Determination of Heavy Metals in Groundwater Around Al-Buraihi Sewage Station in Taiz City, Yemen

Raya Qaid Alansi,1 Abdelhafiez M.A. Mohammed,2 Mahmoud M. Ali,1 Wadie Ahmed Mokbel Ghalib,3 Sajan Chimmikuttanda Ponnappa4

1 Department of Applied Chemistry, Faculty of Applied Science, International University of Africa, Khartoum, Sudan
2 Department of Chemistry, Rabigh College of Science & Arts, King Abdulaziz University, Rabigh, Saudi Arabia
3 Taiz University, Faculty of Medical and Health Sciences, Laboratories Department-Taiz, Yemen
4 VerdeEn Chemicals Pvt. Ltd, Hapur District, Uttar Pradesh, India

Corresponding Author: Sajan Chimmikuttanda Ponnappa sajan.saj@rediff.com

Introduction

The multiparty war in Yemen has continued for the past six years, affecting millions of people.1 In the Taiz Governorate, civilians continue to bear the brunt of the conflict. About 3 million people live in the Taiz Governorate, which accounts for approximately 11.3 percent of the country’s population.2 Since the conflict began in 2015, Taiz—especially Taiz city, the governorate’s capital—has been a hotspot for fighting, with all parties involved reporting violations of international humanitarian law. Long-term heavy artillery exchanges, as well as indiscriminate bombing, sniper fire, rocket attacks, the use of landmines, and airstrikes, have taken place in and around Taiz, even in residential areas.3 Water is one of many commodities that is rapidly depleting in Yemen, sometimes related to the war.

Clean water is essential for human health and quality of life.4 Population expansion has led to an increase in demand for resources which has ultimately led to a global rise in industrialization and urbanization.5 This has increased the demand for freshwater, which has been exploited more than any other resource. The overutilization of water resources has deteriorated the quality of freshwater through contamination and pollution.6 Water contamination is presence of chemicals/foreign materials/substances out of place and/or present at a higher concentrations than normal concentrations that have adverse effects on any non-targeted organism.7 To overcome this problem, water treatment is required.8 Wastewater treatment removes pollutants from wastewater in order to reuse treated water for other activities.9,10 The water crisis faced by many countries is the main cause of the increase in the reuse of treated

Background. In recent years, mitigation of groundwater contamination resulting from the limited availability of freshwater for domestic use has become an important issue. The presence of heavy metals in water could have adverse effects on both plant and animal life.

Objectives. The main objective of the present study was to determine possible heavy metal contamination in groundwater around Al-Buraihi sewage station in Taiz, Yemen and to understand possible sources of contamination and their relationships with groundwater.

Methods. Wastewater samples were collected from a wastewater stabilization pond from Al-Buraihi sewage station and borewell water samples were collected from the vicinity. The presence of heavy metals was quantified using inductively coupled plasma-optical emission spectrometry (ICP-OES). Pearson correlation test was performed to understand the relationship between wastewater and groundwater samples.

Results. Physical variables including pH, electrical conductivity (EC), dissolved oxygen (DO) and temperature and elements such as silver (Ag), arsenic (As), aluminum (Al), barium (Ba), boron (B), cadmium (Cd), chromium (Cr), iron (Fe), molybdenum, nickel (Ni), selenium (Se) and zinc (Zn) exceeded the permissible limits recommended by international standards in wastewater samples.

Conclusions. Treated sewage wastewater in the study area is not suitable for irrigation as the elements/heavy metals are accumulated in soil and plants and may be accumulated in humans and animals through bio-accumulation. In addition, these heavy metals reach the water table and aquifers through percolation, thereby polluting groundwater.

Competing Interests. The authors declare no competing financial interests.

Keywords. pollution, contamination, groundwater, ICP-OES

Received January 30, 2021. Accepted April 6, 2021
J Health Pollution 30: (210604) 2021
© Pure Earth
wastewater worldwide. In arid and semi-arid regions, water resource planning involves the reclamation and reuse of wastewater. However, improper maintenance of wastewater treatment ponds, improper lining or overutilization of wastewater without proper treatment for agricultural practices can lead to the pollution of soil and groundwater. Soil and groundwater may contain pollutants such as heavy metals which can eventually enter the food chain. Toxic heavy metals are harmful to human health and present a threat to both plant and animal life. Monitoring of heavy metals in environmental samples is crucial since most of these heavy metals can influence human health (positively or negatively) even at very low concentrations. The present study aimed to determine the level of heavy metal contamination in the wastewater treatment pond around Al-Buraihi sewage station in Taiz city, Yemen.

