POLLUTION SOURCES TO ZARQA RIVER: THEIR IMPACT ON THE RIVER WATER QUALITY AS A SOURCE OF IRRIGATION WATER

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Keywords: Industrial pollution, irrigation water, pollution sources, wastewater reuse, Zarqa River

Abstract
Over the last forty years, Zarqa River water quality has deteriorated seriously as it receives pollutants from several sources along its course. In addition, its flow has diminished, which reflected negatively on its quality. In this study, pollutants released to the river were identified, quantified and linked to their sources, based on field observations, existing quality data by monitoring agencies, and literature. It was found that the main sources of pollution to the river are wastewater treatment plants in the basin, overflow of wastewater pumping stations located close to the river course, sewer lines, and manholes that pass through the river bed, in addition to industrial, commercial, domestic and agricultural activities along the river course. Main pollutants released to the river from these sources are organics, nutrients, heavy metals, and solid waste. The results showed that the river water is suitable for restricted irrigation downstream of As Samra WWTP and upstream of KTD, although the concentration of some heavy metals have occasionally exceeded the maximum limits allowed by Jordanian standards for reuse in irrigation.

1 Introduction
Because of their environmental significance and contribution to the national water budget, rivers should be protected from pollution as river pollution interferes with all its beneficial uses, affects its ecological balance and the health of the users, and may lead to severe economic loss. Main pollutants that can find their way to rivers are nutrients, i.e., nitrogen and phosphorous, herbicides, pesticides, organics, solids, oil and grease, and heavy metals. High levels of nutrients, which reach rivers from agricultural runoff and inefficiently treated domestic wastewater, can lead to river eutrophication [1-7], and in turn, result in diurnal fluctuation in oxygen and pH levels, severe reduction of light penetration, and high levels of ammonia, which negatively affect aquatic life and may result in fish mortalities [5, 8, 9]. Disposal of inefficiently treated wastewater to rivers can also result in severe consequences on dissolved oxygen levels within the river environment and consequently affect aquatic life and river ecological balance [5, 10-14]. High levels of heavy metals, which can reach rivers from urban runoff, wet deposition [15-18] and the disposal of
improperly treated industrial wastewater render the river environment toxic to many aquatic species, and ultimately disturb its ecological balance. Due to rapid urbanization, economic growth and social development, incidents of river water quality deterioration by anthropogenic activities have been reported all around the world; examples are [10, 19-23]. Restoration of a river environment after a pollution event can be expensive and time consuming, and requires thorough understanding of the underlying physical, chemical, hydrological, hydro-geological, biological and ecological processes [24-28]. Extensive efforts and resources have been invested in many parts of the world in the past two decades to restore the environment of certain polluted rivers [8, 29, 30].

In Jordan, environmental status of Zarqa River has degraded over the last four decades. Flow of Zarqa River used to be perennial, where fish grow, people swim and spend their leisure time. However, due to the gradual abstraction increase from the underlying groundwater basin over the past three decades to satisfy the increasing domestic and agricultural demands, the springs’ flow that feed the river ceased, which ultimately caused the river to flow during winter storms only. In addition, the disposal of inefficiently treated wastewater from As Samra WWTP to the river, which was commenced in 1985, led to serious deterioration of the river environment. Furthermore, many industries exist along the river, which find the river an easy way to dispose of their untreated industrial wastewater, and in some instances solid waste, which accelerated the degradation of the river environment. Due to its importance to Jordan, Zarqa River basin (ZRB) has been thoroughly studied over the last two decades by many researchers. The studies focused on river flow, river water quality, river basin management, climate change impacts on river flow, and quality and pollution sources to the river [31-41]. Despite extensive efforts made to study the Zarqa River Basin (ZRB), no study to date identified and quantified pollutants to the river from the different sources. The objective of this paper is to identify and quantify pollutants that reach the river from different sources and to draw conclusions about the river water suitability for irrigation.

