Stormwater runoff quality generated from an urban and a rural area in the Amman-Zarqa basin

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Abstract

Six storm events were monitored during the winter season extended from October 2012 to April 2013 to investigate the stormwater runoff pollutant concentrations on urban and rural sites in the Amman-Zarqa basin. The average pollutant concentrations of stormwater runoff were significantly different from the urban and rural site. The results showed that the urban site generated stormwater runoff with the highest concentrations of organic pollutants COD and BOD5 (1685 mg/L and 91 mg/L) and dissolved heavy metals Zn, Cu, Pb and Mn (0.106 mg/L, 0.033 mg/L, 0.02 mg/L and 0.189 mg/L respectively). This is mainly due to the high traffic volume at urban site compared with the rural site. While the rural site generated the highest concentrations of total suspended solids TSS (6029 mg/L), nutrients T-N and T-P (31.2 mg/L and 34.3 mg/L) and fecal bacteria TCC, TFCC and E.coli (4.06E+07, 8.00E+05 and 1.31E+05 MPN/100ml, respectively) carried by the stormwater runoff. This is reflecting the presence of anthropogenic pollution sources such as using chemical and nature fertilizers in a rural site. A key constituent of runoff quality (COD, TSS, TKN, T-P, Zn and Pb) from both urban and rural sites are considered very high compared to those reported in other countries. This study has provided a better understanding of the concentrations and sources of stormwater runoff pollutants generated from urban and rural site which is posing a serious threat to water bodies within the Amman-Zarqa basin. Therefore, best management practices and proper land management measures should be taken to minimize the impacts of stormwater runoff.
Keywords: urban, rural, stormwater runoff quality, Amman-Zarqa basin.

WIT Transactions on Ecology and The Environment, Vol 182, © 2014 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/WP140331

1 Introduction

Stormwater runoff generated from urban catchments is widely recognized as a major source of environmental contaminants [1]. The types and levels of pollutants carried by stormwater runoff are directly related to various types of land use and human activities [2, 3].

Converting land uses from rural to urban has been described as a complex process called urbanization. Many studies showed that this process has caused various impacts on ecosystem structure, function, and dynamics [4, 5]. Moreover, one of the major problems for most urbanized countries and regions is the conversion of agricultural land into developed land uses, which is a direct result of urbanization [6].

Expansion of urbanization areas involved many activities such as the increasing activities of population and economic activities, more land to be developed for public infrastructure (e.g. roads, water facilities, and utilities), housing, and industrial and commercial uses. These activities will increase the percentages of impervious surface coverage. The land use and cover changes accompanying urbanization impacts natural ecosystems at multiple spatial scales. It is well known that urbanization activities generated high amounts of stormwater runoff and increased pollutant loading within catchment area [7].

In Jordan, the urbanization areas have continuously increased over the past five decades. The population of Jordan has risen from about 0.9 to 6.4 million between the census dates of 1961 and 2012, According to recent figures provided by department of statistics for 2012, the growth rate was 2.2%, the urban population was 82.6% and the rural population was 17.4% [8]. Amman-Zarqa basin is one of Jordan's important basins. About half the population of Jordan lives within the urban areas of Amman-Zarqa basin. Land uses within the Amman-Zarqa basin watershed range from high density urban areas in the west to typical rural areas at the east of basin [9]. The continuous deterioration of the ecosystem components of the Amman-Zarqa basin since almost three decades is one of the biggest environmental challenges in Jordan. The Amman-Zarqa Basin has been categorized by the Jordanian government as the biggest environmental hotspot. The rapid growth of urbanization activities at Amman-Zarqa basin has changed the balance of urban-rural population as well as has consumed land capable of sustaining rain-fed agriculture, which is a rare commodity in Jordan [10]. Many studies indicate that there is a considerable degradation in the quality of the water resources in the Amman-Zarqa basin (Zarqa river waters) as a result of general deterioration conditions [9, 11, 12]. These conditions are primarily attributed to: general water level declines, irrigation water return flows, human and industrial wastewater along wadi Zarqa, treated wastewater effluents from the existing treatment plants within the basin and the other impacts resulted from the ongoing agricultural activities in the Amman-Zarqa basin. Although a considerable number of studies has focused on the impacts of wastewater (domestic and industrial). However, there is a little knowledge about the impact of stormwater runoff generated from urban and rural areas on the environment in the Amman-Zarqa basin. To protect the basin's ecosystem, it is beneficial to determine the pollutants carried by stormwater runoff and its sources. Therefore, this study was initiated to assess and compare the level of contamination (organic, inorganic, metals, nutrients and fecal) generated from stormwater runoff from urban and rural areas in the Amman-Zarqa basin.

