends to be acidic with pH of 5.6 to 5.7 due to reaction of atmospheric CO_2 with rain water (El-Gammal *et al.*, 2008). However, pH values were higher than this in all stormwater runoff, from either rooftops or roads, with average values of 7.48 for rooftop runoff and 7.54 and

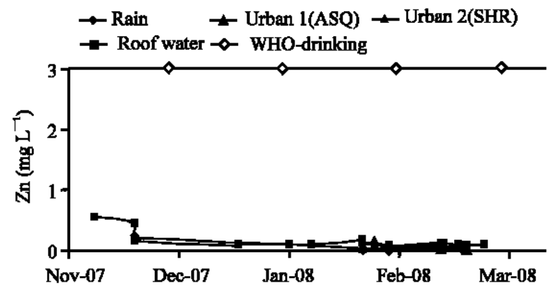

Fig. 8: Zinc concentration in stormwater

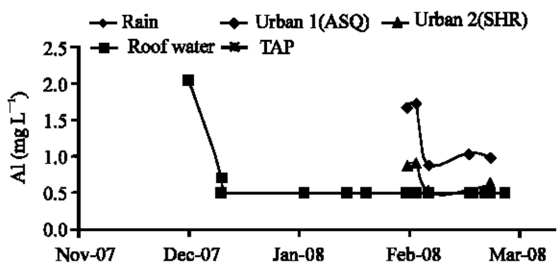

Fig. 9: Aluminum concentration in stormwater in Gaza

7.11 for road runoff at the two measured sites. These higher pH values will help in the precipitation of heavy metals in the soil of infiltration basins.

The most critical constituents of groundwater in Gaza are nitrate and chloride ions, since they are indicators of general pollution and of salinity, respectively. Heavy metals are discussed in the following, as they are also an important issue, as road runoff can potentially mix with wastewater if wastewater manholes overflow in the rainy season.

Nitrate (NO_3): Nitrate is considered to be a general indicator of pollution and was measured in all samples. Nitrate concentrations ranged from 6 to 30 mg L^{-1} in rooftop runoff and were less than 20 mg L^{-1} in urban runoff (Fig. 2). This is much less than the allowable limit for drinking water. Groundwater in Gaza suffers from high concentrations of nitrate. Nitrate concentrations in groundwater will be significantly improved by the recharge of collected stormwater to the aquifer. The low concentrations of nitrate in the collected stormwater will be further decreased during infiltration through nitrification and denitrification processes and more dilute nitrate concentration in groundwater.

Water salinity is measured by its chloride content and in the rooftop runoff samples proved to be low, less than the allowable limits according to WHO (2006). The chloride (Cl) concentration in rooftop runoff was less than 250 mg L^{-1} and lower than this in road runoff (Fig. 3). Groundwater in Gaza suffers significantly from seawater intrusion and deep saline water up-coning. Recharging stormwater will dilute the chloride concentration of the in-situ groundwater and will help to halt seawater intrusion in wells close to the shoreline.

Heavy metals: When stormwater is used for artificial recharge, heavy metals in the water may undergo precipitation and co-precipitation in the upper soil layer, which will help to purify the water. However, if the recharging water is acidic, there is a risk of heavy metals being mobilized by the percolating water. A significant release of heavy metals, such as Cd, Zn, Pb or Cu, during the oxidation of anoxic sediments will occur only if pH falls below 4.5 (Song and Müller, 1998). The value of pH is therefore a key factor in the mobility of heavy metals through the soils of stormwater infiltration basins. The measured pH in all water samples from both rooftop and road runoff fluctuated from 6.8 to 7.2, which is relatively high and which will help to promote the absorption of heavy metals in the soil.

Cadmium (Cd): Some studies have shown that there is a causal relationship between exposure to cadmium and cancer incidence (Kjellstrom *et al.*, 1979), which explains the low allowable limit of cadmium (Cd) in drinking water, set by WHO at 3 $\mu g\ L^{-1}$. In Gaza, cadmium concentrations were low in all samples, at less than 2 $\mu g\ L^{-1}$ in both rooftop and road runoff, which is safe according to WHO and PWA standards. The maximum allowable limit of cadmium for artificial recharge is 0.01 mg L^{-1}, according to JISM (2002) and the PWA (2000) and is 0.003 mg L^{-1} for drinking purposes, according to WHO (2006).

Iron (Fe): Iron (Fe^{3+}) concentrations in rooftop runoff were high (1.5 mg L^{-1}) during the first storm (5.6 mm) of the season on 11th November 2007 and decreased to 0.6 mg L^{-1} in the second storm (47 mm) on 22nd November 2007, i.e., after a ten day dry period. In all following storms, iron concentrations were less than 0.4 mg L^{-1}(Fig. 4). By contrast, iron concentrations were higher in road runoff as collected in the two main lagoons at Asqola (ASQ) and Sheikh Radwan (SHR). Here, iron ranged from 1.20 mg L^{-1} at the beginning of the rainy season, decreasing gradually to 0.44 mg L^{-1} in the last storm. This lies in the expected range of iron concentrations in highway runoff, which is between 2.429 and 10.3 mg L^{-1} (Qin *et al.*, 2004). Collected stormwater in Gaza will not be used directly for drinking purposes but for artificial recharge of groundwater and the allowable limit for this purpose is 5.0 mg L^{-1} as Fe^{3+} (JISM 2002), which is higher than seen in both rooftop and road runoff after the second storm of the season. The iron concentration in runoff in Gaza is also close to the maximum allowable limit (0.3 mg L^{-1}) in drinking water according to PWA (2000) and WHO (2006) standards, which are based on turbidity and water color and not on a health baseline.

Lead (Pb): Lead compounds, such as halides, sulfates, phosphates and hydroxides, are insoluble and therefore less toxic than soluble compounds. Lead is mainly used in acid storage batteries. Automobile exhausts account for about 50% of the total inorganic lead absorbed by humans and there is a strong association between lead and urban airborne particulates (Moore and Ramamoorthy, 1983). The results of lead analyses in the Gaza study area showed that it was less than the detection limit of 3 $\mu g\ L^{-1}$ in the samples of pure rainfall and tap water at the experimental house. In rooftop runoff, lead concentrations were at a maximum at the beginning of the first storm, at 15.6 $\mu g\ L^{-1}$, decreasing to 4 $\mu g\ L^{-1}$ in the second storm and to less than 3 $\mu g\ L^{-1}$ in the remaining storms of the rainy season. However, lead concentrations were greater in road runoff, ranging from 61 $\mu g\ L^{-1}$ at the start of the rainy season to 17 $\mu g\ L^{-1}$ at the end of the season (Fig. 5). Both the lead concentrations ini rooftop and road runoff are acceptable for artificial recharge, for which the allowable lead limit is 200 $\mu g\ L^{-1}$ (JISM, 2002). Lead concentrations in rooftop runoff is also close to the drinking water standard of 10 $\mu g\ L^{-1}$ (PWA, 2000; WHO, 2006).

Copper (Cu): Copper is widely spread in its free state and in sulfides, arsenide, chlorides and carbonates. It is used in electrical, construction, plumping and automotive industries and is binding with organic and inorganic matters. Fortunately, it is rapidly absorbed to sediments and is not acutely toxic to humans (Moore and Ramamoorthy, 1983).

The maximum concentration of copper was in road runoff, with a value of 300 μg L^{-1}. By contrast, copper concentrations in the rest of the samples, from both rooftop and road stormwater runoff, were low, ranging from 3 to 35 μg L^{-1} (Fig. 6). Although, no limit has been derived for copper in water, concentrations over 5 mg L^{-1} lead to color and an undesirable bitter taste (WHO, 2006). However, all the Gaza samples are well below this limit.

Chromium (Cr): Large quantities of chromites are used for the production of stainless steel, chrome plated metals and various chemicals. It is less toxic than other metals, such as cadmium, copper, lead, nickel and zinc. However, epidemiological studies have shown a relationship between occupational exposure to chromates and cancer incidence (Sittig, 1980).

Where samples were taken twice in each storm event, at the beginning and end of each storm, chromium concentrations were high at the start of the storm and lower at its end and this is clear in Fig. 7. The surprise was that the chromium concentration of rooftop runoff was higher than that of road runoff. The high values of chromium in rooftop runoff than are seen in road runoff come from the old pipes of municipal public water supply network. However, the concentrations in both road and rooftop runoff were lower than the recommended limit for drinking water, which is 50 μg L^{-1} (WHO, 2006).

Zinc (Zn): The largest use of zinc is for galvanization of iron and steel products. It is a corrosion resistant material and is used in construction, automobile, building industries such as roofing, siding, office equipment, heating and ventilation ducts. Although, zinc is not considered to be of health concern and no guidelines have been derived for its concentration in drinking water, it has a threshold value of 3 to 5 mg L^{-1}. Above this value, a film will form on water when it is boiled (WHO, 2006). Therefore, concentrations of zinc in water of up to 3 mg L^{-1} are acceptable, although the human requirement for this metal is 15 to 20 mg L^{-1} every day (WHO, 2006). Zinc deficiency in humans can cause effects that include delayed healing and the suppression of enzymatic activity and immune response (Moore and Ramamoorthy, 1983). In the results obtained in Gaza, the maximum zinc concentration was 0.55 mg L^{-1} at the beginning of the first storm of the rainy season, after which all values in both rooftop and road runoff were about 0.1 mg L^{-1} (Fig. 8). This means that the zinc concentration of stormwater is suitable for the reuse of the stormwater.

Aluminum (Al): In rooftop runoff, aluminum was noticed only at the beginning of the rainy season, in the first and second storms. In the rest of the rooftop runoff samples, aluminium concentrations were less than the detection limit of 0.5 mg L^{-1}. Higher values of aluminium were found in road runoff, fluctuating between 1.7 mg L^{-1} and less than 0.5 mg L^{-1} (Fig. 9). According to WHO (2006), both the rooftop and road runoff waters are not acceptable for drinking water use, but could be used for recharging the aquifer.

CONCLUSIONS

The quality of rooftop stormwater runoff in Gaza has been shown to be clean and to be close to the limits set by WHO for drinking purposes. The quality of road stormwater runoff has also been shown to be acceptable for the artificial recharge of groundwater. It is proposed that both rooftop and road stormwater runoff are harvested for artificial infiltration to the groundwater system to replenish the aquifer, which is currently suffers from over-abstraction and from decreasing volumes of recharge due to continuous urbanization. Artificial recharge of groundwater with collected stormwater in Gaza also contributes to the remediation of groundwater, which has been polluted by nitrate and chloride.

The quality of stormwater runoff was good enough for artificial recharge in terms of salinity (Cl^-) and nitrate (NO_3^-), as concentrations of both were very low. Consequently, groundwater in the aquifer will be improved in terms of these two constituents, which currently form the main groundwater quality problems. Organic compounds, which are normally degraded in the uppermost layer of stormwater infiltration basins, were at acceptable levels in rooftop runoff. Relatively high concentrations of Total Organic Carbon (TOC) were found in urban road runoff, which can be explained by minor mixing with wastewater when this floods from manholes onto roads, but this problem could be managed. The results of heavy metal analyses were also encouraging for both rooftop and road stormwater runoff.

The concentrations of poisonous metals, such as cadmium and lead, were found to be close to the international, regional and local standards for artificial recharge purposes. There is no danger of the solution and mobility of these metals in the infiltrating water, since the pH values of all stormwater runoff samples were close to 7.0. Under these conditions, most of the heavy metals will be either absorbed, precipitated or co-precipitated.

On-site rooftop stormwater harvesting will decrease the load on the main urban road runoff collection lagoons and so help to prevent failure of these large scale projects. It will also limit the risk of the mixing of stormwater runoff with wastewater as it flows to central stormwater collection lagoons. More work is required to completely separate the wastewater networks from stormwater networks. If this is done, the quality of road stormwater runoff will improve from the values found in this study and will be closer to the quality of roof stormwater runoff. In the experiment presented in this study, a concrete roof, which is typical of the majority of roof types in Gaza, was tested. However, there other minor types of roofs in Gaza, including bituminous sheets, asbestos corrugated sheets, steel corrugated sheets and other tile roofs. Adopting on-site rainwater harvesting will require changes in construction design, so that rainwater collection systems are included in each building.

REFERENCES

Alo, B.I., A.A. Abayomi, B.A. Osuntogun and K.O. Olayinka, 2007. Urban highway runoff in Nigeria 1: Heavy metals in sheet flow from the main expressway in lagos metropolis. J. Applied Sci., 7: 2800-2805.

Bullermann, M., B. Klein, U. Busweiler, R. Rexroth and W. Sell-Foro, 1990. Regenwasser in Privaten und Offentlichen Gebauden: Qualitative und quantitative Aspekte, Technische Anlagen. Selbstverlag, Darmstadt, Germany, pp: 73-115.

El-Gammal, M.I., M.S. Ibrahim, A.A. Shakour and R.S. El-Henawy, 2008. Precipitation quality and related atmospheric chemistry over the greater damietta area-Egypt. Res. J. Environ. Sci., 2: 252-265.

Engstrom, A.M., 2004. Characterizing water quality of urban stormwater runoff. M.Sc. Thesis, Department of Civil and Environmental Engineering, University of Washington.

GDRC, 2007. Rainwater Harvesting and Utilization. An Environmentally Sound Approach for Sustainable- Urban Water Management: An Introductory Guide for Decision-Makers. Global Development Research Center, France.

GDRC, 2008. Harvesting, conserving and managing rainwater. http://www.gdrc.org/uem/water/rainwater/ introduction.html.

JISM, 2002. Technical regulation of water-reclaimed domestic wastewater. Jordanian Standards 893/2002, 3rd Edition Report, pp: 7.

Kjellstrom, T., L. Friberg and B. Rahnster, 1979. Mortality and cancer morbidity among cadmium-exposed workers. Environ. Health Perspectives, 28: 199-204.

Kumara, G., G. Ajith and N.I. Wickramasinghe, 2003. Community perception on rain water harvesting: Sri Lanka. Proceedings of the 29th WEDC International Conference Towards the Millennium Development Goals, Abuja, Nigeria.

Metcalf and Eddy Consultant Co., 2000. Coastal aquifer management program. Integrated Aquifer Management Plan (Gaza Strip), USAID Study Task 3, Executive Summary and Appendices, Vol. 1, B-G. Gaza, Palestine.

Moore, J.W. and S. Ramamoorthy, 1983. Heavy Metals in Natural Water: Applied Monitoring and Impact Assessment. Springer Verlag, New York, Berlin, Heidelberg, Tokyo, ISBN: 0-387-90885-4.

