Effect of wastewater on the spring water quality of Sarida Catchment – West Bank

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ABSTRACT
This research assessed the effect of untreated wastewater discharged to Sarida Wadi within the Sarida Catchment in the Central West Bank. Spring water from seven springs within the catchment were tested for physical, hydrochemical, and microbiological characteristics in wet and dry seasons. Hydrochemical results of wastewater samples showed that Total Suspended Solids (TSS) and Biological Oxygen Demand (BOD5) exceeded the standards in 93 percent of the samples, and an increase of COD value was recorded in the catchment downstream in the dry season. The springs’ hydrochemical data showed that Ca²⁺ plays a dominant role, and samples from the dry season exceeded the limits for HCO₃⁻. One spring showed high nitrate values, exceeding the 45 mg/L limit. The springs’ microbial results provided overwhelming proof of wastewater contamination and an increasing trend over time of Fecal Coliforms (FC). The analyzed trace elements did not exceed World Health Organization (WHO) guidelines for drinking water with the exception of one spring with an abnormal value for Boron.

1. Introduction
Surface and ground water resources in the West Bank are vulnerable to degradation due to a variety of anthropogenic activities (agriculture, urbanization, and industries). Their quality depends on a multitude of factors and interactions of the geology, weathering products, water-rock interactions, topography and climatic conditions. With only one-third of wastewater generated in the West Bank collected by a sewage network, and less than half of that (roughly 8 million cubic meters per year) (Palestinian Water Authority [PWA], 2018) reaching a well-functioning wastewater treatment facility, poorly managed wastewater is a particular threat to environmental and public health. While the detrimental effects of surface water pollution are more obvious, polluted surface water also contributes to groundwater degradation. Polluted water carrying contaminants from domestic sewage and (poorly or unregulated) industrial discharge infiltrates downward through rocky layers reaching the groundwater. However, wastewater could contaminate drinking water in different patterns which could be originated from cesspits, partially treated wastewater, sludge, and leakages in sewer lines by infiltrating into the ground and polluting groundwater (Gothwal & Shashidhar, 2015). Groundwater is extracted via wells or reemerge as surface water via natural springs which serve as a primary water resource for rural villages to meet their domestic and agricultural water demands. An important study conducted by Mester et al. (2017) emphasized the adverse effects of the surface flowing wastewater on groundwater quality. Permeable constructed sewage tanks (cesspits), which are common in the two-thirds of West Bank households not connected to a sewage network, leak organic and inorganic nitrogen compounds which further degrade the groundwater quality (Mester et al., 2019). Nitrate contamination has been commonly related to the use of fertilizers in the agricultural areas; however, non-agricultural activities can contribute more nitrates to aquifers, especially those underlying urban areas (Wakida & Lerner, 2005). An estimation of ninety percent of developing countries’ discharged wastewater into open areas and water bodies like streams, lakes and ponds without being treated, leads to environmental pollution including groundwater contamination (Ahmed et al., 2017). In addition to anthropogenic activities, complex interactions with natural processes and local environmental conditions such as geology, hydrogeology, weathering, water–rock interactions, topography, tidal effects, and climate also affect groundwater quality (Mohapatra et al., 2011). Moreover, movement of heavy metals in the...
direction of the hydraulic gradient also contributes to groundwater contamination (Battaleb-Looie et al., 2020).

This relationship between contaminated surface water and degraded groundwater is well-documented in other contexts where wastewater is poorly managed. In West Bengal and Bangladesh, unmitigated discharge of untreated wastewater has resulted in concentrations of $\text{NO}_3^-$ and $\text{SO}_4^{2-}$ (both pollutants indicative of wastewater contamination) that are higher than World Health Organization (WHO) standards (McArthur et al., 2012). In Russia, a study to assess groundwater contamination from a sewage sludge landfill showed largely differential values; the layers of soil were characterized by low filtration properties, and as such, high concentrations of nitrogen-containing pollutants were observed in the groundwater (Dregulo & Bobylev, 2021). In Jordan, an assessment for the groundwater quality of the northern Jordanian aquifer which was affected by the local wastewater treatment plant showed that 71 percent of the samples had nitrate concentrations exceeding the threshold value for anthropogenic sources (20 mg/L), and more than 50 percent in excess of WHO standards for drinking water (50 mg/L) (Obeidat et al., 2013). In Saudi Arabia, groundwater quality assessment for irrigation potential was undertaken for Al Misk Lake aquifer, the results showed highly contaminated samples with major ions due to the sewage waste disposal and the resulting leachate in the area (Rehman & Cheema, 2016).