2 Methodology

2.1 Study area

Amman-Zarqa basin is the largest watershed in Jordan and comprises several cities (Amman, Zarqa, Mafraq, Jerash and Balqa) (Figure 1). The total area of the basin 3859 km^2 where around 95% of the area (3594 km^2) is within Jordan and 5% is in Syria reaching to the Syrian city of Salkhad in Jebal al-Arab the Syrian boarders. The Zarqa river is the main watercourse passing through the study area and discharge into King Talal Dam. The Zarqa river consists of two main creeks; the first creek (Sail Al-Zarqa) originates in Amman city centre at Ras Al-Ain, while the other creek (Wadi Duleil) originates from the south of the Syria (Figure 1).

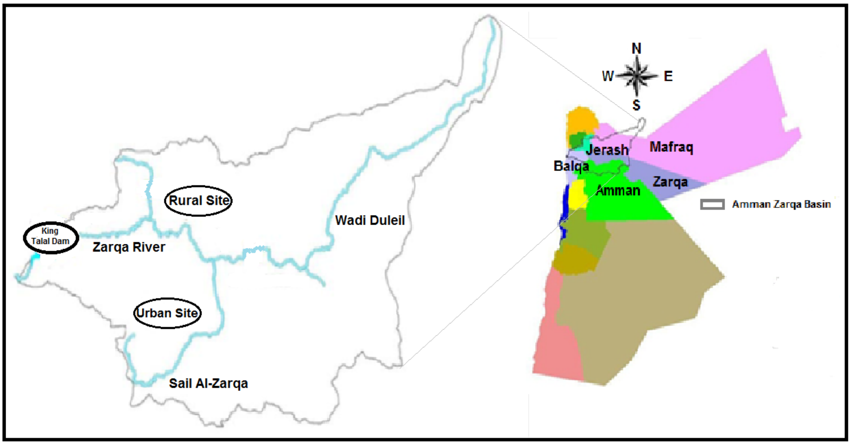

Figure 1: Location map of Amman-Zarqa basin.

The wadi Duleil portion of the basin includes significant amounts of natural habitat and rural or non-urban land uses including small ranches, tree farms, horse stables and rural residential. While the Sail Al-Zarqa portion is highly urbanized and is covered with impervious surfaces including parking lots, roads, commercial and residential buildings, Universities, driveways, and sidewalks.

The average rainfall is 250 mm/year. It drains a total area of 3594 Km^2 within Jordan, and 355 Km^2 in Syria. The total average annual surface water resources of the basin amount to approximately 93 Million Cubic Meters (MCM)/year. The total treated municipal and industrial wastewater discharged to the Zarqa river from the four treatment plants (As-Samra; Jerash; Baqa'a; Abu-Nuseir) in the basin exceeded 86 MCM in 2010. Two sites were chosen to represent the urban and rural areas within the basin, Al-Abdali in Amman city refers to the portion of urban area where intensive residential and commercial activities are exist (high impervious cover). Al-Qunayyah in Jarash city refers to the portion of rural area where mainly agriculture activities are exist (low impervious cover). Table 1 1ists the location of sites including the nearest geographic reference, city, type of land use, total rainfall on winter season 2012–2013 and the receiving body of stormwater runoff.