PWA, 2000. Standards of Drinking Water in the Gaza Strip. Palestinian Water Authority, Gaza, pp: 6.

Qin, H., S.J. Burian, F.G. Edwards and G. Findlay, 2004. GIS-based BMP planning tool for stormwater quality management. University of Utah and University of Arkansas, October 13, 2004. http://ww2. mackblackwell.org/web/research/ALL_RESEARCH_PROJECTS/2000s/2031/MBTC_2031_FinalReport.pdf.

Salem, M., 1963. Geology of groundwater in the area between El-Arish and Gaza. M.Sc. Thesis, Cairo University, Cairo, Egypt.

Sittig, M., 1980. Priority Toxic Pollutants: Health Impacts and Allowable Limits. Noyes Data Corporation, New Jersy.

Sogreah, C., 1998. Master plan for sewerage and stormwater drainage in the Gaza Governorates. Final Report, Gaza, June 1998, pp: 197.

Song, Y. and G. Muller, 1998. Sediment-Water Interaction in Anoxic Freshwater Sediments Mobility of Heavy Metals and Nutrients. Springer-Verlag, Berlin, Heidelberg, New York, ISBN-13: 978-3540650225, pp: 111.

UNESCO, 2000. Rainwater harvesting and artificial recharge of groundwater: A guide to follow. Central Groundwater Board, Indial Ministry of Water Resources, UNESCO and IHP. September 2000. http://www.unesco.org/water/ihp/publications/water_harvesting.pdf.

UNESCO/IHP, 2005. Strategies for Managed Aquifer Recharge (MAR) in Semi-Arid Areas. UNESCO/IHP, Paris, pp: 6.

VANR, 2002. The Vermont Stormwater Management Manual. Vol. II, Stormwater Treatment Standards, USA., pp: 2-7.

WHO, 2006. World Health Organisation Guidelines for Drinking Water Quality. 3rd Edn., World Health Organisation of the United Nations, Rome, Italy, pp: 214-219.

Ziadat, A.H., 2005. Impact of storage tanks on drinking water quality in Al-Karak Province-Jordan. J. Applied Sci., 5: 634-638.

Paper IV

Impact on Gaza Aquifer from Recharge with Partially Treated Wastewater.

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Impact on Gaza aquifer from recharge with partially treated wastewater

Sami M. Hamdan, Abdelmajid Nassar and Uwe Troeger

ABSTRACT

The Gaza Strip suffers from high pressure imposed on its water resources. There is a deficit of about 50 mm^3 every year, which has led to a declination of groundwater level and deterioration of groundwater quality. New water resources are sought to fulfil the water deficit; among them is the artificial recharge of treated wastewater to groundwater. The impact of recharging partially treated wastewater in Gaza was tested through a pilot project implemented east of the existing wastewater treatment plant. The daily application of about 10,000 m^3 of effluent to infiltration basins had an effect on the aquifer, which was monitored through the surrounding operating water wells over five years from 2000 until 2005. Although the monitored wells are operated for irrigation by farmers, impacts were clearly noticed. Groundwater levels improved and an increase in some areas of 0.6 m within three years was observed. The nitrate ion concentration also decreased in the groundwater due to nitrification processes. However, chloride ion, which indicates salinity, increased because the effluent has high chloride concentration. Boron levels increased in some areas to 0.5 mg/l, which could affect sensitive crops grown in the area.

Key words | effluent, groundwater, pollution, recharge, reuse, water quality

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INTRODUCTION

The increasing water demand and limited water resources in Palestine in general, and in the Gaza Strip in particular, have led to the depletion of the water systems quantitatively and qualitatively. The aquifer in the coastal region, i.e., Gaza Strip, suffers from high pressure imposed by supplying domestic and agricultural needs. The overall water use is 164 mm^3 per year, where the overall supply is only 122 mm^3 per year (PWA 2007). This means that there is a deficit of about 42 mm^3 every year. The deficit has led to a continuous declination of groundwater level and deterioration of groundwater quality.

The policy of water resources management is to use non-conventional water resources such as seawater desalination and artificial recharge of groundwater from storm water and treated wastewater. The agricultural demand is almost constant since the agricultural areas are limited or even decreasing. However, the domestic demand increases due to the rapid growth of the population. This increases the amount of wastewater produced and the treated effluent becomes a significant resource of water that could improve the water balance in the region. The reuse of this effluent could be accomplished in two ways: either by direct irrigation to farms and/or through artificial recharge to groundwater, which is then pumped to irrigate farms with reclaimed wastewater.

Water demand is continuously increasing due to economic development and population increase, due to natural growth and returnees, while the water resources are constant or even decreasing due to urban development (CAMP 2000). The Gaza Strip is classified as a semi-arid region and suffers from water scarcity. The renewable amount of water that replenishes the groundwater system is much less than the demanded amount, and this has resulted in deterioration of the groundwater system in both quantitative and qualitative aspects (PWA 2000a). The Palestinian Water Authority seeks other resources to fill

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the water gap between the supply and the demand and to attain sustainable water resources management. There are large quantities of wastewater estimated at 40 mm^3 every year (CMWU 2007) that are produced by the municipal sewerage systems and the treated effluents are disposed to the sea or flooded without good treatment or control to the surrounding areas and underground aquifer. Biological oxygen demand (BOD) is reduced from 440 to 140 mg/l, while chemical oxygen demand (COD) is reduced from 900 to 300 mg/l through the poor treatment at Gaza plant (CMWU 2007). For direct reuse of wastewater, more treatment is needed to reach the Palestinian standards for direct reuse in agriculture.

Some projects adopted by the Palestinian Water Authority were started with the reuse of treated wastewater obtained from the Gaza Wastewater Treatment Plant (GWWTP), which is the case study in this paper. An amount of about 10,000 m^3 is diverted to infiltration basins of an area of four hectares every day (PWA 2004). The crops grown in this area are mostly citrus and olives. The water wells that recover the reclaimed wastewater mixed with native groundwater were monitored for groundwater level fluctuations and chemical analyses of their pumped water.

The quality of the native groundwater in the zone of the pilot project showed high values of nitrate ranging from 39 to 177 mg/l with an average of 118 mg/l as shown in Table 1. The high value of nitrate concentration comes from intensive application of chemical fertilizers in the agricultural activities in the area. The salinity of the native groundwater is expressed in the form of chloride ion ranging from 217 to 607 mg/l so this part of the aquifer is relatively good compared to other regions in the Gaza Strip. Any application of treated wastewater to the aquifer through artificial recharge should be recovered from well-designed recovery wells in addition to continuous monitoring of the groundwater to predict any pollution that may occur. At the same time, the project is at least two kilometres away from public water supply wells that are used for drinking purposes.

Table 1 | Quality of native groundwater in the zone of the pilot project

Well No.	Sampling	EC (μS/cm)	Cl^- (mg/l)	NO_3^- (mg/l)
R/135	25 July 1999	1,465	239	162
R/141	31 March 1999	2,568	607	177
R/255	12 July 2000	1,412	217	144
R/112	30 October 2000	1,680	322	67
R/254	30 October 2000	2,038	392	39
Average		1,833	355	118

According to the Palestinian strategy, a minimal amount of wastewater will be used for agricultural purposes such as soil flushing and irrigation of high-value crops. It is planned that wastewater reuse will be 34 mm^3 in 2010, increasing to 63 mm^3 in 2020 (PWA 2000a). Part of the reused amount will be diverted directly to the farms, and the rest will be recharged artificially through infiltration basins and other schemes to undergo soil aquifer treatment (SAT) processes that purify the effluent. From previous studies on the biological impact on groundwater, it was determined that SAT was efficient in removing faecal coliforms and faecal streptococci, and removed 85% of total BOD and COD applied in the effluent (Abushbak & Al Banna 2005).

Conventional water resources

The Gaza Strip depends mainly on conventional water resources coming from natural infiltration of rainfall that feeds the Pleistocene sandstone aquifer. Average annual rainfall fluctuates from 200 mm in south Gaza to 400 mm in the north, giving a bulk amount of water of about 115 mm^3, from which only 42 mm^3 infiltrate to the aquifer and the rest either evaporates or floods and runs off to the sea. The total supply was 120 mm^3/year, and the total demand was 165 mm^3, which led to a total deficit of about 45 mm^3 (CAMP 2000) and this deficit increases with time. The population in the Gaza Strip was estimated at 1,443,814 in 2006 leading to a total domestic demand of 79 mm^3 and the total agricultural consumption of 85.5, giving a total water demand in the Gaza Strip of 165 mm^3 (PWA 2007). Therefore, there is an annual deficit in the water budget of about 50 mm^3.

Non-conventional water resources

Due to the increasing demand and fixed supply of the groundwater system in Gaza, it became urgent to allocate new non-conventional water resources in order to fill the gap in the water budget. The potential resources that could be used are seawater desalination, wastewater reuse and storm water harvesting. According to a Coastal Aquifer Management Program (CAMP) study in 2000, it was planned that the amounts of treated wastewater that will be reused in 2020 will reach about 60 mm^3 every year and another 55 mm^3 will come from seawater desalination.

Some wastewater reuse projects are seen in the PWA area, in the north, middle and south of the Gaza Strip. In North Gaza the effluent is already flooded to the surrounding are of the wastewater treatment plant without control. According to the Sogreah (2001) feasibility study, it was found that the most feasible solution of this flooding effluent is to use controlled infiltration basins if compared with other solutions such as pumping the effluent to the sea or to the future treatment plant in the east of Northern governorate. The Swedish financed study proposed an area of 3,600 ha to be irrigated with treated wastewater (World Bank 2004a). In Rafah City, in the south of the Gaza Strip, the existing wastewater treatment plant is efficient and needs upgrading. However 10 ha close to the plant are proposed if the effluent is improved and reached WHO guidelines for irrigation (World Bank 2004a). The local people showed acceptance to use reclaimed wastewater. About 60% of the local people in the Gaza Strip are highly willing to use treated reclaimed wastewater for irrigation use, and about 22% are highly willing to use the reclaimed wastewater for domestic uses such as toilet flushing, washing, etc. (World Bank 2004b).

METHODOLOGY

A review of the strategic plans of the wastewater reuse were carried out and interpreted. Part of the treated effluent (10,000 m^3) from the existing wastewater treatment plant in Gaza was diverted to three spread infiltration basins with a total base area of 3.7 hectares (ha) distributed to three ponds: pond 1 with an area of 1.1 ha, pond 2 of 1.3 ha and pond 3 of 1.3 ha (CAMP 2001a) as shown in Figure 1. The three ponds were undergoing one day wetting and two days drying periods. The impact on groundwater levels and chemical quality was evaluated based on previous monitoring of the surrounding groundwater wells in different directions, where the water samples were analysed in the laboratory of the Palestinian Ministry of Agriculture according to the American Standard Method Manual. The samples were analysed for boron, Cl, NO_3, detergents and other ions, of which Cl, NO_3 and boron are interpreted in this paper. Due to different political, financial and social constraints, it was not possible to drill monitoring wells beside the infiltration basins. However, the existing operating wells were sufficient at this stage, and water samples were taken from them.

The infiltration areas located east of the current Gaza Waste Water Treatment Plant (GWWTP) is considered here. This project started in 2000 with the help of USAID through the CAMP project. The treatment plant receives about 40,000 m^3 every day and all of the effluent was pumped to the sea before the construction of the infiltration facilities. In 2000, about 10,000 m^3 were pumped to the infiltration basins.

RESULTS AND DISCUSSION

The infiltration basins are set on an area with groundwater of medium quality between fresh and brackish, where chloride concentration in the area fluctuates between 250 and 500 mg/l and nitrate concentration fluctuates between 50 and 200 mg/l (PWA 2008). The quality of the treated effluent was monitored in the period from January 2002 to November 2004. This showed a range of chloride level between 400 and 600 mg/l, which is slightly greater than that in native groundwater. However, the nitrate level in the treated effluent ranged between 20 and 30 mg/l in the same period, and this will dilute the nitrate concentration in the native groundwater. The Palestinian standards of effluent recharge are set at 600 for chloride and 20 mg/l for nitrate (KfW 2005). The reclaimed wastewater was planned to be pumped from six recovery wells, and the effect of the infiltration process was to be monitored in ten surrounding wells (CAMP 2001b). Due to local political conditions, the monitoring wells were not constructed and the monitoring itself was done in the existing operating wells owned by the farmers.

Impact of infiltration on groundwater levels

The ground elevation at the zone of the pilot projects ranges from 30 to 40 m above sea level, where two clayey

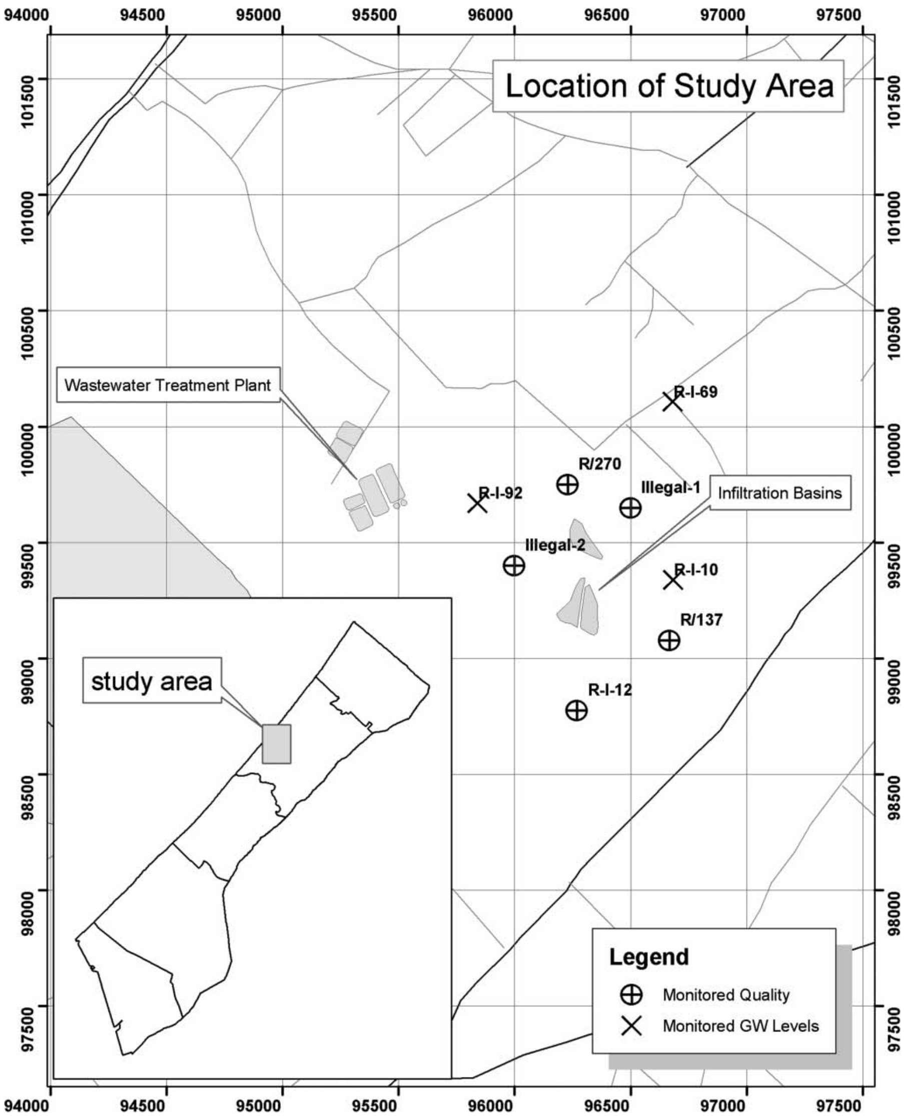

Figure 1 | Location map of infiltration area and monitored wells.

sand layers alternating with sand and sandstone are found at depths of 20 to 30 m below the ground surface (PWA 2001). For recovery well (R/137) ground surface is 40 m and the total depth of the well is 47.62 m and groundwater elevation of 4.0 m a.m.s.l. (PWA 2000b). According to the regional monitoring of groundwater levels, groundwater flows from the east to the sea in the west. However, due to the water mound created by the artificial recharge of wastewater in the study zone, the direction of groundwater flow becomes radial outward from the infiltration basins.