2 Study Area
ZRB is located in northern Jordan and has a total area of 4,586 km$^2$. About 4,074 km$^2$ of the basin area is within Jordan and 512 km$^2$ is within Syria [42]. The basin covers the area from Salkhad in Jebal Al-Arab in Syria at an elevation of 1,460 m to south Amman and then westward to the Jordan Valley at an elevation of about -350 m. Zarqa River starts at Wadi Abdoun in Amman, where the main river feeder, Ras El- Ein spring, is located. It then passes through Russeifa and Zarqa, where it joins Wadi Dhulail and then continues to King Talal Dam (KTD) in the Jordan Valley. The average annual rainfall in the western part of the basin is about 400 mm, whereas it rarely exceeds 150 mm in the eastern part of the basin [38]. The basin includes the following cities: Jordan’s capital Amman, Zarqa, Jarash, part of Mafraq, and part of Balqa. ZRB is the most heavily populated and industrialized basin in Jordan. It houses about 60% of Jordan population [33]. In addition, about 85% of the industries in Jordan are within ZRB [37]. The basin is shown in Figure 1.
3 Materials and Methods

3.1 River survey
A field survey was conducted to identify sources of pollution to the river and to observe river flow. For this purpose, the river was divided into six sections. The sections were identified based on land use/cover and anthropogenic activities prevailing in each section. Sources of pollution and pollutants released by these sources in each section were identified.

3.2 Zarqa River water quality - data collection
Existing water quality data of the river were collected from two sources, which are the Water Authority of Jordan (WAJ), and the Environment Monitoring and Research Central Unit (EMARCU) of the Royal Scientific Society (RSS). WAJ samples Zarqa River regularly. Parameters monitored and frequency of sampling is given in Table 1. Data between 2003 and 2010 were obtained from WAJ. EMARCU operates thirteen telemetric monitoring stations to monitor surface water quality in Jordan, three of which (stations 8, 9 and 10) are located along Zarqa River. Parameters monitored and frequency of sampling is given in Table 1. Data between January 2005 and December 2013 were obtained from EMARCU. The location of WAJ and EMARCU sampling stations are shown in Figure 1.

Figure 1: Zarqa River Basin
3.3 River sampling and analytical procedures
For the purpose of identifying the concentration of certain heavy metals in the vicinity of EMARCU monitoring stations, nine sampling events took place near the stations 8, 9 and 10 between December 2011 and February 2013. Other five sampling events took place between October 2013 and February 2014 in the vicinity of the following industries: pipeline factory, steel factory, textile factory, yeast factory, soft drink factory, food factory, and oil industry for the purpose of verifying pollutants released by these industries. Samples were analyzed for certain heavy metals according to the nature of the industry. The heavy metal analyses were conducted using a Graphic Furnace Atomic Absorption Spectrometer GF-AAS (Thermo Scientific, Elemental SoLAAR M5, UK).

4 Results and Discussion
4.1 River flow
It was observed that Zarqa River flow has diminished. Upstream of the confluence of the river with As Samra WWTP, river flow is intermittent, i.e., the river is almost dry except during winter storms. Downstream of the confluence of As Samra with the river, river flow consists mainly of As Samra effluent during the dry season and of As Samra effluent and flood water during the wet season. Reasons advanced for the diminishing river flow is the gradual abstraction increase from the underlying groundwater in order to satisfy the increasing domestic and agricultural demands in the basin [36, 37].