Table 1: Summary of the characteristics of catchment areas.

Item	Catchment area	
	Urban area	Rural area
Site name	Al-Abdali	Al-Qunayyah
City	Amman	Jarash
Longitude	35º55.797	35º59.816
Latitude	31º57.454	32º14.357
Elevation (m)	787	522
Type of land use	Mix of commercial and residential	Agriculture, bare soil
Receiving water	King Talal Dam (KTD)	King Talal Dam (KTD)
Rainfall (mm) 2012–2013	393.1	291.8

2.2 Sampling methods

Grab stormwater samples were taken from 6 separate storm outfalls at two site, 5 in the rural watershed and 6 in the urbanized watershed during storm events that occurred between October 2012 and April 2013. Storm events were selected for sampling based on the amount of rainfall (>3mm), and at least 1 dry week between storms.

Samples were collected from the first flush of each storm event in order to capture the maximum probable concentration of pollutants that have built-up since the last storm. These samples were distributed to represent rain vents occurred at the beginning, middle, and end of the wet season to account for possible ranges in concentration. The samples were collected and stored at 4 degrees Celsius until analysis. Different types of sampling containers were used such as 1 litre glass bottle for oil and grease, sterilized bottles for microbial examination and 5 litre polyethylene container for the rest of water analysis.

2.3 Analytical methods

Water samples were analysed for numerous water quality parameters, including: pH, Electrical Conductivity (EC),Total Suspended Solids (TSS),Total Dissolved Solids (TDS), Bio-chemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), Ammonia (NH_4), Nitrate (NO_3), Nitrite (NO_2), Total Kjeldhal Nitrogen (TKN), Total Nitrogen (T-N), Total Phosphorous (T-P), Fat, Oil and Grease (FOG), Total Coliform count (TCC), Total Fecal Coliform count (TFCC), Escherichia Coli (E.Coli) and total and dissolved heavy metals; Lead

(Pb), Zinc (Zn), Copper (Cu) and Manganese (Mn). These analyses were conducted at the Environmental Laboratories/Royal Scientific Society according to American Public Health Association (APHA) testing procedures for the analysis of water and wastewater [13].

3 Results and discussion

Catchment land uses and characteristics are playing a major role in the quality of generated stormwater runoff. Different types of pollutants are normally carried by runoff such as nutrients, heavy metals, organic and particulates [3, 14]. The impact of land use on stormwater runoff quality in the Amman-Zarqa basin was evaluated by comparing results from the different catchment areas. The following sections summarize the major pollutants which are commonly found in urban and rural storm water runoff.

3.1 Solids

Solids are one of the most common contaminants found in urban and rural storm water runoff. Solids originate from many sources in urban area including landscaping activities, the erosion of pervious surfaces and dust from road shoulders, litter and other particles deposited on impervious surfaces from human activities and the atmosphere, bank erosion and construction sites, road construction, lot clearing, and any other earth moving activity [15]. While the bare soils are the main source of solids generated at rural areas. Solids is a concern in stormwater runoff as contributor to many water quality, habitat and aesthetic problems in water bodies. It is well known that the solids is carrying many attached pollutants within particles including nutrients and metals.

Table 2 shows the average concentration and range of TSS in storm water from urban and rural sites. As shown in Table 2, the average concentration of TSS (6029 mg/L) in rural area is significantly three times higher than TSS (1694 mg/L) in urban runoff. This is mainly due to the high percentage of uncovered soil and unpaved roads in rural area compared with the urban area. This will expose loosened soil to be carried away by runoff and increase the potential for erosion. The findings of the current study are consistent with those of Waters [15] who found that the agricultural land areas is a major source of TSS and turbidity in receiving stream waters.