The area is surrounded by irrigation wells and monitoring the water levels in these gives an approximate indication of the influence of infiltration on the groundwater levels. Three operating water wells were monitored after the application of treated wastewater infiltration in the allocated basins. In well R-I-10, which is about 500 m east from the infiltration basin, there was an increase in water level of about 0.6 m by the end of 2003, almost constant during the whole period of infiltration since 2000 (Figure 2). The other monitored wells, which are R-I-69 (1,500 m north-east from the basins) and R-I-92 (1,000 m north-west

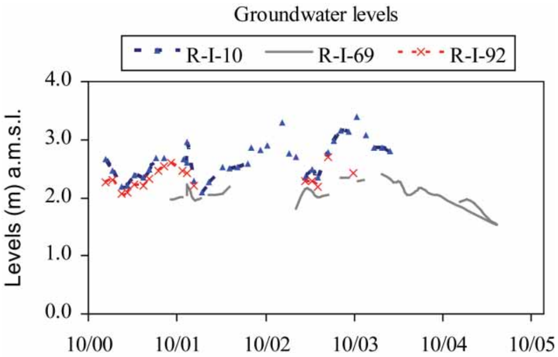

Figure 2 | Groundwater levels in wells around infiltration basins.

from the basins), showed slight decreases in the groundwater levels. No doubt that there was input to the groundwater system from the application of infiltration but the continuous abstraction through irrigation wells in the area hides the positive influence on the groundwater levels.

Impact of infiltration on groundwater quality

Five operating water wells in addition to the effluent recharge basins were selected to study the influence of effluent infiltration on the native groundwater quality. There was a clear increase in the chloride ion concentration in the monitored wells since the concentration level in the effluent is more than that of the native groundwater (Figure 3). The chloride concentrations in the study area range from 200 to 700 mg/l, depending on the layer from which water is pumped. Most of the water supplied through the municipal pipe networks has a chloride level of over 500 mg/l. Consequently, the sewage has naturally almost the same chloride level as this is not affected by the treatment processes in the wastewater treatment plant.

From the chemical analyses of effluent, the chloride level was found to be in the range from 400 to 600 mg/l. According to (Icekson-Tal & Blanc 1998), chloride in applied effluent in the Dan Region was 289 mg/l and after SAT processes it was observed to be 266 mg/l. In Gaza, effluent infiltration has negatively affected the salinity (chloride level) in the native groundwater in the area since chloride came from the high concentration effluent and without removal through SAT. This is considered as a threat to artificial recharge using effluent.

Figure 4 shows that the nitrate level in the effluent is much less than the nitrate level in all of the surrounding monitored wells. A slight decrease in nitrate concentrations was observed in all monitored wells, especially in well R-137, which is the closest to the infiltration basins (about 300 m east of the infiltration basins). In this case the infiltration has improved the quality of the groundwater in terms of nitrate level, from which most of the water wells in the Gaza Strip suffer. In the Dan Region case, the same conclusion was reached where the total nitrogen in the applied effluent decreased from 10.8 to 3.19 mg/l through SAT processes, i.e., removal was 70.5% (Icekson-Tal & Blanc 1998).

From an agricultural aspect, even though boron is an essential micronutrient for plants it may cause toxicity to sensitive crops when concentrations in irrigation water exceed 0.5 mg/l (FAO 2000). Boron concentrations monitored in the infiltrated effluent for 2002 until 2005 fluctuate from about 0.4 to 1.0 mg/l. This has negatively affected water quality in the neighbouring wells, most

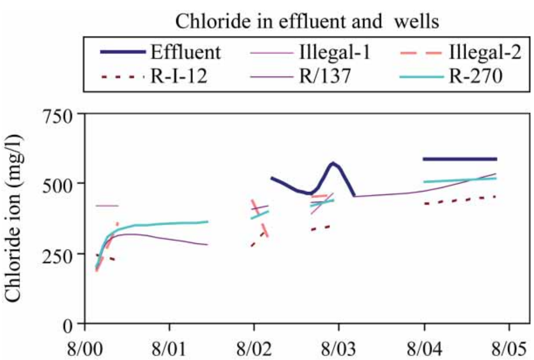

Figure 3 | Chloride levels in effluent and surrounding wells.

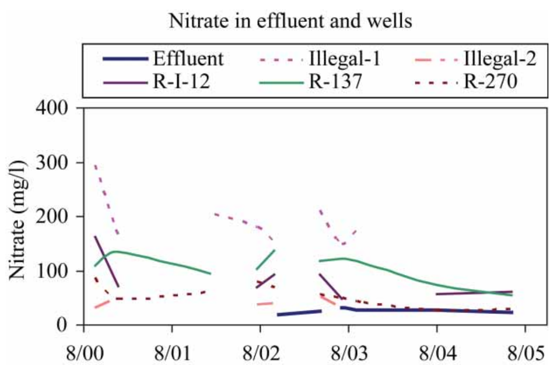

Figure 4 | Nitrate levels in effluent and surrounding wells.

obviously in the well closest to the basins. The boron concentration was 0.234 mg/l in January 2002 and increased to 0.61 mg/l in June 2005 (Figure 5). In other wells, there was a clear increase in boron concentrations. In well R-270, boron increased from 0.232 mg/l in January 2002 to 0.482 mg/l in July 2003 and then decreased to 0.24 mg/l in June 2005. In well R-I-12, boron increased from 0.29 mg/l in January 2001 to 0.635 mg/l in April 2003 and decreased to 0.2 mg/l in June 2005. The latter well results indicate clear influence on native groundwater on boron as SAT is not efficient in removing boron from the infiltrated water. The analyses of more chemical parameters carried out in June 2005 of the effluent and water from surrounding water wells are shown in Table 2 according to PWA (2008).

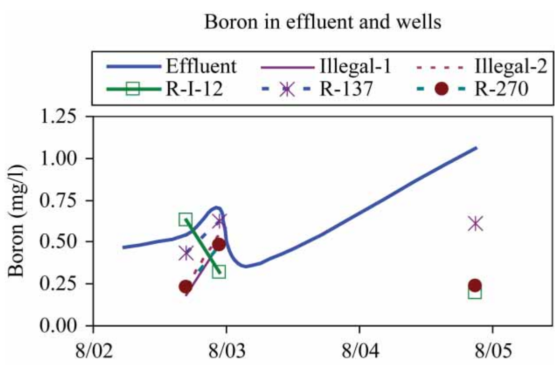

Figure 5 | Boron levels in effluent and surrounding wells.

In a similar area in the Dan Region, boron was removed during percolation in the early stage of the project. However, after several months, boron increased gradually in the recovery wells until it reached the same concentration as the effluent (Idelovitch & Michail 1985; Icekson-Tal & Blanc 1998), and SAT efficiency decreased. Boron removal was minimal (1.8%) as its concentration was 0.54 mg/l in the applied effluent and was observed to be 0.54 mg/l in the groundwater (Icekson-Tal & Blanc 1998).

Locally, in the Gaza Strip, boron compounds are reduced under high pH depending on the process; pH precipitation is likely indicated and advisable. There are some ion exchange compounds that can achieve the desired level, again subject to objectives. For example, a zeolite process with caustic soda may raise the pH to 9.5 or 10. This may precipitate elemental boron by 60%.

Socioeconomic impact

From the economic point of view, a cost estimation was carried out by SWECO (2003) for the infiltration system on infiltration of treated wastewater of the North Gaza governorate. The expected wastewater production for 2012 is 35,600 m^3 every day and it needs 8 ha for infiltration basins. The initial investment cost was 4.58 M USD including infiltration basins and construction of recovery wells

Table 2 | Water quality of effluent and water wells surrounding the infiltration basins

			Water from recovery wells							
Parameter	**Unit**	**Effluent water**	**R-270**	**R-137**	**R-I-54**	**R-I-69**	**R-I-92**	**R-139**	**R-I-10**	**R-I-12**
pH		8.0	7.6	7.2	7.0	7.3	7.8	8.6	7.4	7.4
TDS	mg/l	2,173	1,720	1,860	1,773	1,085	937	664	1,360	1,560
NO_3^{-1}	mg/l	23	30	55	483	265	63	33	101	60
Cl^{-1}	mg/l	587	516	535	376	197	269	120	384	454
B	mg/l	1.1	0.2	0.6	0.2	0.0	0.1	0.2	0.2	0.2
Deterg.	mg/l	0.9	0.1	0.2	0.0	0.0	0.0	0.0	0.1	0.1
Ca^{2+}	mg/l	109	96	104	125	119	55	29	86	80
Mg^{2+}	mg/l	57	79	79	90	68	51	17	73	101
K^{+}	mg/l	37.5	4.5	8.0	2.3	2.5	3.0	2.0	3.8	6.0
Na^{+}	mg/l	406	311	350	298	109	163	157	227	250
TOC	mg/l	11.9	2.0	2.7	1.8	0.2	0.4	0.4	2.4	1.9
BOD	mg/l	45.0	5.0	7.0	2.2	4.6	3.2	3.5	1.3	2.3
COD	mg/l	135	10.0	11.0	10.0	0.0	10.0	5.0	10.0	0.0

and pipes, while the operational cost was 0.14 M USD per year. Assuming that the investment system will operate for 20 years to infiltrate 35,600 m^3 per day i.e., 12.3 mm^3 per year, this will give an initial investment cost of 0.019 USD for each cubic metre infiltrated. The operational and maintenance costs for each cubic metre will be 0.018 USD. The total cost for each cubic metre is 0.037 USD for every cubic meter, which has been also reached by (Nassar *et al.* 2009), where 0.04 USD per cubic metre was estimated for operational costs. This cost is acceptable for Gaza, which is considered as a scarce water region. At the same time, the farmers pay 0.5 USD for each cubic metre pumped for irrigating their crops (PWA 2006). According to the survey conducted in a later study (PWA 2006), the farmers showed interest and willingness to pay 0.14 USD for each cubic meter of reclaimed effluent, where 68% of farmers in north Gaza and 91% of farmers in south Gaza are willing to use reclaimed wastewater either as direct reuse or from recovery wells (Nassar *et al.* 2009).

To convince the users, the reclaimed wastewater should be treated through the SAT in addition to preventing technical problems occurring in the distribution system and establishing an appropriate institutional framework to operate the system. The quality levels of reclaimed wastewater for irrigation should be managed well in terms of suspended solids to avoid blockage of the irrigation system, nutrients to adjust fertilization, salinity to estimate soil leaching requirement and control of pathogens to protect public health. The infiltration system itself needs to be properly assessed environmentally to prevent hazards to the neighbouring residents. From the other side, the public should be aware of the advantages of the new water sources, together with economic incentives to reclaim wastewater with a lower price than well water.

The current wastewater production is 32.7 mm^3 per year for the partial coverage of wastewater networks and it is estimated at 51.6 mm^3 if full coverage of wastewater services is achieved, as shown in Table 3. With a population growth rate of 3.5%, the total wastewater production will increase to 80 mm^3 per year by 2020. According to the National Water Plan (PWA 2000a), this will provide an input to water resources of about 60 mm^3 per annum by 2020.

Table 3 | Wastewater production in Gaza governorates[a]

Governorate	Population (capita)	Coverage percent (%)	Wastewater production (m^3/day)	Production with full coverage (m^3/day)
North Area	298,125	68.51	16,341	23,851
Gaza	546,959	79	48,243	61,067
Middle area	223,679	64	11,420	17,843
Khanyounis	299,918	20.60	4,942	23,988
Rafah	183,649	59.79	8,784	14,691
			89,730	141,440

Total production = 32.7 million m^3/year and 51.6 million m^3/year for full coverage, and based on average per capita of 80 l/day.
[a]CMWU (2007).

CONCLUSION AND RECOMMENDATIONS

Like other scarce water countries in the region, there is an urgent need to look for new non-conventional water resources such as reuse of reclaimed wastewater. The policy of the Palestinian Water Authority is to reduce the amount of fresh water to be used for irrigation (83 mm^3/year) by replacement with reclaimed wastewater after ensuring sufficient treatment. This new water resource will play an important role together with other resources, e.g., seawater desalination and harvesting of storm water, in the sustainability of the water resources in the Gaza Strip. Potentially, about 63 mm^3 of treated wastewater (22% of total water demand) could be available for reuse by 2020 (CAMP 2000).

Although the quantity of effluent infiltrated to the aquifer is currently small compared to the strategic planned amounts, it has had a slight positive impact on improving the continuous declined water table, which rose 0.6 m. A positive decrease in the nitrate concentrations in the recipient aquifer was observed. However, the trend of boron concentrations is a concern as concentrations in the aquifer exceed the WHO recommended value of 0.5 mg/l.

Chloride concentration in the public water supply is high in most of the areas in the Gaza Strip, and consequently the chloride level will be high in wastewater and treated effluent since this is not removed by wastewater treatment. Consequently, recharged effluent had negative impact on the chloride concentrations in the aquifer and is a challenge for artificial recharge of groundwater under the local conditions. It is recommended to reduce the salinity of the public water supply to reduce the level of chloride in the treated wastewater so that effluent becomes suitable for infiltration.