4.2 Pollution sources Zarqa River
Pollution sources to the river were identified and classified, as given in Table 1.

Table 1: Parameters monitored and frequency of sampling of WAJ and EMARCU

<table>
<thead>
<tr>
<th>WAJ monitoring program</th>
<th>Parameters</th>
<th>Frequency of sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH, TDS, TSS, COD, BOD$_5$, TN, NO$_3$, NH$_4$, PO$_4$, E. coli.</td>
<td>Monthly from all sampling stations</td>
<td></td>
</tr>
<tr>
<td>MBAS, nematode eggs, turbidity, FOG, B, SO$_4$, Na, Mg, CN, Ni, Ca, HCO$_3$, As, Be, Cu, Fe, Mn, Ni, Pb, Se, Cd, Zn, Cr, Cl$^-$, Al, V, Co, Mo, Li, F</td>
<td>Once every three months from selected locations provided that all locations are sampled twice yearly.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EMARCU monitoring program</th>
<th>Parameters</th>
<th>Frequency of sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stations 8 and 10: COD, temperature, turbidity, TN, TP, EC, pH</td>
<td>TP and TN are sampled every six hours</td>
<td></td>
</tr>
<tr>
<td>Station 9: COD, temperature, turbidity, EC, pH</td>
<td>All other parameters are sampled hourly</td>
<td></td>
</tr>
</tbody>
</table>
4.2.1 Wastewater treatment plants and wastewater pumping stations

Four wastewater treatment plants (WWTP) in ZRB that dispose of their treated effluent to the river were identified. These WWTPs are As Samra, Jarash, Abu Nsair and Al-Baqa’a. Among these four WWTPs, As Samra is the largest, as it treats about 90% of the wastewater generated in Amman and Zarqa, the two largest cities in Jordan. The effluents of the other three WWTPs, which are located downstream of As Samra, are negligible compared with As Samra. In addition to these WWTPs, two wastewater pumping stations within the river basin were identified, which are Einghazal pumping station and West Zarqa pumping station. The effluent of the WWTPs and the overflow of the two wastewater pumping stations are sources of high organic pollution to the river, in addition to different types of solids, nutrients, i.e., different nitrogen and phosphorus compounds, cations and anions, a variety of pathogens, and heavy metals, which come from some industries that are connected to or illegally dispose of their wastewater to the wastewater collection system. Figure 2 shows the WWTPs and the wastewater pumping stations in ZRB. This figure shows that the two wastewater pumping stations are located on the river course upstream of the river confluence with the As Samra WWTP effluent.

4.2.2 Landfills

Two landfills in the river basin were identified, which are Al Russeifa and Al Ghabawi landfills. The two landfills are located upstream of the river confluence with As Samra WWTP (Figure 2). Al Russeifa is very close to the river course posing high risk to the underlying groundwater [43, 44].
4.2.3 Power plants
Two power plants in the river basin were identified, which are Al-Hussein and As Samra power plants, as shown in Figure 2. The figure shows that the two power plants are located upstream of the river confluence with As Samra WWTP effluent. The figure also shows that the two power plants are close to each other as well as to the river course. The power plants are sources of gases rich in nitrogen and sulfur produced by fuel burning for electricity production, which can find their way to the river by atmospheric deposition.

4.2.4 Gas stations
Plenty of gas stations exist in the basin, many of which are close to the river course (Figure 3). Leak from these gas stations poses pollution risk to the river as well as to the underlying in ZRB groundwater. The most of these gas stations are located along Wadi Dhulail upstream of the confluence of the river with As Samra WWTP effluent.

4.2.5 Industrial estates
Large number of diverse industries exists along the river course. These industries were identified and classified into the following categories: tanning, fabrics, pharmaceutical, phosphate mines and factory, paper and cartoon, wood based industries, marble industries, food industries, cosmetics, petrochemicals, paints, battery, detergents, aluminum industries, petroleum refinery, Amman slaughterhouse, and Pepsi factory and pond. These industries are sources of a wide range of pollutants. Table 2 gives the number of industries within each category as well as typical pollutants.
released by each industry based on literature. These industries are sources of heavy metals, organics, nutrients, different types of solids, cations and anions, fat, oil and grease, and solid waste. Figure 4 shows the spatial distribution of these industries within the river basin. This figure shows that most of the industries are located upstream of the river confluence with As Samra WWTP very close to the river course.