Given the known relationship between surface water pollution and ground water quality, we assume there to be negative effects on spring water in the area surrounding Sarida Wadi as a result of un- and under-treated wastewater discharges to the wadi from Salfit, Ara’el, and other communities in the catchment. The main objective of this research is to illustrate and quantify the effects of poor surface water quality in Sarida Wadi on groundwater quality, as represented by spring water, in the surrounding area, and assess the spring water’s suitability for domestic and agricultural purposes.

2. Methods
2.1. Study area
The focus of this study is Saradah catchment, which includes the Palestinian communities of Salfit (pop. # 11,602), Kafr Al-Dik (pop. # 5,903), and Brouqin (pop. # 4,303), and the Israeli colony of Ara’el (pop. # 20,456), (PCBS., 2019) is located in the middle of the northern West Bank, about 20 km to the south-west of the city of Nablus, between 32 degrees latitude and 35 degrees longitude (LRC, 2008), and at an altitude of 250-570 meters above sea level. Sarida is one of the largest catchments in West Bank, with hot dry summers and mild wet winters. The wind is northwesterly and southwesterly with 237 (km/day) speed average, and the atmospheric pressure is high (ARIJ, 2011). While the mean annual actual evapotranspiration was about 66–70 percent of precipitation (Jebreen et al., 2018). The study area lies within the western aquifer basin, and is composed of Cenomanian-Turonian limestone which is karstic due to the dissolution process of the limestone system (Issar, 2000). The eponymously named seasonal stream flowing through Sarida catchment, Sarida Wadi, is approximately 12 km long and is considered as a strategic replenishment resource for the Palestinian Western Basin (Figure 1). Sarida Wadi is directly affected by discharged wastewater from Salfit and Ara’el, which is discharged to the environment with little to no treatment.

3. Sampling campaigns and analyzing methodology
Sampling campaigns were conducted in the wet season in May of 2013, and the dry season in

Figure 1. Location of Sarida Catchment, Sarida Wadi, and sampling locations.
November of 2013. In each campaign, water samples were collected from each of the seven major springs in Sarida catchment: Al-Fawwar, Al-Mizrab, Al-Msila, Al-Yanbou’, Al-Matwi, Al-Shalal and Al-Adas. Sampling points along Sarida Wadi included five point of interest (in order from upstream to downstream): Salfit wastewater (WW) discharge (Salfit WW), Ara’el wastewater discharge (Ara’el WW), approximately 2 km downstream of the confluence of the two wastewater flows from Salfit and Ara’el (WW After Mixing), Brouqin wastewater discharge (Brouqin WW), and the ending point within the study area (WW Path End) (Figure 1).