The colour values in urban site is much higher than the rural site this is might be due to high organic load (COD and BOD5) at urban site. The EC and turbidity values were slightly similar at urban and rural sites. The FOG concentrations of stormwater runoff generated from urban site (15 mg/L) is much higher than the rural site. This is might be due to the high traffic volume in urban site. Moreover, the FOG values are less than the detection limits (<8 mg/L) for all collected samples at rural site. The results also showed that the average concentrations of COD (1685 mg/L) and BOD5 (281 mg/L) at urban site are higher than the concentrations of COD (554 mg/L) and BOD5 (91 mg/L) at rural site. In spite of

Table 2: Chemical characteristics of stormwater runoff samples collected from urban and rural sites during October 2012 and May 2013.

Typical parameters	Urban area		Rural area	
	Average concentration, mg/L (range)	No. of samples	Average concentration, mg/L (range)	No. of samples
pH	7.58 (7.31–7.86)	6	7.82 (7.38–8.73)	5
Color	88 (25–150)	6	48 (30–80)	5
Turbidity	955 (15–3080)	6	988 (60–2300)	5
COD	1685 (156–3896)	6	554 (86–1975)	5
BOD5	281 (208–354)	2	91 (17–166)	2
EC	767 (324–1453)	6	683 (358–1094)	5
TSS	1694 (280–2932)	6	6029 (68–24150)	5
DOC	130.7 (55.4–206.0)	2	330.6 (28.1–633)	2
FOG	15.0 (<8.0–44.2)	6	<8 (<8.0)	5

high values of organic load at urban site, it is interested to note the DOC concentration at urban site (130.7 mg/L) is lower than the rural site (330.6 mg/L). In general, organic carbon compounds are a result of decomposition processes from dead organic matter such as plants which is frequently occurred at rural site more than urban.

3.2 Oxygen-demanding substances and dissolved oxygen

Some indicators are mainly used to describe the organic substances found in urban storm water such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC). As shown in Table 2, the level of pollutant concentrations generated from urban site such BOD5, COD and oil and grease were relatively higher than those measured at rural site.

It is important to mention here that for both sites, runoff concentrations for conventional parameters such as BOD5, COD, nutrients, TSS, and oil and grease were high compared with those measured for similar catchments in earlier studies. This is suggesting that high loads of these parameters will be carried out by stormwater runoff in Amman-Zarqa basin towards King Talal dam.

3.3 Nutrients

Nutrients can originate from both urban and rural land uses and will be transported by stormwater runoff to water bodies. Anthropogenic sources of nutrients from urban land uses include household fertilizers, animal waste, soil erosion, yard clippings, phosphate-containing cleaning agents and wastewater leaked from sewer systems, wet and dry deposition from the atmosphere, construction activities, and garbage [16, 17]. However, at rural area, nutrients sources include pasture, agriculture, forests, and animal waste [16].

Table 3 shows that the results of nutrients parameters T-N (31.2 mg/L) and T-P (34.3 mg/L) generally were much higher at rural catchment than the urban (T-N 16.58 mg/L and T-P 4.54 mg/L). This is maybe due to the high applications of fertilizers (Chemical fertilizers and manure) in agriculture land.

A watershed containing these elevated nutrient concentrations in the storm water runoff resulting in eutrophication of the water body [18]. Eutrophication is the most global prevalent water quality problem in lakes and reservoirs. It is a result of high-nutrient loads (mainly phosphorus and nitrogen), which substantially impairs beneficial uses of water. Total nitrogen concentrations exceeding 5 mg/L in water often indicate pollution from human and animal waste or fertilizer runoff from agricultural areas. Some studies have reported that eutrophication exists in the King Talal dam [19].

Anthropogenic sources of nitrates include animal waste and fertilizer. The results showed that the nitrate concentration in rural site was higher than the urban site (Table 3). This is consistent with the reported findings in the literature that the runoff from farms, lawns, animal feedlots, and dairies can contain high concentrations of nitrate [20].