Methods

Al-Buraihi sewage station in Taiz city is located in the Al-Buraihi area, to the northeast of Taiz. The upper and lower altitudes of this area consist of a preliminary processing unit. Pond 1 is located at higher altitude while ponds 2 and 3 at a lower altitude. The sewage station is located between longitudes $10^\circ\ 39'$ and $30^\circ\ 39'$ N and latitudes $80^\circ\ 150'$ and $80^\circ\ 151'$ E. The climatic condition of Al-Buraihi area is warm and semi-dry, with an average annual temperature of $25^\circ$C. Al-Buraihi station consists of four basins as shown in Figure 1. The first and the second basin have an area of 18000 m$^2$, with a depth of 4.25 m. These basins operate alternatively at an interval of four years each. They are anaerobic ponds. The third basin has an area of 248800 m$^2$ and 5.3 m depth. This is a facultative pond and the fourth basin has an area of 146800 m$^2$ and 5.3 m depth and is a maturation pond. None of the four basins have any protection from the natural surroundings.

### Abbreviations

| EC     | Electrical conductivity |
ponds has a concrete lining. Before the construction of Al-Buraihi wastewater station, this area was a swampy region with few wells.

Materials

All chemicals and reagents used in the present study were of analytical grade (AR) nitric acid (65% American Chemical Society (ACS)), International Standards Organization (ISO)), perchloric acid (HClO₄) (70% ACS, ISO) and sulfuric acid (H₂SO₄) (98%–VWR) extra pure were used. Standard solutions of salts of elements (1000 mg/L) were purchased from Scharlau, Spain. All glassware was soaked in 10% nitric acid and washed with Millipore distilled water before use.

Instrumentation

An inductively coupled plasma-optical emission spectrometer (ICP-OES) with an axially viewed configuration (VISTA MPX, Varian, Mulgrave, Australia) equipped with a solid-state detector, Stumar-master mist chamber, and V-groove nebulizer was employed for element determinations using a standard calibration method. Electrical conductivity (EC) and pH were determined in-situ using a multipurpose electronic Jenway 4520 conductivity/total dissolved solids (TDS) meter and Hanna portable pH meter, respectively. The dissolved oxygen concentration of wastewater samples was measured immediately in the field by using Inolabmulti 720, (Willis Towers Watson (WTW)).

Wastewater and groundwater sampling

Water sample collection for the present study was performed during the summer season in 2017 (July to September). Thirty-two wastewater samples were taken from three positions at different times to determine heavy metal concentrations in wastewater stabilizing ponds in Al-Buraihi (Figure 2). Groundwater samples were also collected from the borewells located around the proximity of the wastewater station (Figure 3). It should be noted that the wastewater station is located in a geographically higher region compared to the borewells from which the groundwater samples were collected. The collected samples were transported in an ice box to be kept under ambient temperature until analysis. Wastewater samples were stored in a fridge at approximately 4°C. All samples were acidified at the time of collection with nitric acid (HNO₃) (5mL) to prevent microbial degradation of heavy metals and to ensure sterility. All plastic containers for samples were prewashed with distilled water before being used.

Sample Preparation

Wastewater samples were pretreated with concentrated HNO₃ to prevent microbial degradation of heavy metals. Then, 10 mL of wastewater samples were digested by adding 7.0
Alansi et al.

Heavy Metals in Groundwater Around Al-Buraihi Sewage Station, Yemen

Figure 3 — Groundwater sampling points

Figure 4 — Schematic sketch of the study area showing the possibilities of wastewater percolation reaching groundwater (channel and aquifer)
mL of $\text{HNO}_3$ (65%), 3.0 ml hydrogen peroxide ($\text{H}_2\text{O}_2$) (30%) and diluted to 50 mL with distilled water. All reagents were of analytical grade (AR) and purchased from (Scharlau-JPN) including standard stock solutions of known concentration of different heavy metals. All analyses were done in triplicate. The analytical procedure followed for these tests were the procedures given in the operation manuals of the instrument used and by the American Public Health Association (APHA) 1999.28

Statistical analysis

Statistical Program for the Social Sciences (SPSS) version 26 software was used to calculate the descriptive statistics of mean, standard deviation, and correlation analysis. The data collected were discussed in terms of average and 95% confidence intervals. Statistical differences between means were compared using the least significant differences (LSD) with a $P$ value ≤ 0.05 indicating significance.