All samples were analyzed at the laboratory of Birzeit University in Ramallah. The five samples from Sarida Wadi were collected by hand in 1-Liter high density polyethylene bottles, and analyzed for pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD₅) parameters. The BOD₅ was analyzed by 5-Day BOD₅ Technique, COD was analyzed by wet chemistry method, and TSS by Whatman 934-AH glass microfiber filter (Rice & Baird, 2017). Spring water samples were collected by 1-Liter sterilized glass bottles. All samples were acidified for trace elements analysis, with 69 percent nitric acid (14.4 M); a Perkin–Elmer ICP Optima 3000 was used to detect iron, copper, zinc, chromium, lead, cadmium, cobalt and magnesium. A Sharewood 4010 flame photometer was used to determine calcium, sodium and potassium. A HP 8453 Diode Array Spectrophotometer was used to determine nitrate and sulfate concentrations. A Hanna pH multi-meter was used onsite for the determination of pH, TDS, EC and temperature. A Metrohm 716 titrator used to determine chloride and bicarbonate concentrations. Spring water samples were collected by 1-Liter sterilized glass bottles and analyzed for pH, TDS, EC by titration methods, while major cations (Na⁺, K⁺, Ca²⁺ and Mg²⁺) were analyzed by inductively coupled plasma mass spectrometry (ICP-MS), major anions (NO₃⁻, SO₄²⁻ and Cl⁻) except HCO₃⁻ were analyzed by Cooling Ion Analyzer (CIA) using AOAC titration method (Robert 2001). Seventeen trace elements (Beryllium (Be), Boron (B), Vanadium (V), Iron (Fe), Cobalt (Co), Arsenic (As), Selenium (Se), Barium (Ba), Thallium (Tl), Lead (Pb), Aluminum (Al), Chromium (Cr), Manganese (Mn), Nickel (Ni), Copper (Cu), Zinc (Zn) and Cadmium (Cd)) were analyzed at Al-Quds University Laboratories by (ICP-MS). For TC and FC tests were collected in sterile 100 ml, glass bottles, then cooling in an ice box and transferred to the laboratory on the same day for biological tests. The TC and FC analyses were conducted at the laboratory of Birzeit University in Ramallah. The hydrochemical results were analyzed by Aquachem software package and Excel analyzing package.

4. Results and discussion

Hydrochemical analysis of the spring water samples indicated their general qualitative properties and their suitability for domestic and agricultural uses. Variations in quality between springs were explained based on the human and agricultural activities surrounding the springs, and analysis of samples collected along Sarida Wadi provides indicators for spring water pollution.

4.1. Wastewater sources

The average values of the two samples collected (wet and dry season) from the Salfit and Ara’el wastewater discharge locations are presented in Tables 1 and 2, and indicate the quality difference between the two wastewater sources. Slightly higher values for Salfit wastewater in terms of pH average of (7.3, 7), Total Dissolved Solids average (TDS) (778, 817 mg/L) and Electrical Conductivity average (EC) (1633, 1556 m/s/cm) are shown than Ara’el’s wastewater as well as TSS, COD and Phosphate radical parameters for the wet and dry seasons, respectively. Values were lower for Ara’el’s wastewater discharge compared to Salfit due to Ara’el’s wastewater being subject to primary treatment before discharging it into the wadi (PWA, 2012). BOD₅ value is

| Parameter | pH | TDS mg/L | EC (µS/cm) | TSS (mg/L) | BOD (mg/L) | COD (mg/L) | PO₄ (mg/L) |
|-----------|----|----------|------------|------------|------------|------------|------------|
| Salfit    | 7.6| 705      | 1408       | 668        | 57         | 142        | 7.4        |
| Ara’el    | 6.6| 955      | 1911       | 403        | 377        | 507        | 3.1        |

| Parameter | pH | TDS mg/L | EC (µS/cm) | TSS (mg/L) | BOD (mg/L) | COD (mg/L) | PO₄ (mg/L) |
|-----------|----|----------|------------|------------|------------|------------|------------|
| Salfit    | 7.1| 929      | 1858       | 479        | 255        | 622        | 8.4        |
| Ara’el    | 7.5| 601      | 1201       | 155        | 87         | 312        | 3.9        |
higher in Ara’el colony (232 mg/L) than Salfit wastewater (156 mg/L), which is due to the exposed channel, where other natural sources of organics such as dead plants, animal wastes, and soil organic content may be incorporated into it. Moreover, the parameter of phosphate radical showed differentiated values between Salfit with 7.9 mg/L as double amounts compared to Ara’el’s with 3.5 mg/L.

The BOD<sub>5</sub> of samples collected along Sarida Wadi ranges between 77 and 377 mg/L and reaches 19 mg/L at the end point, where the flow in the wadi mixes with water from Al Matwi spring. The BOD<sub>5</sub> values measured from the dry season sampling increase with each sampling station due to the effect of the wastewater contribution of Bruqin and Kafr Al-Dik communities (Figure 2). The abnormally high value of BOD<sub>5</sub> in Ara’el WW wet season sampling is attributed to the runoff and transport of organic materials, including livestock animal wastes and dead plants, towards the wadi resulting in algal growth.