Ammonia (NH4) originates from different sources such as dead plants and animals, animal excrement, fertilizers (chemical and manure) and wastewater from sewer network. Ammonia, similar to other nutrients, is considered as contributor in eutrophication phenomenon as well as high concentrations can be toxic to marine organisms [21]. The results in Table 3 showed that the ammonia concentration in the rural site was higher than the urban site.

Table 3: Nutrients characteristics of stormwater runoff samples collected from urban and rural sites during October 2012 and May 2013.

Typical parameters	Urban area		Rural area	
	Average Concentration, mg/L (Range)	No. of samples	Average Concentration, mg/L (Range)	No. of samples
T-P	4.54 (1.16–10.1)	6	34.3 (0.5–163.0)	5
T-N	16.58 (5.1–42.4)	6	31.2 (7.3–99.1)	5
NH4-N	3.70 (3.7)	6	5.3 (<3.7–10.1)	5
T.K.N	15.65 (4.5–41.1)	6	26.4 (<4.5–98.9)	5
NO3-N	0.43 (0.226–0.8)	6	4.27 (<0.226–11.3)	5
NO2-N	0.50 (0.001–2.5)	6	0.49 (0.007–0.958)	5

3.4 Heavy metals

The results of heavy metals in Table 4 showed that the average concentration of dissolved Zn, Cu, Pb and Mn (0.106 mg/L, 0.033 mg/L, 0.02 mg/L and 0.189 mg/L respectively) at urban site are much higher than those of rural site

(0.027 mg/L, <0.01 mg/L, <0.02 mg/L and 0.127 mg/L respectively). The total average values of total Zn, Cu and Pb (2.17 mg/L, 0.284 mg/L and 0.382 mg/L respectively) at urban site are much higher than those of rural site (1.071 mg/L, 0.165 mg/L and 0.268 mg/L respectively), while the total Mn (0.637 mg/L) at urban site was lower than at rural site (5.329 mg/L). It is not surprising that concentration of total Mn was higher at agriculture catchment. Although Mn is an additive to unleaded gasoline but the main source could be from an agriculture activities in rural area. Also, this is may be due to the high value of the average TSS (6029mg/l in Table 2) which reflects the original composition of natural soil (Mn-oxides).

In general, the results of heavy metals concentrations generally were higher at urban site than at the rural site (agriculture). This might be due to the high traffic activities and percent of street areas at urban catchment. Several street runoff studies in literature have shown that the concentration of metals is positively correlated with the number of vehicles travelling the street during the rainfall event [22]. It would be expected that the urban areas experience more traffic volume than the rural sites in the Amman-Zarqa basin. Zinc, copper and lead were identified as the most urgent concern as pollutants in stormwater runoff [1]. Sources of these metals in the highway environment are include tires, galvanized metal, motor oil, diesel fuel, brake pads, plated parts in vehicles, Portland cement concrete, various asphalt concrete formulations, shingle-asphalt, atmospheric deposition [23].

Table 4: Heavy metals characteristics of stormwater runoff samples collected from urban and rural sites during October 2012 and May 2013.

Typical parameters	Urban area		Rural area	
	Average concentration, mg/L (range)	No. of sample s	Average concentration, mg/L (range)	No. of sample s
Zn (Total)	2.170 (2.100–2.240)	2	1.071 (0.071–2.070)	2
Pb (Total)	0.284 (0.232–0.335)	2	0.165 (<0.010–0.320)	2
Cu (Total)	0.382 (0.309–0.455)	2	0.268 (0.035–0.500)	2
Mn (Total)	0.637 (0.616–0.658)	2	5.329 (0.057–10.600)	2
Zn (Dissolved)	0.106 (<0.016–0.236)	6	0.027 (<0.016–0.054)	5
Pb (Dissolved)	0.033 (<0.010–0.120)	6	<0.01 (<0.01)	5
Cu (Dissolved)	0.020 (<0.020–0.021)	6	<0.02 (<0.02)	5
Mn (Dissolved)	0.189 (0.026–0.314)	6	0.127 (<0.017–0.556)	5