Results

Wastewater and borewell water samples were subjected to ICP-OES analysis. The results were compared with the water quality standards obtained from World Health Organization (WHO), Yemen Standardization, Metrology and Quality Control Organization (YSMO), Joint Food and Agriculture Organization of the United Nations (FAO)/WHO Expert Committee on Food Additives (JECFA), and Indian Standard for Drinking Water as per Bureau of Indian Standards (BIS) specifications (IS 10500-2012).29 The water quality standards are given in Table 1. In total, 32 wastewater samples were collected from three wastewater stabilizing ponds depending on their size. Eight samples were collected from pond 1. Twelve samples each

| Variable | Wastewater | Drinking water |
|----------|-------------|----------------|
| Ag       | 0.010<sup>a</sup> | 0.1<sup>d</sup> |
| Al       | 2<sup>a</sup> | 5<sup>b</sup> | 0.9<sup>e</sup> | 0.03 |
| As       | 0.05<sup>a</sup> | 0.1<sup>b</sup> | 0.01<sup>c</sup> | 0.01<sup>d</sup> |
| B        | 1.0<sup>a</sup> | 2—0.7<sup>b</sup> | 2.4<sup>c</sup> | 0.5<sup>d</sup> |
| Ba       | 1<sup>a</sup> | 0.7<sup>c</sup> | 0.7<sup>d</sup> |
| Be       | 0.1<sup>a</sup> | 0.1<sup>b</sup> | 0.01<sup>c</sup> |
| Cd       | 0.01<sup>a</sup> | 0.01<sup>b</sup> | 0.003<sup>c</sup> |
| Co       | 0.05<sup>a</sup> | 0.05<sup>b</sup> |
| Cr       | 0.02<sup>a</sup> | 0.1<sup>b</sup> | 0.05<sup>c</sup> | 0.05<sup>d</sup> |
| Cu       | 0.2<sup>a</sup> | 0.2<sup>b</sup> | 2<sup>c</sup> |
| Fe       | 5<sup>a</sup> | 5<sup>b</sup> | 0.3<sup>d</sup> |
| Li       | 2.5<sup>a</sup> | 5<sup>b</sup> |
| Mn       | 0.2<sup>a</sup> | 0.2<sup>b</sup> | 0.1<sup>d</sup> |
| Mo       | 0.01<sup>a</sup> | 0.01<sup>b</sup> | 0.07<sup>c</sup> |
| Ni       | 0.2<sup>a</sup> | 0.5<sup>b</sup> | 0.07<sup>c</sup> | 0.02<sup>d</sup> |
| Pb       | 0.2<sup>a</sup> | 5<sup>b</sup> | 0.01<sup>c</sup> | 0.01<sup>d</sup> |
| Sb       | 0.02<sup>a</sup> | 0.02<sup>b</sup> | 0.02<sup>c</sup> |
| Se       | 0.05<sup>a</sup> | 0.02<sup>b</sup> | 0.04<sup>c</sup> | 0.01<sup>d</sup> |
| Sn       | 10<sup>a</sup> | 10<sup>b</sup> |
| Sc       | 5<sup>a</sup> | 5<sup>b</sup> |
| Zn       | 60<sup>a</sup> | 30<sup>d</sup> |
| Sr       | 200<sup>a</sup> | 200<sup>b</sup> |
| K        | 200<sup>a</sup> | 200<sup>b</sup> | 75<sup>d</sup> |
| Mg       | 30<sup>a</sup> |
| Na       | 6.5—8.4<sup>a</sup> | 8.4—6.5<sup>b</sup> | 6.5—8.5<sup>d</sup> |
| Ca       | >2.0<sup>a</sup> | 2<sup>b</sup> |
| P        | 40<sup>a</sup> |

Abbreviations: EC, electrical conductivity; DO, dissolved oxygen; OM, organic matter; Temp, temperature; SAR, sodium absorption ratio.

<sup>a</sup>Yemen Standardization, Metrology and Quality Control Organization<sup>29</sup>
<sup>b</sup>Joint FAO/WHO Expert Committee on Food Additives (JECFA)<sup>30</sup>
<sup>c</sup>BIS Bureau of Indian Standards? (Yes)(10500-2012) water quality standards.<sup>32</sup>
were collected from ponds 2 and 3. The collected samples were analyzed using ICP-OES. Descriptive statistics of the physicochemical properties of wastewater samples collected from the study area are given in Table 2. Since there were only three borewells in proximity to the study area, groundwater samples were collected from these borewells. The location, depth, and physicochemical properties of borewell water samples are given in Table 3. The samples collected were designated as B1, B2, and B3. A graphical representation of the physicochemical variables of the wastewater samples is given in Figure 5. A graphical representation of the physicochemical variables of the borewell samples is given in Figure 6. Descriptive statistical values of all the elements including heavy metals for the wastewater samples collected from the three ponds are given in Table 4. For comparison, the mean value of the elements for the wastewater samples is included with the results of the borewell water samples in Table 5. To understand the relationship between wastewater samples and groundwater.