Similar to the BOD<sub>5</sub> trend, the lower COD concentration in Ara’el’s wastewater discharge is a result of steady year-round fresh water consumption in Ara’el, including November, compared to Salfit where freshwater availability is limited in the dry season. This leads to Ara’el’s wastewater being dilute compared to Salfit’s wastewater which affects the COD concentrations in the wadi (Figure 3).

An increase in pH has was also observed from the ‘End Point’ sampling site, which can be attributed to the presence of stone quarries along the wadi’s track. The same trend was identified in both the wet and dry season sampling campaigns. There were high values of EC in the ‘Ara’el WW’ samples in both seasons caused by the wet season runoff, in which clays and soluble salts are directly transported towards the wadi from the surrounding area. These sediments with high ion exchange rates and salt content raise the EC levels of Ara’el’s wastewater discharge in the wet season (May) compared to the low EC level of the dry season (November).

5. Quality of spring water

According to the classification of Todd (1980), all samples were classified per TDS as fresh water and ranged between 207 and 339 mg/L. The analysis of major cations revealed the dominance of Ca<sup>2+</sup> component as groundwater is developed in dolomite and limestone formations. It ranged between (53-90 mg/L) with the maximum value recorded in Al-Adas spring for the two seasons, with average of (85 mg/L), which may refer to the intensive water carbonate rocks interactions (Figures 4 and 5).

The Mg<sup>2+</sup> concentration values within the study area were correlated with the Ca<sup>2+</sup> values due to the dolomitic nature of the springs’ aquifer. The results show that Al-Adas spring had the highest value of Mg<sup>2+</sup> in the two rounds of sampling with an average of 38 mg/L. The increasing trend of Na<sup>+</sup> is due to the application of fertilizers in local agriculture. The potassium (K<sup>+</sup>) content analyses confirmed the negative impact of the potassium-rich fertilizers on water quality, especially in Al-Matwi and Al-Fawwar springs where intensive agriculture is practiced. The K<sup>+</sup> concentration in these two springs exceeded WHO limits of 12 mg/L (Ling et al., 2019; WHO, 2017). With the exception of these two samples, all the tested results were recorded as acceptable for drinking water purposes according to WHO guidelines.

Major anions indicate that the large variations of HCO<sub>3</sub><sup>-</sup> concentration between the wet and dry season sampling campaigns, is explained by bicarbonate concentration in its qualitative recharging process. The analyses of the tested samples show that the springs are in excess of the WHO limit 200 mg/L HCO<sub>3</sub><sup>-</sup> (Figures 6 and 7). Furthermore, Al-Matwi spring had a relatively high chloride concentration as a result of Sarida Wadi and nearby fertilizer-amended farmlands. The same result was found for Al-Mizrab spring, which is affected by sewage-source pollution of cesspits in the nearby village of Der Ghassana.
Usually groundwater contains low concentrations of nitrate ($\text{NO}_3^-$) which is considered as a strong evidence for sewage pollution source (WHO, 2017). There were no sites exceeding the WHO limit for springs water which is 45 mg/L with the exception of Al-Matwi spring in the wet season (May). This can be justified by the karstic nature of the springs emerging formation that lies within the effect of wastewater flow according to the dip of strata in the study area. A relatively slight increase in $\text{SO}_4^{2-}$ concentration at Al-Shalal spring sample of 42 mg/L in the dry season (November) is because of its proximity to Sarida Wadi, a similar justification can be made for Al-Matwi spring in the wet season (May) with 35 mg/L.

Two microbial parameters were measured for the spring water samples: total coliform (TC) and fecal coliform (FC) and showed a significant variation for TC between the two rounds of sampling. The wet season samples recorded higher contamination levels than the dry season samples. In winter season; an increased amount of generated runoff in addition to the wastewater flow bring more pollutants from the drainage system paths to the main wadi flow path due to flushing processes inside the catchment. The springs recharge sites lies within the wastewater flow path, which explains the variation concentration of FC and TC between wet and dry seasons. According to the WHO drinking water guidelines, which determines the TC and FC limits to zero, all analyzed samples revealed sewage contamination, particularly Al-Shalal and Al-Mizrab springs (Tables 3 and 4).