Previous studies have shown that infiltration of effluent through soil layers removed microorganisms and a large part of organic matter. In areas with a high boron level in effluent, it is recommended to use conventional treatment technologies (metal hydroxide precipitation) to reduce the boron level. Reverse osmosis (RO) is another recommended technology for boron reduction.

From the economic aspect, reuse through infiltration of effluent is feasible. The total cost of infiltrated effluent is 0.035 USD per cubic metre. However, more efforts are still needed on the socioeconomic and technical aspects. On the technical dimension, the applied effluent should be treated well in the treatment plant so that its constituents do not exceed the standards adopted by the Palestinian Water Authority based on WHO standards, in addition to the well-control on the management of infiltration spread basins. On the socioeconomic dimension, the public should be prepared to accept the idea of replacing their well water with distributed reclaimed wastewater for irrigation, and they should be economically encouraged through the pricing of the received water.

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REFERENCES

Abushbak, Th. H. & Al Banna, M. 2005 Soil aquifer treatment system using secondary treated wastewater: Sheikh Ejlin plant, Gaza. In *Proceedings of Conference on Water, Values and Rights*. Ramalla, Palestine 20095, p. 492.

CAMP 2000 *Coastal Aquifer Management Program. Volume I. Integrated Aquifer Management Program, Task 3. Metcalf and Eddy in association with Camp Dresser & McKee and Khatib & Alami*, Gaza, May 2000, pp. 3.1–3.15.

CAMP 2001a *Coastal Aquifer Management Program. Feasibility Study and Conceptual Design for Gaza Wastewater Treatment Plant, Task 23. Metcalf and Eddy in association with Camp Dresser & McKee and Khatib & Alami*, Gaza, March 2001, pp. 8.9–8.10.

CAMP 2001b *Coastal Aquifer Management Program, Task 25. Metcalf and Eddy in association with Camp Dresser & McKee and Khatib & Alami*, Gaza, September 2001, pp. 3.13–3.15.

CMWU 2007 *Databases of the Coastal Municipal Water Utility*. Gaza, 2007.

FAO 2000 *User Manual for Irrigation with Treated Wastewater*. Cairo, Egypt, p. 9.

Icekson-Tal, N. & Blanc, R. 1998 Wastewater treatment and groundwater recharge for reuse in agriculture. Dan Region Recharge Project, Shafdan. In *Proceeding of International Conference TISAR 98*. Rotterdam, 1998, p. 103.

Idelovitch, E. & Michail, M. 1985 Groundwater recharge for wastewater reuse in the Dan Region Project: summary of five-year experience, 1977–1981. In: *Artificial Recharge of Groundwater* (T. Asano, ed.). California State Water Resources Control Board and Department of Civil Engineering University of California. Butterworth Publishers. Boston. London. Sydney. Wellington. Durban. Toronto, pp. 502.

KfW 2005 *Sludge and Effluent Reuse Study for Gaza Central Area*. Concept Report, Volume I. Dorsch Consult, Gaza, July 2005, p. 3–2.

Nassar, A. R., Al-Najar, H. & Al-Dadah, J. 2009 Socio-economic aspect of wastewater reuse in the Gaza Strip. *J. Environ. Sci. Tech.* **2** (4), 170–178.

PWA 2000a *National Water Plan*. The Palestinian Water Authority, Gaza, December 2000, p. 5 (B-2-6).

PWA 2000b *Summary of Palestinian Hydrologic Data, Volume 2: Gaza*. Palestinian Water Authority, Data Bank Department, with technical and financial support USAID and USGS, p. 440.

PWA 2001 *Impact of Gaza Wastewater Treatment Plant Infiltration Basins on Groundwater Quality*. Water Resources and Planning Department, Hydrology Section, December 2001, p. 4.

PWA 2004 *Hydrogeological Impact Assessment of GWWTP Infiltration Basins on Local Groundwater*. Gaza, December 2004, p. 6.

PWA 2006 *Effluent Reuse Study for Khan Younis Governorate*. Finland Project-PWA, Gaza, July 2006, pp. 32, 54.

PWA 2007 *Agricultural and Municipal Water Demand in Gaza for the Year 2006*. Gaza, September 2007.

PWA 2008 Databases of the Palestinian Water Authority on groundwater quality (accessed 4 May 2008).

Sogreah 2001 *Beit Lahia Wastewater Project*. Interim Report. Gaza, July 2001.

SWECO 2003 *Northern Gaza WWTP Infiltration System*. Final Report. SWECO International AB, Stockholm, October 2003, pp. 71–72.

World Bank 2004a *West Bank and Gaza Wastewater Treatment and Reuse Policy Note. Volume 2: Preferred Reuse Options and Pilot Projects*. June 2004, pp. 13–17.

World Bank 2004b *West Bank and Gaza Wastewater Treatment and Reuse Policy Note. Volume 2: Accompanying Annexes to the Main Text, Annex E*. June 2004, pp. 30–40.

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Appendices

Appendix A. Stormwater Runoff in All Zones

A1- Stormwater Runoff in Zone (Z1)

Landuse in Z-1	***Area, A1 (km2)***	***Area, A2 over Sand dunes***	***(Cp) of planned land surface***	***(Ce) of Existing land surface***	***Rain (I) mm/year***	***Storm water of planned landuse (Cp * I *(A1-A2))***	***Storm water of existing landuse (Ce * I *(A1-A2))***
Urban Areas							
Built-up	3.985		0.865	0.865	405	1,394,752	1,394,752
Existing Industrial Area	1.200		0.865	0.865	405	419,920	419,920
Urban Development	4.076	2.172	0.865	0.150	405	1,426,567	115,551
Subtotal Urban	***9.260***					***3,241,240***	***1,930,223***
Suburbs							
Cultivated	1.098		0.150	0.150	405	66,624	66,624
Important Natural Resource 1	2.137	2.136	0.075	0.075	405	26	26
Natural Resource 2	8.223	0.067	0.075	0.075	405	247,513	247,513
Natural Resource 2 TW	8.589		0.075	0.075	405	260,646	260,646
Nature Reserve	4.106	4.104	0.075	0.075	405	55	55
Waste Water Treatment Site	0.355		0.000	0.000	405	0	0
Subtotal Suburbs	***24.508***					***574,864***	***574,864***
Total (Mm3)	***33.77***					***3.82***	***2.51***

A2- Stormwater Runoff in Zone (Z2)

Landuse in Z-2	***Area, A1 (km2)***	***Area, A2 over Sand dunes***	***(Cp) of planned land surface***	***(Ce) of Existing land surface***	***Rain (I) mm/year***	***Storm water of planned landuse (Cp * I *(A1-A2))***	***Storm water of existing landuse (Ce * I *(A1-A2))***
Urban Areas							
Built-up	4.406		0.865	0.865	418	1,591,752	1,591,752
Urban Development	1.099	1.093	0.865	0.15	418	396,996	337
Subtotal Urban	***5.504***					***1,988,748***	***1,592,089***
Suburbs							
Fisheries Site	0.019		0.865	0.865	418	6,710	6,710
Important Natural Resource 1	12.891	12.778	0.075	0.075	418	3,523	3,523
Nature Reserve	2.219	2.210	0.075	0.075	418	271	271
Recreation	2.737	2.711	0.075	0.075	418	818	818
Tourism Development	1.097	0.068	0.325	0.075	418	139,692	32,237
Subtotal Suburbs	***18.963***					***151,014***	***43,558***

A3- Stormwater Runoff in Zone (Z3)

Landuse in Z-3	***Area, A1 (km2)***	***Area, A2 over Sand dunes***	***(Cp) of planned land surface***	***(Ce) of Existing land surface***	***Rain (I) mm/year***	***Storm water of planned landuse (Cp * I *(A1-A2))***	***Storm water of existing landuse (Ce * I *(A1-A2))***
Urban Areas							
Built-up	21.6455		0.865	0.865	358	6,706,978	6,706,978
Urban Development	18.4755	5.018	0.865	0.15	358	5,724,726	723,077
Existing Industrial Area	0.0336		0.865	0.865	358	10,413	10,413
Proposed Industrial Area	1.3321		0.865	0.15	358	412,773	71,579
Free Trade Zone	1.2132		0.865	0.15	358	375,921	65,189
Harbour	0.1763		0.865	0.865	358	54,642	54,642
Subtotal Urban	***42.876***					***13,285,452***	***7,631,877***
Suburbs							
Cultivated	7.4896		0.15	0.15	358	402,435	402,435
Fisheries Site	0.0568		0.865	0.865	358	17,590	17,590
Important Natural Resource 1	0.0496	0.006	0.075	0.075	358	1,170	1,170
Natural Resource 2	0.3234		0.075	0.075	358	8,690	8,690
Natural Resource 2 TW	1.0889		0.075	0.075	358	29,256	29,256
Recreation	1.0879	1.067	0.075	0.075	358	548	548
Tourism Development	0.2113	0.043	0.325	0.075	358	19,569	4,516
Waste Water Treatment Site	0.2313		0	0	358	0	0
Subtotal Suburbs	***10.5389***					***479,256***	***464,203***
Total (Mm3)						***13.76***	***8.10***

A4- Stormwater Runoff in Zone (Z4)

Landuse in Z-4	*Area, A1 (km2)*	*Area, A2 over Sand dunes*	*(Cp) of planned land surface*	*(Ce) of Existing land surface*	*Rain (I) mm/year*	*Storm water of planned landuse (Cp * I *(A1-A2))*	*Storm water of existing landuse (Ce * I *(A1-A2))*
Urban Areas							
Built-up	4.051		0.865	0.865	343	1,202,205	1,202,205
Urban Development	9.031	0.177	0.865	0.865	343	2,680,196	2,627,531
Proposed Industrial Area	0.141		0.865	0.15	343	41,800	7,249
Free Trade Zone	0.238		0.865	0.15	343	70,670	12,255
Subtotal Urban	***13.461***					***3,994,871***	***3,849,240***
Suburbs							
Cultivated	17.329		0.15	0.15	343	891,781	891,781
Important Natural Resource 1	7.179	2.710	0.075	0.075	343	114,995	114,995
Natural Resource 2 TW	4.194		0.075	0.075	343	107,913	107,913
Nature Reserve	2.721	0.343	0.075	0.075	343	61,171	61,171
Recreation	0.521	0.449	0.075	0.075	343	1,867	1,867
Soild Waste Disposal Site	0.150		0	0	343	0	0
Waste Water Treatment Site	0.385		0	0.15	343	0	19,814
Subtotal Suburbs	***32.479***					***1,177,727***	***1,197,542***
Total	***45.94***					***5.17***	***5.05***

A5- Stormwater Runoff in Zone (Z5)

Landuse in Z-5	***Area, A1 (km2)***	***Area, A2 over Sand dunes***	***(Cp) of planned land surface***	***(Ce) of Existing land surface***	***Rain (I) mm/year***	***Storm water of planned landuse (Cp * I *(A1-A2))***	***Storm water of existing landuse (Ce * I *(A1-A2))***
Urban Areas							
Built-up	3.089		0.865	0.865	313	836,323	836,323
Urban Development	2.575	0.705	0.865	0.15	313	506,000	87,746
Existing Industrial Area	0.168		0.865	0.865	313	45,467	45,467
Proposed Industrial Area	0.579		0.865	0.15	313	156,800	27,191
Subtotal Urban	***6.411***					***1,544,591***	***996,727***
Suburbs							
Cultivated	7.876		0.15	0.15	313	369,755	369,755
Cultivated by treated water	5.427		0.15	0.15	313	254,776	254,776
Fisheries Site	0.031		0.865	0.865	313	8,428	8,428
Important Natural Resource 1	12.070	4.333	0.075	0.075	313	181,602	181,602
Mawasi	2.410	2.370	0.075	0.075	313	923	923
Natural Resource 2	0.500	0.127	0.075	0.075	313	8,757	8,757
Natural Resource 2 TW	1.546		0.075	0.075	313	36,282	36,282
Recreation	1.102	1.052	0.075	0.075	313	1,194	1,194
Soild Waste Disposal Site	0.021		0	0	313	0	0
Tourism Development	0.021	0.018	0.325	0.075	313	335	77
Subtotal Suburbs	***31.003***					***862,053***	***861,795***
Total	***37.41***					***2.41***	***1.86***

A6- Stormwater Runoff in Zone (Z6)