4.2.6 Sewer lines
Main sewer lines and manholes were observed along the river bed at Al Russeifa upstream of the confluence of As Samra effluent with Zarqa River. Leaks and overflow from these manholes and sewers are sources of raw wastewater rich in organics and nutrients.

4.2.7 Organics and solids
Main sources of organic pollution to the river are effluents of the WWTPs, food industries, Amman slaughter house, flood of the two wastewater pumping stations, flood from the sewer line that passes through the river bed in the upstream, and agricultural runoff from surrounding farms during the rainy season. Table 3 gives the organics and solids pollution to Zarqa River as observed by the project sampling program and by WAJ monitoring program. It is worth mentioning that the extremely high concentrations observed are local, immediately downstream of certain industries. Figure 5 shows the COD concentration at EMARCU monitoring station 10 between 2005 and 2013.
Careful investigation of this figure reveals that COD concentration in Zarqa River has dropped between 2005 and 2012, which is mainly due to the upgrade of As Samra WWTP in 2007 from a natural system to a mechanical one. This figure also shows a significant variation of COD concentration over time with peaks that exceed 100 mg/L after 2007 and 150 mg/L before 2007. A close look at the figure shows that these peaks occur during the rainy season, which means that they are associated with agricultural runoff from surrounding farms and/or with runoff from other sources upstream, i.e., flood of wastewater pumping stations, Amman slaughterhouse, and sewer lines in the river bed.

Table 2: Industries along Zarqa River and their pollutants

<table>
<thead>
<tr>
<th>Type of Industries</th>
<th>Number of industries</th>
<th>Typical Pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanning industries</td>
<td>2</td>
<td>TDS, TSS, BOD, COD, NH₄⁺, SO₄²⁻, S²⁻, P, Al, Cr, oil and grease [45, 46]</td>
</tr>
<tr>
<td>Fabric industries</td>
<td>15</td>
<td>TSS, BOD, COD, NH₄⁺, SO₄²⁻, S²⁻, oil and grease, Cd, Cr, Pb, Zn, CN [47, 48]</td>
</tr>
<tr>
<td>Pharmaceutical industries</td>
<td>2</td>
<td>COD, BOD [48]</td>
</tr>
<tr>
<td>Phosphate mines and factory</td>
<td>2</td>
<td>P</td>
</tr>
<tr>
<td>Paper and cartoon industries</td>
<td>18</td>
<td>TDS, TSS, BOD, COD, Ca, Na, Cr, Cl, color [46, 49]</td>
</tr>
<tr>
<td>Wood based industries</td>
<td>9</td>
<td>TDS, COD, Polyphenols [50]</td>
</tr>
<tr>
<td>Marble industries</td>
<td>47</td>
<td>TDS, BOD, COD, HCO₃⁻, Ca²⁺, Mg²⁺, K⁺, Cl⁻, NO₃⁻, SO₄²⁻, Na⁺, Al³⁺, Fe, Mn, Zn, Cu, Pb, Cr, Cd, Ni, solid waste [51]</td>
</tr>
<tr>
<td>Food industries</td>
<td>34</td>
<td>TDS, TSS, COD, BOD, oil and grease, P, H₂S, NH₄⁺, SO₄²⁻, Fe, Cl⁻, fat and oil [46, 47]</td>
</tr>
<tr>
<td>Cosmetics</td>
<td>3</td>
<td>TDS, TSS, BOD, COD, fat and oil [52]</td>
</tr>
<tr>
<td>Paints</td>
<td>4</td>
<td>TSS, COD, BOD, P, TKN, Cl⁻, SO₄²⁻ [53]</td>
</tr>
<tr>
<td>Aluminum industries</td>
<td>4</td>
<td>TDS, TSS, BOD, COD, Fe, Zn, Cr, Cu, Cd, Pb, Ni, Mn [54]</td>
</tr>
<tr>
<td>Petroleum refinery</td>
<td>1</td>
<td>BOD, COD, TSS, Al, As, Cd, Cr, Cu, Pb, Ni, Zn [46]</td>
</tr>
<tr>
<td>Amman slaughterhouse</td>
<td>1</td>
<td>BOD, COD, VSS, N, TSS [46, 55]</td>
</tr>
<tr>
<td>Pepsi factory and pond</td>
<td>1</td>
<td>BOD, COD, TSS, COD, Cd, Cu, Fe, Mn, Ni, Pb, Zn [54]</td>
</tr>
<tr>
<td>Battery factory</td>
<td>1</td>
<td>Pb, Cd, Cu, TSS, TDS, Hg, Ni, Fe, Al, Zn [47, 56]</td>
</tr>
<tr>
<td>Detergents</td>
<td>3</td>
<td>COD, BOD, oil and grease, B [57, 58]</td>
</tr>
<tr>
<td>Petrochemical industries</td>
<td>49</td>
<td>COD, phenols, hydrocarbons, grease, sulfide [59, 60]</td>
</tr>
</tbody>
</table>