The guideline limit for FC bacteria in unrestricted irrigation is 41000 FC bacteria/100 ml and 4105 FC bacteria/100 ml for restricted irrigation according to WHO standards (WHO, 2017). For restricted irrigation, there is evidence to support the need for a guideline limit for exposure to FC bacteria to protect farm-workers, their children and nearby populations from enteric viral and bacterial infections (Ursula et al., 2000).

Trace elements have stiff resistance to degradation in nature and are thus classified as persistent (Arnason & Fletcher, 2003). Despite the absence of any exceeded value for seventeen measured trace metals, there were some abnormal values recorded (Table 5). Nickel (Ni) in Al-Fawwar and Al-Shalal springs was twice as high as Ni concentrations recorded for the other springs, which is attributed to the wastewater flows in Sarida Wadi. Similarly, Al-Mizrab spring, which is also exposed to wastewater infiltration from nearby cesspits, also showed relatively high Ni values. Boron (B) appears in a relatively higher concentration in Al-Fawwar compared to other springs as a result of the heavy use of fertilizers and irrigation with poor quality water (wastewater). The contamination of Al-Yanbou spring with
Aluminum ($\text{Al}^{3+}$) and Iron ($\text{Fe}^{2+}$) were observed in higher levels than the others because of naturally occurring $\text{Al}^{3+}$ and $\text{Fe}^{2+}$ in rocks and clays, such as bauxite mineral forming dissolution process in the aquifer (Table 5).

### 6. Spring water classification

All the results were plotted using the Piper diagram and fell within the earth alkaline water type with prevailing bicarbonate. Plotting the results using the Durov diagram reveals that 92 percent of all samples are within the domain of $\text{Ca}^{2+}$–$\text{Mg}^{2+}$–$\text{HCO}_3^-$, which indicates frequently recharging water from limestone and dolomite terrains to the carbonate aquifers, this is in line with two different studies, the first is hydro-chemical study in Al Matwi Wadi, which is located in the same catchment, and showed the same spring water classification (Ghanem & Ahmad, 2014), while the other study resulted the same water type of the central western aquifers which in turn include this study area (Ghanem et al., 2016). Eight percent of the measured samples showed the water type of $\text{Ca}^{2+}$-$\text{Na}^{+}$–$\text{Mg}^{2+}$–$\text{HCO}_3^-$ represented in the Al-Fawwar spring water in the dry season (November). This abnormal Na concentration is explained by the application of Na-containing fertilizers in the spring’s surroundings which infiltrates into the groundwater (Figure 8).

Salinity serves as a good indicator for the suitability of a water source to be used for irrigation of agriculture. All the samples were plotted in the Wilcox

### Table 3. Total coliforms in (cfu/100 ml) in Springs of Sarida Catchment in Wet and Dry rounds.

| Springs names | Al-Fawwar | Al-Yanbou | Al-Shalal | Al-Matwi | Al-Mizrab | Al-Adas |
|---------------|-----------|-----------|-----------|----------|-----------|---------|
| May 2013      | 10600     | 23000     | 120000    | 13000    | 95000     | 18000   |
| November 2013 | 2914      | 109       | 29000     | 16       | 44000     | 2200    |

### Table 4. Fecal Coliforms in (cfu/100 ml) in Springs of Sarida catchment in wet and dry rounds.

| Springs Names | Al-Fawwar | Al-Yanbou | Al-Shalal | Al-Matwi | Al-Mizrab | Al-Adas |
|---------------|-----------|-----------|-----------|----------|-----------|---------|
| May 2013      | 1000      | 1300      | 12000     | 500      | 34000     | 1200    |
| November 2013 | 28        | Nil       | 60        | Nil      | 45        | 15      |