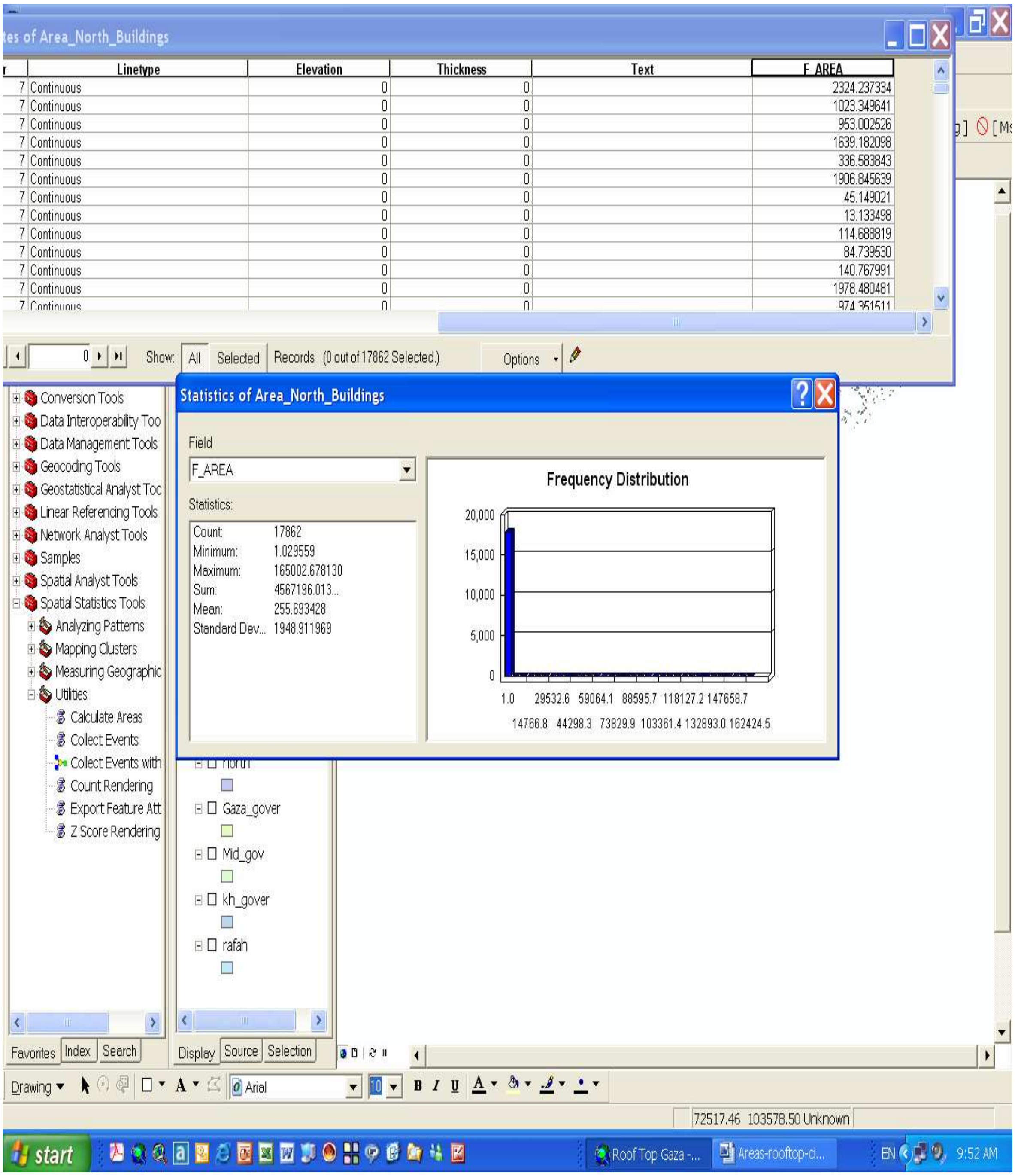
Landuse in Z-6	***Area, A1 (km2)***	***Area, A2 over Sand dunes***	***(Cp) of planned land surface***	***(Ce) of Existing land surface***	***Rain (I) mm/year***	***Storm water of planned landuse (Cp * I *(A1-A2))***	***Storm water of existing landuse (Ce * I *(A1-A2))***
Urban Areas							
Built-up	9.848		0.865	0.865	283	2,414,555	2,414,555
Urban Development	23.673	0.063	0.865	0.15	283	5,804,361	1,003,866
Subtotal Urban	***33.521***					***8,218,917***	***3,418,421***
Suburbs							
Cultivated	26.990		0.15	0.15	283	1,147,550	1,147,550
Fisheries Site	0.045		0.865	0.865	283	11,066	11,066
Mawasi	9.724	7.729	0.075	0.075	283	42,406	42,406
Natural Resource 2	14.722	1.971	0.075	0.075	283	271,077	271,077
Nature Reserve	12.096	7.575	0.075	0.075	283	96,103	96,103
Recreation	0.563	0.525	0.075	0.075	283	801	801
Tourism Development	8.271	7.857	0.325	0.075	283	38,175	8,810
Waste Water Treatment Site	0.141		0	0	283	0	0
Subtotal Suburbs	***72.551***					***1,607,179***	***1,577,813***
Total	***106.07***					***9.83***	***5.00***

A7- Stormwater Runoff in Zone (Z7)

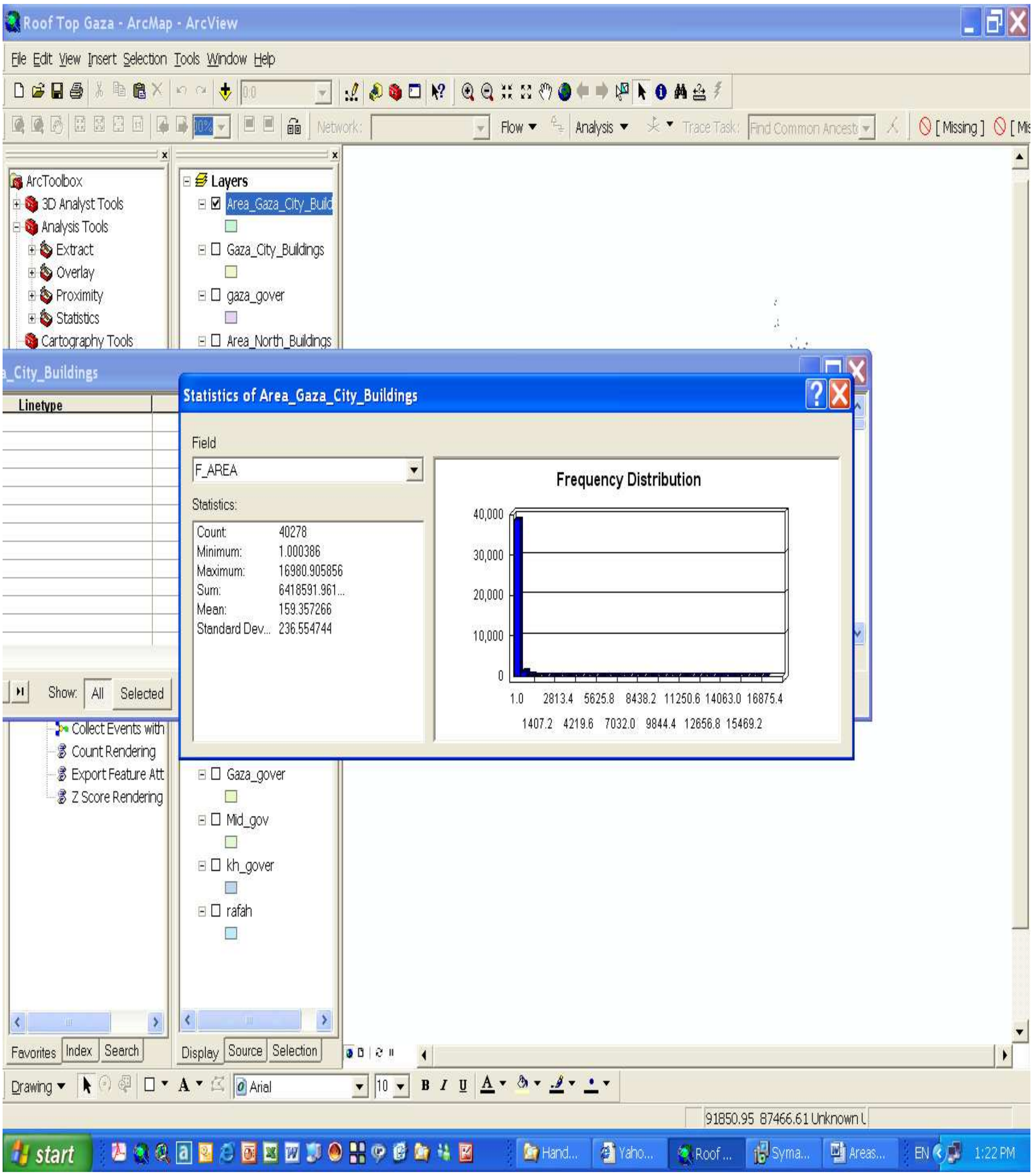
Landuse in Z-7	Area, A1 (km2)	Area, A2 over Sand dunes	(Cp) of planned land surface	(Ce) of Existing land surface	Rain (I) mm/year	Storm water of planned landuse (Cp * I *(A1-A2))	Storm water of existing landuse (Ce * I *(A1-A2))
Urban Areas							
Airport	7.110		0.8	0.800	230	1,308,884	1,308,884
Built-up	5.596		0.865	0.865	230	1,113,906	1,113,906
Urban Development	6.044	0.289	0.865	0.150	230	1,202,941	198,622
Proposed Industrial Area	2.640		0.865	0.150	230	525,479	91,124
Free Trade Zone	1.241		0.865	0.150	230	247,007	42,834
Subtotal Urban	***22.632***					***4,398,217***	***2,755,369***
Suburbs							
Cultivated	21.466		0.15	0.150	230	740,914	740,914
Fisheries Site	0.006		0.865	0.865	230	1,191	1,191
Mawasi	2.077	2.070	0.075	0.075	230	118	118
Natural Resource 2	8.967	0.004	0.075	0.075	230	154,690	154,690
Nature Reserve	4.890	4.631	0.075	0.075	230	4,464	4,464
Recreation	0.113	0.106	0.075	0.075	230	115	115
Tourism Development	2.709	0.413	0.325	0.075	230	171,690	39,621
Waste Water Treatment Site	0.134		0	0.150	230	0	4,617
Subtotal Suburbs	***40.362***					***1,073,181***	***945,729***
Total	***62.99***					***5.47***	***3.70***

Appendix B. GIS Calculations of Areas of Rooftop and Yards

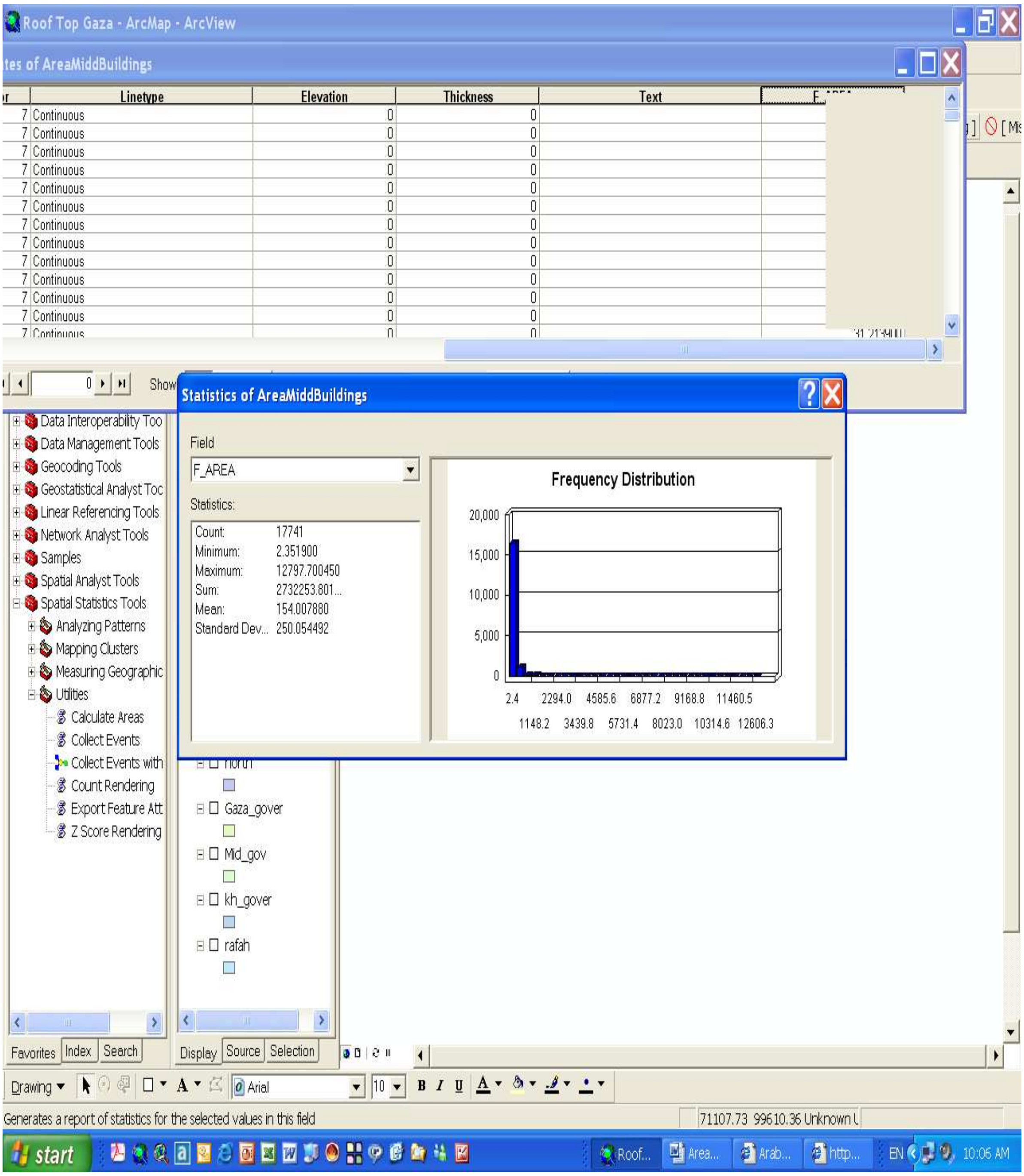
B1
Rooftop and Yards Areas in North Gaza