3.5 Microbiological parameters

Urban areas have many land use activities generating fecal microbial contamination in runoff include domestic animals and urban wildlife and draining of stormwater runoff to sewer network systems [24]. However, there are a wide range of sources of fecal contamination in the runoff in rural areas include rural grazing areas where fecal bacteria results from manure deposition by the animals [24, 25] and from using of manure as fertilizer [26, 27].

The results indicated that runoff water pollution by fecal bacteria TCC, TTCC and E-coli (4.06E+07, 8.00E+05 and 1.31E+05 MPN/100ml, respectively) is higher in rural site than the urban site (Table 5).

Table 5: Fecal bacteria characteristics of stormwater runoff samples collected from urban and rural sites during October 2012 and May 2013.

Typical parameters	Urban area		Rural area	
	Average Concentration MPN/100ml, (Range)	No. of samples	Average Concentration, MPN/100ml (Range)	No. of samples
TCC	1.56E+06 (1.30E+05-5.00E+06)	6	4.06E+07 (1.40E+03-1.60E+08)	5
TTCC	9.21E+04 (2.40E+04-8.00E+05)	6	8.00E+05 (1.70E+02-2.40E+06)	5
E-Coli	1.75E+04 (1.30E+03-8.00E+04)	6	1.31E+05 (1.70E+02-5.00E+05)	5

Key constituents of runoff quality were compared to those reported in other countries. Average concentrations of COD, TSS, TKN, T-P, Zn and Pb (1685 mg/L and 1694 mg/L, 15.65 mg/L, 4.54 mg/L, 2.17 and 0.284 mg/L respectively) in the present study are much higher than the study results of Isfahan/Iran (561 mg/L, 161 mg/L, 6.65 mg/L, 0.274 mg/L 0.342 and 0.278 mg/L respectively) [28], and higher than the results of Guangzhou/China (308 mg/L, 416 mg/L, 7.32 mg/L, 0.39 mg/L, 1.76 and 0.118 mg/L respectively) [29].

It is important to mention here that the two monitored sites discharges their polluted runoff directly to a receiving water bodies in particular to King Talal dam without any control on their quality. Therefore, there is a crucial need to manage the quantity and quality of stormwater runoff generated in Amman-Zarqa basin by implementing pollution prevention measures such as regulating the discharge of stormwater runoff to water bodies.

4 Conclusions

The results showed that the levels of organic pollutants COD and BOD5 and dissolved heavy metals Zn, Cu, Pb and Mn from the urban site were higher than those for rural site. This is mainly due to the high traffic volume at urban site compared with the rural site. However, the nutrient concentrations (T-N and T-P) and fecal bacteria (TCC, TFCC and E.coli) at urban site were lower than the rural site. The average pollutant concentrations of stormwater runoff were significantly different from the urban and rural site. It is clear that watershed land use is responsible for providing both a source and mechanism for transport of chemical and bacteriological pollutants to water bodies. It is believed that the high nutrient concentrations (T-N and T-P) and fecal bacteria (TCC, TFCC and E.coli) of stormwater runoff reflects the uses of chemical and nature fertilizers at rural site. In general, key constituents of runoff quality from both urban and rural sites are considered very high compared to those reported in other countries. This study has provided a better understanding of the concentrations and sources of stormwater runoff pollutants generated from urban and rural site which is posing a serious threat to water bodies within the Amman-Zarqa basin. Therefore, best management practices and proper land management measures should be taken to minimize the impacts of stormwater runoff.

Acknowledgement

The Jordan Scientific Research Fund (SRSF)/Ministry of Higher Education and Scientific Research provided full support for this research.

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