### Table 5. Trace elements concentrations (ppb) in Springs of Sarida Catchment in dry season (November, 2013).

| Spring Name   | B   | V   | Fe  | Co  | As  | Se  | Ba  | Pb  | Al  | Cr  | Mn  | Ni  | Cu  | Zn  | Ti  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Al-Shalal     | 33.92 | 1.55 | 52.83 | 0.27 | 0.18 | 0.38 | 21.25 | 0.19 | 63.96 | 0.19 | 19.42 | 8.01 | 3.70 | 21.82 | 0.01 |
| Al-Fawwar     | 307.49 | 5.01 | 47.01 | 0.37 | 0.16 | 0.37 | 34.48 | 0.01 | 2.59 | 36.13 | 8.20 | 36.13 | 0.52 | 6.58 | 0.00 |
| Al-Matwi      | 54.15 | 2.24 | 7.02 | 0.20 | 0.25 | 0.43 | 18.73 | 0.03 | 3.53 | 0.27 | 0.07 | 1.83 | 1.05 | 9.91 | 0.01 |
| Al-Yanbou     | 35.68 | 2.76 | 163.17 | 0.17 | 0.19 | 0.47 | 10.34 | 0.06 | 230.81 | 0.70 | 2.42 | 1.75 | 0.24 | 1.98 | 0.00 |
| Al-Mizrab     | 32.20 | 2.08 | 6.45 | 0.11 | 0.15 | 0.43 | 10.77 | 0.17 | 11.45 | 0.40 | 0.21 | 1.77 | 0.21 | 4.48 | 0.01 |
| Al-Adas       | 29.21 | 1.29 | 24.16 | 0.21 | 0.10 | 0.32 | 17.84 | 0.48 | 19.67 | 0.18 | 0.41 | 1.73 | 0.15 | 1.20 | 0.10 |
| WHO, 2017 Guidelines | 1000 | 3    | 500  | 50  | 50  | 1000 | 10  | 200 | 1000 | 20  | 1000 | 3000 | 2    |

Figure 8. The Durov diagram for measured Spring’s water samples of Sarida catchment in wet (May, “M”) and Dry (November, “N”) Seasons (2013) Combined.
diagram which relates SAR to EC (Figure 9). The results show that all springs sampled had SAR values below ten referring to relatively low salinity effects and are therefore situated in an excellent class for irrigation suitability (Wilcox, 1955). Based on the EC values of the springs, the water is suitable to irrigate all kinds of fruits, vegetables, and field crops (Todd, 2007). These results are consistent with another groundwater quality study of the central aquifers in the West Bank (Jebreen et al., 2018) that concluded analyzed spring waters were suitable for agricultural irrigation activities.

Another qualitative modeling study (GLA method) conducted by Ghanem et al. (2017) on Sarida and Al-Natuf aquifers of West Bank classified the catchments as having high and medium sensitivity to pollution, thus underscoring importance of studying the various pollutants affecting the quality of groundwater, including raw wastewater, and monitoring their effects over time.

7. Conclusion

The analyzed hydrochemical results present evidence that there is a strong connection between the wastewater flow in Sarida Wadi and spring water quality system in the drainage catchment. Intensive agricultural activities, including the use of agri-chemicals (fertilizers and pesticides) in the vicinity of the springs, also contribute negatively to the spring water quality which was evident through the relatively high concentrations of NO₃⁻, Cl⁻, Na⁺ and K⁺ in Al-Matwi and Al-Fawwar springs. The high values of TC and FC are due to the significant increase of wastewater discharge into the catchment recharge areas of the spring sources. TDS levels for the sampled springs were considered as fresh water, which is suitable for all kinds of agricultural and livestock activities, and EC values confirmed the spring water is suitable for irrigation of fruits, vegetables, and field crops. The research highlights the need for improved wastewater management and monitoring of surface and ground water quality in the catchment. It is recommended that decision-makers take appropriate measures necessary to limit the discharge of raw wastewater into the wadi and to find an alternate solution to prevent environmental pollution. The research highlights the need for improved wastewater management and monitoring of surface and ground water quality in Sarida Wadi in order to ensure the health and safety of the farmers and residents who rely on springs in Sarida catchment for their agricultural and domestic water needs. A hydrogeological study including groundwater modeling, as well as solute transport modeling is recommended to further inform waste management in the catchment, and a groundwater vulnerability assessment is needed in order to protect spring recharge zones from wastewater contamination.

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