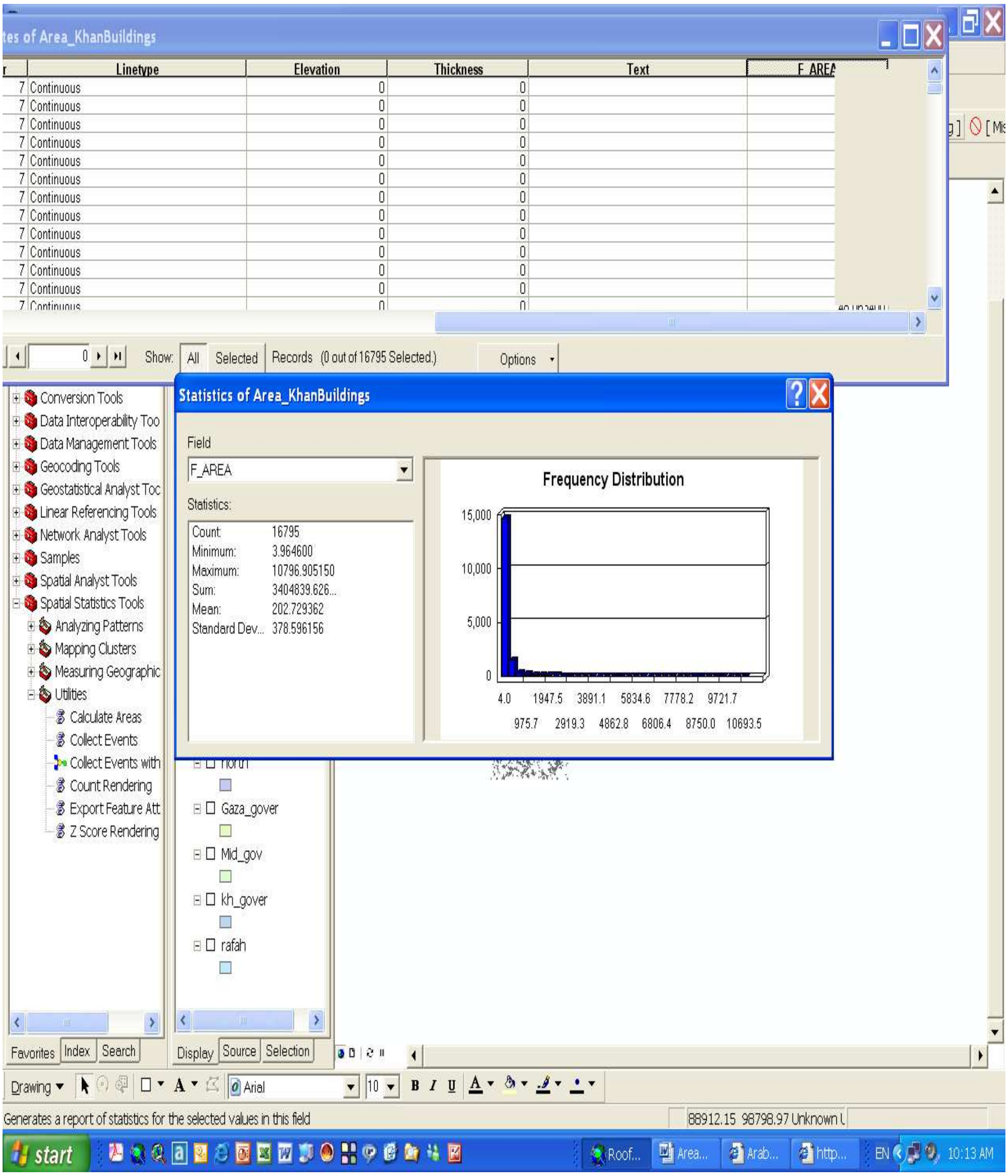
B2
Rooftop and Yards Areas in Gaza City



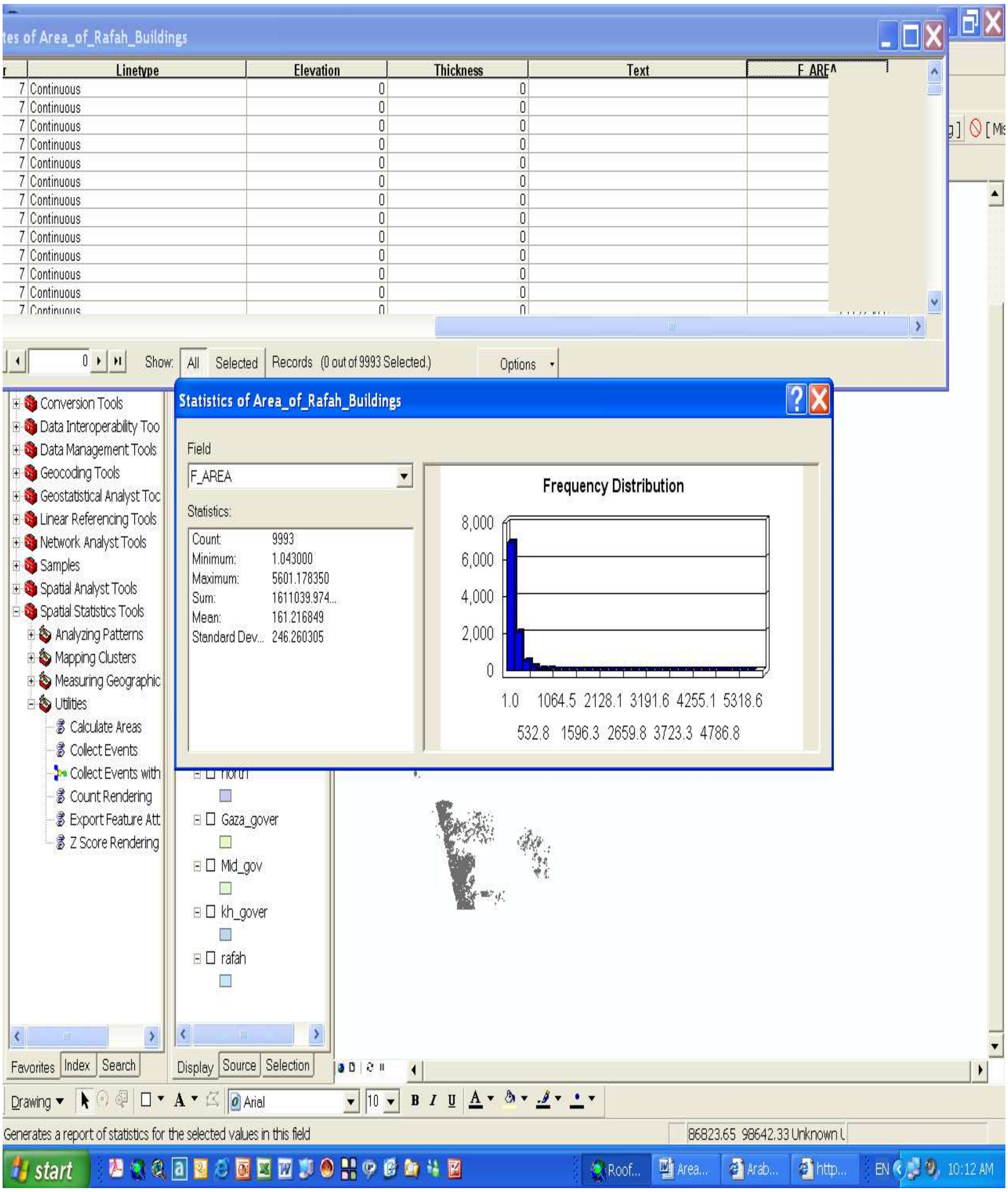
B3
Rooftop and Yards Areas in Middle Area



B4
Rooftop and Yards Areas in Khan Younis



B5
Rooftop and Yards Areas in Rafah



Appendix C: Rooftop Flow Measurements

C1

Storm number	Storm Date	Storm Duration (Hours)	Storm Rainfall (mm)	Initial Meter reading	Current meter reading	Drained Volume (m3)	Collected water (m3)=(F)-(E)+(G)	Roof Area (m2)	Bulk quantity fallen on roof(m3) =(D)*(I)	Harvesting Efficiency (%) =100*(H)/(J)	Water Sampling	Intensity
R1	15-Oct-07	2	1.2	3.335	3.335	0.000	0.000	236.3	0.284	0.0		0.6
R2	7-Nov-07	1	0.6	3.335	3.335	0.000	0.000	236.3	0.142	0.0		0.6
R3	9-Nov-07	1	0.6	3.335	3.335	0.000	0.000	236.3	0.142	0.0		0.6
R4	10-Nov-07	1	0.6	3.335	3.335	0.000	0.000	236.3	0.142	0.0		0.6
STR1	*11-Nov-07*	*2*	*5.6*	*3.335*	*3.757*	*0.158*	*0.580*	*236.3*	*1.323*	*43.8*	*Yes*	2.8
R5	20-Nov-07	3	1.2	3.757	3.757	0.020	0.020	236.3	0.284	7.2		0.4
STR2A	22-Nov-07	10	43.4	3.757	11.789	0.158	8.190	236.3	10.255	79.9	*Yes*	4.3
STR2B	22-Nov-07	1	3.4	11.789	12.107	0.158	0.476	236.3	0.803	59.3	*Yes*	3.4
R6	2-Dec-07	1	1.9	12.993	12.993	0.104	0.104	236.3	0.449	23.1		1.9
R7	16-Dec-07	1	1.2	12.993	12.993	0.017	0.017	236.3	0.284	6.0		1.2
R8	19-Dec-07	1	0.3	12.993	12.993	0.000	0.000	236.3	0.071	0.0		0.3
STR3A	20-Dec-07	1	4.7	12.993	13.429	0.158	*0.594*	236.3	1.111	53.5	Yes	4.7
STR3AB	20-Dec-07	1.5	5.3	13.429	13.967	0.158	*0.696*	236.3	1.252	55.6		3.5
STR3B	20-Dec-07	0.5	6.5	13.967	15.160	0.158	*1.351*	236.3	1.536	88.0	Yes	13.0

C2

Storm number	Storm Date	Storm Duration (Hours)	Storm Rainfall (mm)	Initial Meter reading	Current meter reading	Drained Volume (m3)	Collected water (m3)=(F)-(E)+(G)	Roof Area (m2)	Bulk quantity fallen on roof(m3) =(D)*(I)	Harvesting Efficiency (%) =100*(H)/(J)	Water Sampling	Intensity
STR4A	3-Jan-08	1	3.1	15.160	15.253	0.158	0.251	236.3	0.733	34.3	Yes	3.1
STR4AB	4-Jan-08	1	3.7	15.253	15.782	0.158	0.687	236.3	0.874	78.6		3.7
STR4B	4-Jan-08	1	7.8	15.782	17.258	0.158	1.634	236.3	1.843	88.6		7.8
R9	9-Jan-08	1	0.3	17.258	17.258	0	0.000	236.3	0.071	0.0		0.3
STR5	9-Jan-08	10	5	17.258	17.530	0.158	0.431	236.3	1.182	36.4	Yes	0.5
R10	22-Jan-08	1	1.2	17.530	17.530	0.006	0.006	236.3	0.284	2.1		1.2
R11	22-Jan-08	1	0.3	17.530	17.530	0	0.000	236.3	0.071	0.0		0.3
STR6A	23-Jan-08		5.9	17.530	The water meter was clogged and the storage was overflowed						Yes	
STR6B	23-Jan-08		14.3	–	The water meter was clogged and the storage was overflowed						Yes	
STR7A	26-Jan-08	2	2.8	19.181	19.235	0.158	0.212	236.3	0.662	32.0	Yes	1.4
STR7AB	26-Jan-08	1.25	5	19.235	20.171	0.000	0.936	236.3	1.182	79.2		4.0
STR7AC	26-Jan-08	2.5	1.9	20.171	20.295	0.158	0.283	236.3	0.449	63.0		0.8
STR7AD	27-Jan-08	1	3.4	20.295	20.795	0.158	0.658	236.3	0.803	81.9		3.4
STR7AE	27-Jan-08	0.5	0.6	20.795	20.795	0.094	0.094	236.3	0.142	66.3		1.2

C3

Storm number	Storm Date	Storm Duration (Hours)	Storm Rainfall (mm)	Initial Meter reading	Current meter reading	Drained Volume (m3)	Collected water (m3)=(F)-(E)+(G)	Roof Area (m2)	Bulk quantity fallen on roof(m3) =(D)*(I)	Harvesting Efficiency (%) =100*(H)/(J)	Water Sampling	Intensity
STR7AF	29-Jan-08	0.5	1.24	20.795	20.799	0.158	0.162	236.3	0.293	55.2		2.5
STR7AG	30-Jan-08	1.5	2.79	20.799	21.213	0.158	0.572	236.3	0.659	86.8		1.9
STR7AH	30-Jan-08	4	1.86	21.213	21.405	0.158	0.349	236.3	0.440	79.5		0.5
STR7B	30-Jan-08	12.5	11.78	21.405	23.909	0.137	2.642	236.3	2.784	94.9	Yes	0.9
R12	12-Feb-08	1	0.31	23.909	23.909	0.000	0.000	236.3	0.073	0.0		0.3
R13	12-Feb-08	1	0.31	23.909	23.909	0.000	0.000	236.3	0.073	0.0		0.3
STR8A	13-Feb-08	2	9.3	23.909	25.508	0.158	1.757	236.3	2.198	79.9	Yes	4.7
STR8AB	13-Feb-08	1.5	3.72	25.508	26.216	0.000	0.709	236.3	0.879	80.6		2.5
STR8AC	13-Feb-08	1.5	2.79	26.216	26.745	0.000	0.529	236.3	0.659	80.2		1.9
STR8AD	13-Feb-08	3	2.79	26.745	27.128	0.137	0.520	236.3	0.659	78.8		0.9
STR8AE	13-Feb-08	1	0.62	27.128	27.128	0.028	0.028	236.3	0.147	19.1		0.6
STR8AF	14-Feb-08	2	4.03	27.128	27.725	0.158	0.755	236.3	0.952	79.3		2.0
STR8AG	14-Feb-08	1	0.62	27.725	27.725	0.032	0.032	236.3	0.147	21.8		0.6
STR8AH	14-Feb-08	1	3.41	27.725	28.097	0.158	0.530	236.3	0.806	65.8		3.4

C4

Storm number	Storm Date	Storm Duration (Hours)	Storm Rainfall (mm)	Initial Meter reading	Current meter reading	Drained Volume (m3)	Collected water (m3)=(F)-(E)+(G)	Roof Area (m2)	Bulk quantity fallen on roof(m3) =(D)*(I)	Harvesting Effeciency (%) =100*(H)/(J)
STR8B	14-Feb-08	1	2.17	28.097	28.282	0.137	0.322	236.3	0.513	62.8
R14	15-Feb-08	1	0.31	28.282	28.282	0.000	0.000	236.3	0.073	0.0
STR9A	18-Feb-08	8.5	8.06	28.282	29.662	0.137	1.517	236.3	1.905	79.7
STR9AB	19-Feb-08	2.5	1.24	29.662	29.741	0.158	0.237	236.3	0.293	80.9
STR9AC	19-Feb-08	9	6.2	29.741	30.930	0.137	1.326	236.3	1.465	90.5
STR9B	20-Feb-08	6.5	3.72	30.930	31.532	0.158	0.760	236.3	0.879	86.5
R15	25-Feb-08	1	0.62	31.532	31.532	0.006	0.006	236.3	0.147	4.1
STR10A	25-Feb-08	1	4.96	31.532	32.083	0.158	0.709	236.3	1.172	60.5
STR10AB	25-Feb-08	5	8.68	32.083	33.667	0.158	1.742	236.3	2.051	84.9
STR10B	25-Feb-08	2.5	3.1	33.667	34.206	0.000	0.539	236.3	0.733	73.6
STR11	31-Mar-08	1.5	4.65	34.206	34.503	0.158	0.455	236.3	1.099	41.4

Head with intensity more than 10 mm/hour **34.5 mm**

Head with intensity less than 10 mm/hour **186.58 mm**

Total annual head **221.08 mm**

C5

Summary of the rain Storms

Storm number	Storm Date	Storm Duration (Hours)	Storm Rainfall (mm)	Initial Meter reading	Current meter reading	Drained Volume (m3)	Collected water (m3)=(F)-(E)+(G)	Roof Area (m2)	Bulk quantity fallen on roof(m3) =(D)*(I)	Harvesting Efficiency (%) =100*(H)/(J)	Water Sampling
STR1	11-Nov-07	2	5.6	3.335	3.757	0.158	0.580	236.3	1.323	43.8	Yes
STR2	21-Nov-07	16.5	46.8	3.757	12.10715	0.316	8.666	236.3	11.059	78.4	Yes
STR3	20-Dec-07	6.5	16.5	12.99275	15.1599	0.474	2.641	236.3	3.899	67.7	Yes
STR4	4-Jan-08	20	14.6	15.1599	17.2575	0.316	2.414	236.3	3.450	70.0	Yes
STR5	9-Jan-08	10	5	17.2575	17.53	0.158	0.431	236.3	1.182	36.4	Yes
STR6	23-Jan-08	6.5	20.2	17.53	**The water meter was clogged and the storage was overflowed**						Yes
STR7	26-30 Jan/08	115	31.37	19.181	23.909	1.179	5.907	236.3	7.413	79.7	Yes
STR8	13-14 Feb/08	45.5	29.45	23.909	28.282	0.808	5.181	236.3	6.959	74.4	Yes
STR9	19-20 Feb/08	37.5	19.22	28.282	31.5323	0.632	3.882	236.3	4.542	85.5	Yes
STR10	25-Feb-08	16.5	16.74	31.5323	34.2055	0.316	2.989	236.3	3.956	75.6	Yes

