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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

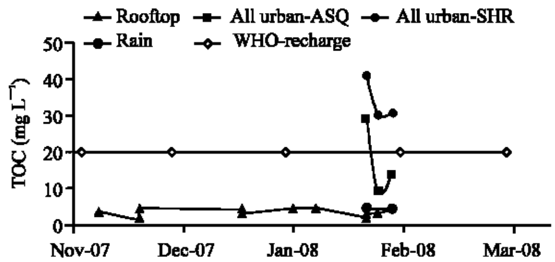

Fig. 1: Total organic carbon in stormwater in Gaza

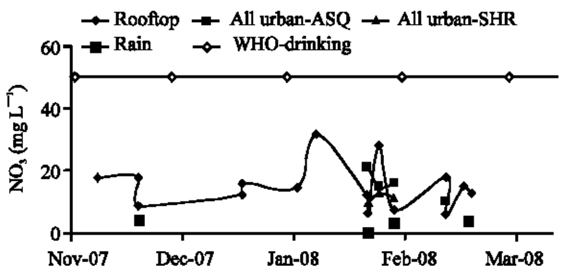

Fig. 2: Nitrate concentration in stormwater in Gaza

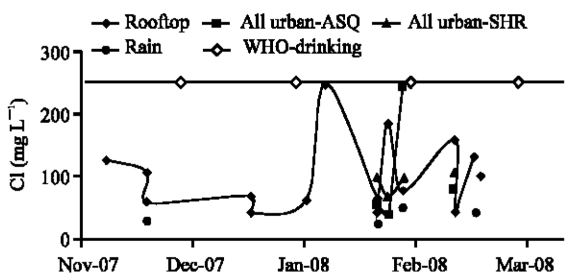

Fig. 3: Chloride concentration in stormwater in Gaza

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.

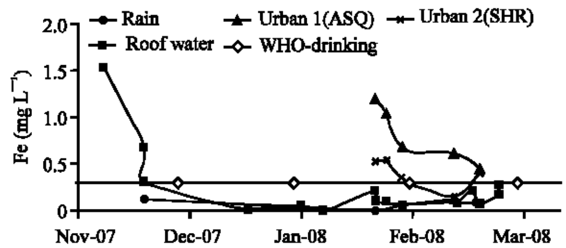

Fig. 4: Iron concentration in stormwater in Gaza

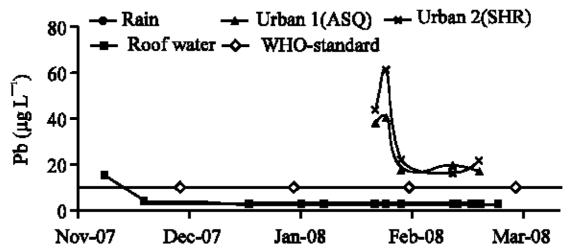

Fig. 5: Lead concentration in stormwater in Gaza

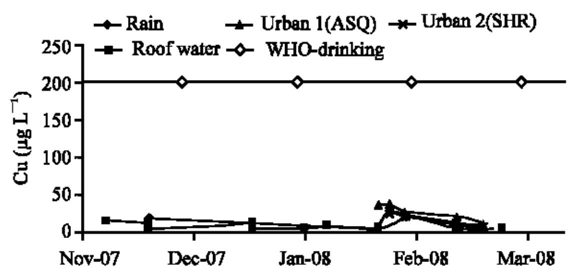

Fig. 6: Copper concentration in stormwater in Gaza

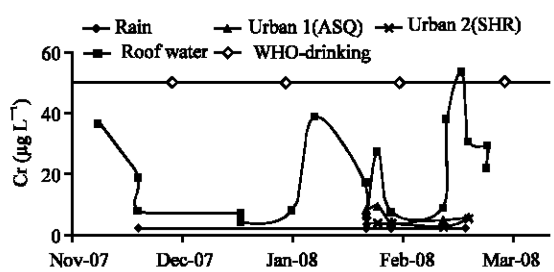

Fig. 7: Chromium concentration in stormwater in Gaza

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

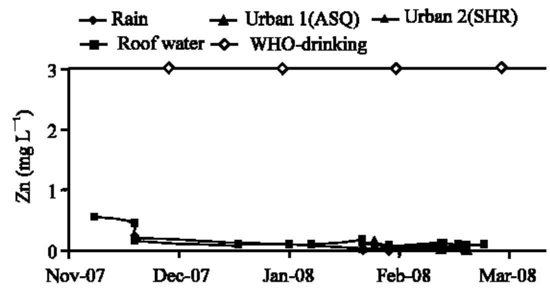

Fig. 8: Zinc concentration in stormwater

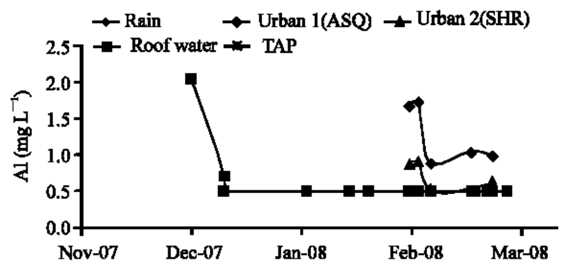

Fig. 9: Aluminum concentration in stormwater in Gaza

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 μg L^{-1}. In Gaza, cadmium concentrations were low in all samples, at less than 2 μg 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 μg 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 μg L^{-1}, decreasing to 4 μg L^{-1} in the second storm and to less than 3 μg L^{-1} in the remaining storms of the rainy season. However, lead concentrations were greater in road runoff, ranging from 61 μg L^{-1} at the start of the rainy season to 17 μg 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 μg L^{-1} (JISM, 2002). Lead concentrations in rooftop runoff is also close to the drinking water standard of 10 μg 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 $\mu g\ L^{-1}$. By contrast, copper concentrations in the rest of the samples, from both rooftop and road stormwater runoff, were low, ranging from 3 to 35 $\mu g\ L^{-1}$ (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 $\mu g\ L^{-1}$ (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.

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