### Table 2 — Descriptive Statistics of Physicochemical Properties of Wastewater Samples Collected from the Study Area

| Variables | Unit | Minimum | Maximum | Mean | SD |
|-----------|------|---------|---------|------|----|
| pH        |      | 7.6     | 8.4     | 8.075| 0.255|
| EC        | dS/m | 6.0     | 7.2     | 6.463| 0.459|
| DO        | mg/L | 0.3     | 2.1     | 0.750| 0.748|
| Temp.     | °C   | 28.3    | 37.8    | 31.563| 3.967|
| pH        |      | 8.1     | 8.7     | 8.325| 0.171|
| EC        | dS/m | 5.4     | 7.8     | 6.325| 0.637|
| DO        | mg/L | 0.2     | 6.2     | 1.608| 1.778|
| Temp.     | °C   | 24.0    | 33.4    | 28.758| 2.753|
| pH        |      | 8.6     | 8.9     | 8.750| 0.079|
| EC        | dS/m | 5.7     | 7.6     | 6.950| 0.552|
| DO        | mg/L | 1.4     | 13.9    | 5.617| 4.309|
| Temp.     | °C   | 22.8    | 35.3    | 28.625| 4.332|

### Table 3 — Physicochemical Properties of Groundwater Samples Collected from Study Area

| Borewell | Depth (m) | Locations | Elevation (m) | pH | EC (μS/cm or dS/m) | Temp (°C) | DO₂ (mg/L) | Placement |
|----------|-----------|-----------|---------------|----|-------------------|-----------|------------|-----------|
| B1       | 17        | 391603    | 1511077       | 7.8| 5590/5.59         | 28.9      | 3.3        | Open bore well |
| B2       | 12        | 392856    | 1508260       | 8  | 7880/7.88         | 27.2      | 2          | Close to manhole of wastewater used |
| B3       | 14        | 395541    | 1510717       | 7.43| 7180/7.18         | 28.1      | 3.4        | Animals drinking water |

Abbreviations: EC, electrical conductivity; DO, dissolved oxygen; Temp, temperature; B1, Borewell1; B2, Borewell 2; B3, Borewell3.
### Table 4 — Descriptive Statistics of Elements in Water Samples Collected from Wastewater Ponds