4.2.8 Raw sewage

Raw sewage finds its way to the river from two main sources which are overflow of sewer lines and manholes that pass through the river bed in the upstream, and overflow of the two wastewater pumping stations, which are Ain Ghazal and West Zarqa pumping stations. Amman slaughter house is also a source of high liquid organic waste to the river. It is important to note that the raw sewage and the raw liquid waste from Amman slaughter house are transported
downstream with the flood water during the wet season. However, during the dry season, this waste result in the formation of ugly swamps that produce offensive odors and mosquitoes in addition to being aesthetically unpleasant due to the high temperature and long residence time.

Table 3: Organic and solids pollution from industries along the river

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration range&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Concentration range&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDS (mg/L)</td>
<td>601 – 59,955&lt;sup&gt;3&lt;/sup&gt;</td>
<td>262 - 1,844</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>8.5 - 377</td>
<td>1 - 1,676</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>0 – 8,375</td>
<td>4 - 979</td>
</tr>
<tr>
<td>BOD₅ (mg/L)</td>
<td>0 - 800</td>
<td>3 – 1,159</td>
</tr>
</tbody>
</table>

<sup>1</sup>These results are based on the project sampling program; <sup>2</sup>WAJ regular sampling program 2003-2010; <sup>3</sup>The high TDS concentration was detected downstream of fodder industry

4.2.9 Nutrients

Main sources of nutrients to the river are the effluents of the WWTPs, flood from the two wastewater pumping stations and sewer lines, and agricultural runoff from surrounding farms at the river bank. Figure 6 shows TN and TP concentrations at EMARCU monitoring station number 10. It also shows a reduction of TN and TP concentrations in Zarqa River over time. The main reason advanced for this reduction is the upgrade of As Samra WWTP from a natural treatment system to a mechanical treatment one, and the inclusion of a nutrient removal unit. Similar to the COD trends, TN and TP concentrations show occasional peaks during the wet season, which are caused by agricultural runoff and runoff from the upstream that washes flooded wastewater from the two wastewater pumping stations and the sewer lines that pass through the river bed. The high TP and
TN concentrations show that Zarqa River is autotrophic, which has further consequences on the river environment such as wide diurnal variations of pH and dissolved oxygen levels, poor light penetration, and disturbance of river ecological balance [2, 61].

4.2.10 Heavy metals
Table 4 summarizes sources of heavy metal pollution of Zarqa River based on typical characteristics of the wastewater from the industries that exist along the river (Table 2). It shows that certain groups of industries are the main source of heavy metals, which are marble industry, aluminum industry, tanning industry, fabrics industry, petroleum refinery, Pepsi industry, pulp industry, detergent industry, and battery factory. Analysis of the data and samples collected from different sections of the river reveal that Fe, Cr, Zn, Cu, Ni, Mn, Cd, B and Pb were detected in the river. Based on the most comprehensive sampling program by WAJ, it was found that the concentrations of Cr, Ni, Mn, Cd, B and Pb have exceeded the Jordanian standards no. 202/2007 for reuse of industrial wastewater in irrigation at different frequencies. However, it is important to note that downstream of KTD, where the mixture of Zarqa River water and King Abdulla Canal water is used for unrestricted irrigation, the concentration of these heavy metals is projected to drop several orders of magnitude due to mixing the river water with fresh water from King Abdulla Canal. Upstream of KTD, the river water is used for restricted irrigation only.