Appendix D. Chemical Analyses of Rooftop and Road Stormwater

D1

Chemical Analyses of Rooftop Rainwater

Sample No	Date	PH	EC	TDS	Cl^-	$SO4^-$	NO_3^-	Ca^{+2}	Mg^{+2}	K^+	Na^+	Alkalinity $CaCO_3$	HCO_3^-	CO_3^{-2}	Hardness CaCO3
STR 1	11-Nov-07	7.82	623	415.3	125	70	17	30	15	4	76	40	49	0	136
STR 2 A (start of storm)	22-Nov-07	7.51	511	340	105	49	18	12	19	4	52	24	29	0	107
STR 2 B (End of storm)	22-Nov-07	7.61	247	164.7	57	25	9	9	10	2	29			0	64
STR 3A	20-Dec-07	8.45	355	236	67	59	12	19	22	3	34			0	137
STR 3B	20-Dec-07	6.81	184.8	123.2	42	19	16	7	15	2	20	10	12	0	81
STR 4A	4-Jan-08	7.81	265	176.7	60	27	15	9	15	2	34	14	7	0	84
STR 5	9-Jan-08	7.44	1153	768.7	246	102	31	41	31	7	162	50	61	0	229
STR 6A	23-Jan-08	7.25	335	223.3	63	85	12	11	17	3	48	24	29	0	97
STR 6B	23-Jan-08	7.29	136.2	90.8		12	6	10	20	2	15	40	49	0	106
STR 7A	26-Jan-08	6.94	843	562	184	47	28	46	11	4	115	54	66	0	162
STR 7B	30-Jan-08	8.27	318	212	76	25	7	11	15	3	41	34	41	0	89
STR 8A	13-Feb-08	7.01	631	420.7	157	60	18	18	25	5	78	28	34	0	146
STR 8B	13-Feb-08	7.78	176	117.3		30	6	6	14	2	24	36	44	0	75
STR 9A	18-Feb-08	7.1	690	460	132	112	15	42	16	5	73	26	32	0	173
STR 9B	20-Feb-08	7.17	480	320	99	43	13	14	11	4	53	34	41	0	79
Average Values		7.5	463.2	308.7	100	51	15	19	17	3	57	30	36	0	118

D2

Chemical Analyses of Road Stormwater collected in Lagoons

Sample No	ASQ1	ASQ2	ASQ3	ASQ4	SHR1	SHR2	SHR3	SHR4	Average
Sampling date	23-Jan-08	26-Jan-08	30-Jan-08	13-Feb-08	23-Jan-08	26-Jan-08	30-Jan-08	13-Feb-08	
Analyses date	4-Feb-08	4-Feb-08	4-Feb-08	21-Feb-08	4-Feb-08	4-Feb-08	4-Feb-08	21-Feb-08	
PH	7.28	7.83	8.1	6.94	6.99	7.18	7.5	6.76	7.478
EC (u moh/cm)	411	282	544	502	655	497	554	647	5944.4
TDS (mg/l)	274	188	362	334.7	436.7	331.3	369	431.3	3962.84
Chloride Cl(-)(mg/l)	53.18	38.29	242	77.99	98.55	67.36	95	104.22	2191.827
Sulfate-SO4(-2) (mg/l)	42.4	20.35	30.53	36.63	59.36	28.83	32.22	33.92	322.68
Nitrate-NO3(-) (mg/l)	21.27	14.7	15.94	9.97	9.58	12.59	11.18	6.66	11.881
Calcium-Ca(+2) (mg/l)	33.35	19.88	25.65	32.32	50.98	30.3	28.86	37.03	71.801
Magnesium-Mg(+2) (mg/l)	20.54	20.36	27.15	15.2	2.66	14.72	25.11	18.11	169.057
Potassium K(+) (mg/l)	11.25	6.5	8.25	9.25	12.5	9	10	10	58.55
Sodium Na(+) (mg/l)	54.74	24.34	99.93	46.1	78.29	49.97	64.78	53.46	1167.292
Total alkalinity as (CaCO3) (mg/l)	112			106.04			120.05		117.242
HCO3(-) (mg/l)	136.64			129.32			146.4		142.984
CO3(-2)	0	0	0	0	0	0	0	0	0
Hardness as CaCO3 (mg/l)	168	133.6	176	143.6	138.4	136.4	175.6	167.2	876.04

D3

Organic and Inorganic Carbon Analyses of Rood and Rooftop Rainwater

Sample No	Sampling date	Analyses date	TC (mg/l)	IC (mg/l)	TOC (mg/l)
ASQ1	1/23/2008	2/7/2008	60.66	28.94	30.05
ASQ2	1/26/2008	2/4/2008	26.41	18.15	8.25
ASQ3	1/30/2008	2/7/2008	35.572	22.0832	13.49
DB1	1/23/2008	2/4/2008	29.065	18.167	10.897
DB2	1/30/2008	2/7/2008	27.28	27.06	0.22
Rain2	1/23/2008	2/4/2008	5.419	0.797	4.621
Rain3	1/30/2008	2/7/2008	5.4076	1.2854	4.1222
SHR1	1/23/2008	2/7/2008	77.45	36.585	40.875
SHR2	1/26/2008	2/7/2008	58.9875	28.941	30.045
SHR3	1/30/2008	2/7/2008	63.38	32.89	30.48
STR1	11/11/2007	12/17/2007	16.6124		3.602
STR2A (start of storm)	11/22/2007	12/17/2007	9.5828		1.8219
STR2B (End of storm)	11/22/2007	12/17/2007	9.498		4.5237
STR3A	12/20/2007	2/7/2008	9.8547	5.7528	4.1019
STR3B	12/20/2007	2/7/2008	6.4894	3.2791	3.2103
STR4	1/3/2008	2/7/2008	7.9798	3.4424	4.5374
STR5	1/9/2008	2/7/2008	18.151	13.545	4.606
STR6A	1/23/2008	2/4/2008	8.1704	6.1879	1.9194
STR6B	1/23/2008	2/4/2008	7.3252	4.5772	2.748
STR7A	1/26/2008	2/4/2008	12.9236	9.7251	3.1985
STR7B	1/30/2008	2/7/2008	9.6851	5.5154	4.1697
TAP	1/26/2008	2/7/2008	88.675	81.485	6.885

D4

Heavy Metal Analyses of Rood and Rooftop Rainwater

Tröger / Hamdan

Code	Sample No	Date	Flame (ppm)			Graphit (ppb)			
			Zn	Fe	Al	Cu	Pb	Cd	Cr
3	Rain2	23-Jan-08	0.032	0.000	< 0,5	< 4 µg	< 3 µg	< 2 µg	< 2 µg
19	Rain3	30-Jan-08	0.021	0.065	< 0,5	19.85	< 3 µg	< 2 µg	< 2 µg
21	Rain4	19-Feb-08	0.030	0.078	< 0,5	< 4 µg	< 3 µg	< 2 µg	< 2 µg
18	STR1	11-Nov-07	0.549	1.533	2.03	14.96	15.62	< 2 µg	36.38
12	STR2A	22-Nov-07	0.436	0.678	0.68	12.20	3.65	< 2 µg	18.24
17	STR2B	22-Nov-07	0.159	0.313	< 0,5	< 4 µg	4.23	< 2 µg	7.90
1	STR3A	20-Dec-07	0.071	0.000	< 0,5	11.29	< 3 µg	< 2 µg	6.50
10	STR3B	20-Dec-07	0.084	0.026	< 0,5	5.04	< 3 µg	< 2 µg	3.73
8	STR4	3-Jan-08	0.093	0.044	< 0,5	< 4 µg	< 3 µg	< 2 µg	8.00
6	STR5	9-Jan-08	0.084	0.004	< 0,5	7.84	< 3 µg	< 2 µg	38.98
9	STR6A	23-Jan-08	0.174	0.214	< 0,5	< 4 µg	< 3 µg	< 2 µg	16.92
15	STR6B	23-Jan-08	0.109	0.111	< 0,5	< 4 µg	< 3 µg	< 2 µg	5.51
14	STR7A	26-Jan-08	0.101	0.095	< 0,5	27.13	< 3 µg	< 2 µg	27.10
4	STR7B	30-Jan-08	0.070	0.057	< 0,5	23.35	< 3 µg	< 2 µg	7.21
11	STR8A	13-Feb-08	0.106	0.123	< 0,5	< 4 µg	< 3 µg	< 2 µg	8.66
7	STR8B	14-Feb-08	0.109	0.099	< 0,5	< 4 µg	< 3 µg	3.16	37.54
20	STR9A	18-Feb-08	0.099	0.218	< 0,5	< 4 µg	< 3 µg	< 2 µg	53.33
13	STR9B	20-Feb-08	0.082	0.067	< 0,5	< 4 µg	< 3 µg	< 2 µg	30.78

D5

Heavy Metal Analyses (cont'd)

Code	Sample No	Date	Flame (ppm)			Graphit (ppb)			
			Zn	Fe	Al	Cu	Pb	Cd	Cr
2	STR10B	25-Feb-08	0.115	0.259	< 0,5	< 4 µg	< 3 µg	< 2 µg	21.78
24	ASQ1	23-Jan-08	0.098	1.201	1.66	35.08	38.00	< 2 µg	8.13
25	ASQ2	26-Jan-08	0.117	1.064	1.71	36.14	40.61	< 2 µg	9.38
31	ASQ3	30-Jan-08	0.081	0.654	0.88	25.77	17.60	< 2 µg	4.41
26	ASQ4	13-Feb-08	0.049	0.616	1.03	19.20	19.82	< 2 µg	4.76
29	ASQ5	20-Feb-08	0.036	0.439	0.97	11.43	17.33	< 2 µg	5.41
30	SHR1	23-Jan-08	0.081	0.536	0.88	256.40	43.99	< 2 µg	4.23
27	SHR2	26-Jan-08	0.166	0.542	0.90	23.86	61.31	< 2 µg	3.57
23	SHR3	30-Jan-08	0.033	0.349	0.51	21.45	22.19	< 2 µg	3.46
22	SHR4	13-Feb-08	0.022	0.157	< 0,5	11.56	16.42	< 2 µg	2.57
28	SHR5	20-Feb-08	0.064	0.398	0.64	6.80	21.91	< 2 µg	5.13
32	DB1	23-Jan-08	0.061	0.655	2.51	29.37	15.38	< 2 µg	7.77
33	TAP	26-Jan-08	0.112	0.259	< 0,5	5.85	< 3 µg	< 2 µg	23.76

Appendix E. Infiltration Measurements in House Infiltration Pit

E1

22-November 2007 (Infiltration Measurements)

Time HH:MM	Depth to Water Surface	Head Difference	Time difference in seconds	Accumulated Time (seconds)	Infiltration Rate (cm/sec) = (C)/(D)	Infiltration Rate **(m/day)**=E*24*3600/100	Head of water (cm) =92-(B)
4:58:12	12						80
5:00:15	38	26	113	113	0.23	199	54
5:02:00	53.5	15.5	105	218	0.15	128	38.5
5:03:45	66	12.5	105	323	0.12	103	26
5:07:00	80	14	195	518	0.07	62	12

09-January 2008 (Infiltration Measurements)

Time HH:MM	Depth to Water Surface	Head Difference	Time difference in seconds	Accumulated Time	Infiltration Rate (cm/sec) = (C)/(D)	Infiltration Rate **(m/day)**=E*24*3600/100	Head od water (cm) =92-(B)
6:49:50	32						60
6:51:30	43.5	11.5	100	100	0.12	99	48.5
6:57:00	66.5	23	210	310	0.11	95	25.5
6:59:30	74.5	14	150	460	0.09	81	17.5

13-February 2008 (Infiltration Measurements)

Time HH:MM	Depth to Water Surface	Head Difference	Time difference in seconds	Accumulated Time	Infiltration Rate (cm/sec) = (C)/(D)	Infiltration Rate **(m/day)**=E*24*3600/100	Head od water (cm) =92-(B)
6:43:00	4						88
6:48:30	15	11	330	330	0.03	29	77
6:57:00	28	13	510	840	0.03	22	64
7:05:00	39	11	480	1320	0.02	20	53

E2

14-February 2008 at 6:00 AM (Infiltration Measurements)

Time HH:MM	Depth to Water Surface	Head Difference	Time difference in seconds	Accumulated time (seconds)	Infiltration Rate (cm/sec) = (C)/(D)	Infiltration Rate **(m/day)**=E*24*3600/100	Head od water (cm) =92-(B)
6:25:45	9						83
6:31:45	23	14	300	300	0.05	40	69
6:39:00	35.5	12.5	435	735	0.03	25	56.5
6:48:00	48	12.5	540	1275	0.02	20	44
6:56:30	57	9	510	1785	0.02	15	35
7:07:30	65.5	8.5	660	2445	0.01	11	26.5

25-February 2008 at 7:00 AM (Infiltration Measurements)

Time HH:MM	Depth to Water Surface	Head Difference	Time difference in seconds	Accumulated Time (seconds)	Infiltration Rate (cm/sec) = (C)/(D)	Infiltration Rate **(m/day)**=E*24*3600/100	Head of water (cm) =92-(B)
16:01:00	7						85
16:06:30	25	18	330	330	0.05	47	67
16:11:00	36.5	11.5	270	600	0.04	37	55.5
16:17:30	50	13.5	330	930	0.04	35	42
16:25:00	61	11	390	1320	0.03	24	31
16:33:00	70	9	480	1800	0.02	16	22
16:40:00	74.5	4.5	420	2220	0.01	9	17.5

E3

14-February 2008 at 6:00 PM (Infiltration Measurements)

Time HH:MM	Depth to Water Surface	Head Difference	Time difference in seconds	Accumulated Time (seconds)	Infiltration Rate (cm/sec) = (C)/(D)	Infiltration Rate **(m/day)**=E*24*3600/100	Head od water (cm) =92-(B)
16:30:45	10.5						81.5
16:36:00	22	11.5	345	345	0.03	29	70
16:43:00	33	11	420	765	0.03	23	59
16:49:00	41.5	8.5	360	1125	0.02	20	50.5
16:54:00	47.5	6	300	1425	0.02	17	44.5
17:00:00	53.5	6	360	1785	0.02	14	38.5
17:06:00	59	5.5	360	2145	0.02	13	33
17:14:00	65	6	480	2625	0.01	11	27
17:22:00	69.5	4.5	480	3105	0.01	8	22.5

19-February 2008 at 7:00 AM (Infiltration Measurements)

Time HH:MM	Depth to Water Surface	Head Difference	Time difference in seconds	Accumulated time (seconds)	Infiltration Rate (cm/sec) = (C)/(D)	Infiltration Rate **(m/day)**=E*24*3600/100	Head of water (cm) =92-(B)
7:33:30	15						77
7:39:30	28	13	360	360	0.04	31	64
7:45:00	37	9	330	690	0.03	24	55
7:51:30	46	9	330	1020	0.03	24	46
7:57:00	52	6	330	1350	0.02	16	40
8:06:00	59.5	7.5	540	1890	0.01	12	32.5
8:16:00	66.5	7	600	2490	0.01	10	25.5
8:26:30	71.5	5	570	3060	0.01	8	20.5

Appendix F. Socioeconomic Questionnaires

F1
Questionnaire for Water Experts

Questionnaire to adopt Rainwater Harvesting in the Gaza Strip
For Water Professionals and Institutions

Please underline the suitable answer

Professional Experience

Name (Optional): …………………………………….