4.2.11 Solid waste
It was observed that upstream of As Samra confluence with Zarqa River, solid waste and debris is scattered in many section of the river. The sources of this solid waste are industries, commercial facilities, domestic sources and nomadic people, who live by the river at the very upstream. In addition, many masonry workshops and car maintenance workshops exist along the river course at some sections, which are other sources of solid waste to the river.
Table 4: Sources of heavy metal pollution of Zarqa River

<table>
<thead>
<tr>
<th>Heavy metals</th>
<th>Source industries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>Marble, Aluminum, Pepsi, Battery factory</td>
</tr>
<tr>
<td>Cr</td>
<td>Tanning, Fabrics, Marble, Aluminum, Paper, Petroleum refinery and Pepsi</td>
</tr>
<tr>
<td>Zn</td>
<td>Marble, Fabric, Aluminum, Paper, Petroleum refinery, Pepsi, Battery factory</td>
</tr>
<tr>
<td>Cu</td>
<td>Marble, Aluminum, Paper, Petroleum refinery, Pepsi, Battery factory</td>
</tr>
<tr>
<td>Ni</td>
<td>Marble, Aluminum, Paper, Petroleum refinery, Pepsi, Battery factory</td>
</tr>
<tr>
<td>Pb</td>
<td>Marble, Aluminum, Paper, Petroleum refinery, Pepsi, Battery factory</td>
</tr>
<tr>
<td>Mn</td>
<td>Marble, Aluminum, Pepsi</td>
</tr>
<tr>
<td>Cd</td>
<td>Marble, Fabric, Aluminum, Petroleum refinery, Pepsi, Battery factory</td>
</tr>
<tr>
<td>(Se)</td>
<td>Marble</td>
</tr>
<tr>
<td>(Al)</td>
<td>Marble, Tanning, Aluminum, Petroleum refinery, Battery factory,</td>
</tr>
<tr>
<td>Hg</td>
<td>Paper, Battery factory</td>
</tr>
<tr>
<td>(As)</td>
<td>Petroleum refinery</td>
</tr>
<tr>
<td>(B)</td>
<td>Detergents</td>
</tr>
<tr>
<td>(CN-)</td>
<td>Fabric</td>
</tr>
</tbody>
</table>

5 Conclusions
The results showed that the river suffers from environmental degradation. Due to over abstraction of the underlying groundwater, river flow has diminished. The river receives high organic pollution from WWTPs that discharge their inefficiently treated effluent into it. Other sources of organic pollution of the river are overflow of wastewater pumping stations, leaks from sewer lines that pass through the river bed, overflow from Amman slaughterhouse, and agricultural runoff. In terms of nutrients, the river is autotrophic due to high concentration of nitrogen and phosphorus discharged into the river from inefficiently treated domestic wastewater and agricultural runoff. The river also suffers from heavy metals pollution, which mainly comes from industries that exist along the river course. Specific heavy metals were linked to their upstream industrial sources. Solid waste disposal to the river is another problem that further aggravates its environmental degradation. The river water downstream of As Samra and upstream of KTD is found suitable for restricted irrigation. Downstream of KTD, the water quality is expected to improve due to mixing with fresh water from King Abdulla Canal.

6 Acknowledgements
The authors would like to express their gratitude to the Scientific Research Support Fund in Jordan for funding this research (grant number 2010\07\01\v) and to the DAAD and Exceed Swindon project, which made the participation at this workshop possible.
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