1. Institution

   1) Governmental 2) Academic 3) NGO or International 4) Private
2. Field of experience

   1) Water resources 2) Engineering 3) Environment 4) Others
3. Years of Experience

   1) Less than 5 years 2) 5 – 10 years 3)10 – 15 years 4) More than 15 years

Satisfaction of Water Situation in Gaza Strip as a whole

4. Your satisfaction of supplied water ***quantity***

   1) Very good 2) good 3) poor 4) very poor
5. Your satisfaction of supplied water ***quality***

   1) Very good 2) good 3) poor 4) very poor
6. Do you think that Rainwater harvesting is needed to improve water quantity and quality in Gaza Strip

   1) Very important 2) Important 3) Fair 4) Not important

Rainwater harvesting methods

7. Are you or your institution willing to adopt or encourage implementation of rainwater harvesting system at single houses ***having*** gardens:

   1) Individual houses 2) Neighborhoods 3) soak away in roads 4) central storm water lagoons
8. Are you or your institution willing to adopt or encourage implementation of rainwater harvesting system at houses in cities ***without*** gardens:

   1) Individual houses 2) Neighborhoods 3) soak away in roads 4) central storm water lagoons
9. Are you or your institution willing to adopt or encourage implementation of rainwater harvesting system at houses in tower buildings with many floors?

1) Individual houses 2) Neighborhoods 3) soak away in roads 4) central storm water lagoons

10. Are you or your institution willing to adopt or encourage implementation of rainwater harvesting system at houses in Refugee Camps:

    1) Individual houses 2) Neighborhoods 3) soak away in roads 4) central storm water lagoons

11. Are you or your institution willing to adopt or encourage implementation of rainwater harvesting system at houses in rural areas with large open areas:

    1) Individual houses 2) Neighborhoods 3) soak away in roads 4) central storm water lagoons

Uses of storm water

12. Your preference of rainwater harvesting uses

    1) For drinking uses 2) For direct non-drinking domestic uses

    3) For irrigation uses 4) For artificial recharge of the aquifer.

Institutional aspects

13. Are you or your institution willing to adopt or encourage small scale (on-site rainwater harvesting) and in which level:

    1) Fund raising 2) implementation 3) monitoring 4) none

14. Means of implementation for individual houses if implemented:

    1) Public awareness 2) pre-requisite for new construction 3) pre-requisite for services supply e.g. water and electricity 4) Other means including enforcement

Maintenance and finance if rainwater harvesting is implemented

15. Responsibility of maintenance of rainwater harvesting system for individual houses Should be:

    1) Completely government or water institutions 2) Completely house owner

    3) Both house owner and government 4) NGO's or international institutions

16. Costs of rainwater harvesting systems ***construction*** Should be financed by::

    1) The government or its local authority 2) The local people 3) Local water utilities 4) Shared among them.

17. Costs of rainwater harvesting systems ***maintenance*** Should be financed by:

    1) The government or its local authority 2) The local people 3) Local water utilities 4) Shared among them.

Thank You for Your Time

F2
Questionnaire for Local People (in Arabic)

استبيان من أجل استغلال مياه الأمطار كمصدر مياه إضافي

أخي المواطن الكريم

السلام عليكم ورحمة الله وبركاته

يرجى التكرم بإعطائنا قليل من الوقت لتعبئة هذا الاستبيان لاستطلاع رأيك في دراسة مدى الاستفادة من مياه الأمطار في قطاع غزة لتعويض النقص في مصادر المياه والتي تعاني منها فلسطين بشكل عام وقطاع غزة بشكل خاص، يرجى من حضرتكم توخي الدقة في الإجابة على الأسئلة التالية، ونشكركم على تعاونكم ومساعدتكم لإتمام هذا العمل.

م. سامى حمدان

جوال: 0599417130

<u>معلومات عامة</u>

1. المدينة.............................. الحى: ....

2. المهنة

1) موظف أو متقاعد 2) أكاديمي (أستاذ جامعة) 3) أعمال حرة (4 عاطل عن العمل

3. العمر

1) أقل من 30 سنة 2) 30 – 45 سنة 3) 45 – 60 سنة 4) أكبر من 60 سنة

4. مستوى التعليم

1) إعدادية أو أقل 2) ثانوية عامة 3) خريج كلية متوسطة أو جامعة 4) دراسات عليا

<u>معلومات عن البناية</u>

5. نوع البناية

1) شقة فى برج سكنى 2) بيت خاص في المدينة 3) بيت فى قرية صغيرة 4) بيت فى مخيم لاجئين

5) مؤسسة أكاديمية أو تعليمية 6) فندق 7) مصنع

6. عدد أدوار البناية

1) طابق واحد 2) طابقين 3) ثلاث طوابق 4) أكثر من ذلك

7. مساحة البناية

1) أقل من 200 متر مربع 2) 200- 400 متر مربع

3) 400 – 700 متر مربع 4) أكثر من 700 متر مربع

8. مساحة الأرض المقام عليها البيت

1) أقل من 250 متر مربع 2) 250 – 600 متر مربع

3) 600 – 1000 متر مربع 4) أكثر من 1000 متر مربع

<u>مصدر المياه الذى يزود البناية</u>

9. مصدر المياه لأغراض الشرب لديكم

1) مياه البلدية أو مصلحة المياه 2) من بئر مياه خاص

3) موزع مياه بالسيارة 4) جهاز تحليه خاص داخل البناية

10. مصدر المياه للأغراض الأخرى غير الشرب لديكم

1) مياه البلدية أو مصلحة المياه 2) من بئر مياه خاص

3) موزع مياه بالسيارة 4) غير ذلك ----------------

<u>رضى المواطن عن خدمات المياه المزودة للبناية</u>

11. ما مدى رضاكم عن كميات المياه التى تحصلون عليها؟

1) جيدة جدا " المياه متوفرة طول الوقت" 2) جيدة " المياه متوفرة 50 % من الوقت

3) ضعيفة " بضع ساعات يوميا" 4) ضعيف جدا " انقطاع المياه لأكثر من يوم كامل"

12. ما مدى رضاكم عن نوعية المياه التى تحصلون عليها؟

1) جيدة جدا " اللون والرائحة والطعم" 2) جيدة "يوجد بعض الملوحة"

3) ضعيفة " ملوحة واضحة جدا" 4) ضعيف جدا "ملوحة غير محتملة"

<u>رغبة المواطن باستغلال مياه الأمطار وبناء وصيانة نظام تجميع مياه الأمطار</u>

على افتراض بأن استغلال مياه الأمطار سوف يساهم في تحسين نوعية المياه التي تصل بيوتكم إضافة إلى زيادة في الكميات التي تصل إلى بيوتكم، فما رأيكم فى ما يلى:

13. هل تعتقد بأن هناك حاجة ملحة لاستغلال مياه الأمطار كمصدر مياه اضافى لتحسين وضع المياه

1) ضرورى جدا 2) ضروري 3) ممكن 4) غير مقتنع

14.هل أنت مستعد للسماح ببناء وحدة تجميع لمياه الأمطار وترشيحها فى الأرض خلال حفر امتصاصية داخل سور بنايتكم ؟

1) نعم بمساحة 4 متر مربع وأكثر 2) نعم بمساحة من 2 إلى 4 متر مربع

3) غير متوفرة مساحة في بنايتي لهذا الغرض 4) غير مستعد في كل الأحوال

15. هل أنت مستعد للمساهمة في تمويل بناء وحدة تجميع والترشيح داخل سور بنايتكم، حيث يكلف إنشاء هذا النظام 800 دولار لبناية مساحتها 300 متر مربع، و 1000 دولار لبناية مساحتها 500 متر مربع، و 1500 دولار لبناية مساحتها 1000 متر مربع.

1) نعم وأتحمل جميع التكاليف 2) نعم وأساهم بنسبة 50 % من التكاليف

3) نعم وأساهم بنسبة 25 % من التكاليف 4) غير مستعد للمساهمة بأي تكاليف

16. هل أنت على استعداد لتنظيف سطح بنايتكم لاستقبال مياه أمطار نظيفة؟

1) نعم بشكل دوري كل شهر 2) نعم من وقت لآخر حسب الرواسب والأتربة الجوية

3) مرة واحدة في السنة قبل فصل الشتاء 4) غير مستعد لتنظيفه من أجل هذا الغرض

17. إذا كانت وحدة استغلال مياه الأمطار المكونة من خزان بلاستيكى وأنابيب وحفر امتصاصية داخل سور بنايتكم، هل أنت على استعداد لتنظيفها ؟

1) بشكل دورى كل شهر 2) من وقت لآخر حسب الرواسب

3) مرة واحدة قبيل فصل الشتاء 4) غير مستعد لتنظيفه

<u>مجال إعادة استخدام مياه الأمطار لدى المواطن</u>

18- هل تفضلون إعادة استخدام مياه الأمطار التى تم تجميعها ؟

1) لأغراض الشرب.

2) إعادة استخدامها فى البناية لغير أغراض الشرب مثل الغسيل والحمامات

3) ري الحدائق الداخلية أو الخارجية

4) ترشيحها في باطن الأرض من خلال حفر امتصاصية داخل سور بنايتكم.

5) ترشيحها في باطن الأرض من خلال حفر امتصاصية في ساحة مخصصة لذلك قريبة منكم.

6) لا أفضل استخدامها في أي مجال.

نشكركم على تعاونكم

م. سامي حمدان

F3
Translation of Questionnaire for Local People

Questionnaire to harvest rainwater as a new water resource

Dear citizen,

I ask your help to fill the following questionnaire to get your opinion in rainwater harvesting in the Gaza Strip to compensate the deficit in the water resources budget of water resources in Palestine in general, and in the Gaza Strip in particular. Your precise answers for the questions are greatly appreciated. Last, I would like to thank you for your help and cooperation.

Sami Hamdan
Mobile: 0599 417130

General Information

1. **City…………………………. District………………….**
2. **Job**
   1) Employee or retired 2) Academic 3) Private 4) Unemployed
3. **Age**
   1) Less than 30 years 2) 30-45 yrs 3) 45-60 yrs 4) More than 60 yrs
4. **Education**
   1) Preparatory school and less 2) Secondary school
   3) College or university 4) Higher Education

Information on building

5. **Type of house**
   1) Apartment in tower 2) Private house in city
   3) Private house in village 4) House in refugee camp
6. **Number of storey (floors)**
   1) Single floor 2) Two floors 3) Three floors 4) More than three floors
7. **Area of house building**
   1) Less than 200 m^2 2) 200 – 400 m^2
   3) 400 – 700 m^2 4) More than 700 m^2

8. **Total area of land on which the house exists**

   1) Less than 250 m^2 2) 250 – 600 m^2

   3) 600 – 1000 m^2 4) More than 1000 m^2

Building water supply

9. **Source of water for drinking purposes**

   1) Municipality or water utility 2) Private water well

   3) Water vendor 4) In house desalination unit

10. **Source of water for domestic purposes (non drinking)**

   1) Municipality or water utility 2) Private water well

   3) Water vendor 4) Others ….

Satisfaction of public water supply

11. **Satisfaction of water quantity**

   1) Very good (Full time water availability) 2) Good (50% water availability)

   3) Poor (25%-50% water availability) 4) Very poor (< 25% water availability)

12. **Satisfaction of water quality**

   1) Very good (color, taste and odor) 2) Good (some salinity)

   3) Poor (tasted salinity) 4) Very poor (Intolerable salinity)

Willingness of citizen to construction and maintenance of RWH

Based on improvement of your public water supply due to rainwater harvesting, please indicate your opinions in the following questions,

13. **Is there an urgent need for rainwater harvesting as additional water resource?**

   1) Very important 2) Important 3) Possible 4) I do not believe in it.

14. **Are you willing to allow for construction of RWH around your house?**

   1) Yes with 4 m^2 and more 2) Yes with 2-4 m^2

   3) There is no available land at my house 4) Non-willing at all

15. **Are you willing to participate in financing the construction of RWH around your house, where it costs $800 for roof area of 300$m^2$, $1000 for roof area 500$m^2$ and $1500 for roof area of 1000 m^2?**

1) Yes, and bear all costs   2) Yes, and participate with %50 of costs

3) Yes, and participate with %25 of costs   4) Non-willing to bear any cost

16. Are you willing to clean your roof?

1) Yes, every month   2) Yes, when there are sediments on roof

3) Once a year before rainy season   4) Non-willing to clean it

17. Are you willing to clean the RWH system i.e. storage tank infiltration pits or pipes

1) Yes, every month   2) Yes, when there are sediments

3) Once a year before rainy season   4) Non-willing to clean it

Citizen's use of harvested rainfall

18. Do you prefer reuse of harvested rainfall?

1) For drinking uses

2) In building non-drinking uses for e.g. washing and toilet flushing

3) Irrigation of internal and external gardens

4) Artificial recharge through infiltration pits around your house

5) Artificial recharge through a common infiltration pit away from your house

6) I do not prefer to reuse harvested rainfall in any case

Thank you for cooperation

Sami Hamdan