| Element | Pond I (n =8) mg/L | | Pond II (n =12) mg/L | | Pond III (n =12) mg/L | |
|---------|--------------------|---|----------------------|---|-----------------------|---|
|         | Min                | Max | Mean | SD | Min | Max | Mean | SD | Min | Max | Mean | SD | |
| Ca      | 77.99              | 509.02 | 348.8 | 182.3 | 36.74 | 426.35 | 290.4 | 130.49 | 31.201 | 378.04 | 208.00 | 115.02 | |
| K       | 30.35              | 88.899 | 64.80 | 18.30 | 42.39 | 88.405 | 62.66 | 11.85 | 45.104 | 94.849 | 69.233 | 12.672 | |
| Mg      | 109.72             | 567.59 | 408.9 | 198.9 | 166.89 | 734.41 | 518.8 | 187.4 | 156.23 | 878.94 | 604.35 | 280.37 | |
| Na      | 404.12             | 891.23 | 709.5 | 154.2 | 633.4 | 1162.4 | 840.81 | 147.4 | 748.00 | 1239.9 | 974.38 | 135.59 | |
| P       | 12.85              | 81.527 | 34.3 | 24.6 | 12.58 | 59.649 | 24.084 | 14.5 | 5.287 | 23.345 | 13.932 | 6.38 | |
| Ag      | 0.005              | 38.892 | 11.115 | 15.6 | 0.011 | 23.031 | 3.339 | 6.79 | 0.013 | 25.412 | 4.855 | 9.4023 | |
| Al      | 0.000              | 0.857 | 0.506 | 0.278 | 0.000 | 0.744 | 0.397 | 0.29 | 0.000 | 4.097 | 0.555 | 1.152 | |
| As      | 0.000              | 0.115 | 0.043 | 0.041 | 0.000 | 0.084 | 0.02 | 0.03 | 0.000 | 0.068 | 0.019 | 0.027 | |
| B       | 1.042              | 1.317 | 1.198 | 0.868 | 0.086 | 1.209 | 0.944 | 0.24 | 1.366 | 2.215 | 1.838 | 0.246 | |
| Ba      | 0.000              | 8.826 | 1.213 | 3.079 | 0.000 | 0.204 | 0.03 | 0.05 | 0.000 | 0.111 | 0.019 | 0.029 | |
| Be      | 0.000              | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.00 | 0.000 | 0.010 | 0.011 | 0.029 | |
| Cd      | 0.000              | 0.084 | 0.019 | 0.029 | 0.000 | 0.021 | 0.004 | 0.00 | 0.000 | 0.012 | 0.011 | 0.029 | |
| Co      | 0.000              | 0.015 | 0.007 | 0.004 | 0.000 | 0.048 | 0.01 | 0.011 | 0.000 | 0.035 | 0.012 | 0.009 | |
| Cr      | 0.000              | 5.403 | 0.691 | 1.904 | 0.002 | 1.552 | 0.14 | 0.443 | 0.000 | 9.641 | 0.823 | 2.777 | |
| Cu      | 0.013              | 0.071 | 0.040 | 0.025 | 0.000 | 0.100 | 0.026 | 0.028 | 0.000 | 0.252 | 0.039 | 0.077 | |
| Fe      | 0.000              | 2.781 | 0.754 | 0.866 | 0.000 | 6.718 | 0.863 | 1.849 | 0.160 | 8.411 | 1.435 | 2.399 | |
| Li      | 0.067              | 0.084 | 0.074 | 0.007 | 0.053 | 0.081 | 0.069 | 0.009 | 0.037 | 0.084 | 0.069 | 0.014 | |
| Mn      | 0.046              | 0.196 | 0.107 | 0.048 | 0.016 | 0.252 | 0.079 | 0.062 | 0.001 | 0.157 | 0.045 | 0.041 | |
| Mo      | 0.000              | 0.028 | 0.011 | 0.009 | 0.000 | 0.118 | 0.019 | 0.034 | 0.000 | 0.046 | 0.012 | 0.016 | |
| Ni      | 0.000              | 0.107 | 0.033 | 0.033 | 0.000 | 1.497 | 0.151 | 0.425 | 0.000 | 0.085 | 0.027 | 0.026 | |
| Pb      | 0.011              | 0.103 | 0.045 | 0.033 | 0.014 | 0.051 | 0.033 | 0.010 | 0.004 | 0.107 | 0.043 | 0.031 | |
| Sb      | 0.000              | 0.078 | 0.029 | 0.032 | 0.000 | 0.078 | 0.020 | 0.026 | 0.000 | 0.084 | 0.014 | 0.024 | |
| Sc      | 0.000              | 0.072 | 0.029 | 0.032 | 0.000 | 0.230 | 0.036 | 0.069 | 0.000 | 0.138 | 0.026 | 0.043 | |
| Sn      | 0.000              | 0.203 | 0.078 | 0.081 | 0.000 | 0.220 | 0.049 | 0.067 | 0.000 | 0.603 | 0.116 | 0.219 | |
| Zn      | 0.014              | 0.379 | 0.145 | 0.115 | 0.063 | 11.796 | 1.242 | 3.342 | 0.016 | 2.521 | 0.493 | 0.906 | |
### Table 5 — Elements Present in Wastewater Ponds and Borewell Water

|                | Mean values of variables of pond samples mg/L | Borewell water sample variables mg/L |
|----------------|-----------------------------------------------|--------------------------------------|
|                | Pond 1  | Pond 2  | Pond 3  | B1      | B2      | B3      |
| Ca             | 348.863 | 290.414 | 208.000 | 228.26  | 164.34  | 186.56  |
| K              | 64.802  | 62.661  | 69.233  | 28.54   | 20.88   | 24.08   |
| Mg             | 408.943 | 518.899 | 604.352 | 156.92  | 144.36  | 148.88  |
| Na             | 709.591 | 840.871 | 974.381 | 289.45  | 236.32  | 246.72  |
| P              | 34.354  | 24.084  | 13.932  | 15.46   | 8.84    | 12.334  |
| Ag             | 11.115  | 3.339   | 4.855   | 1.24    | 0.60    | 0.72    |
| Al             | 0.506   | 0.397   | 0.555   | 0.12    | 0.08    | 0.08    |
| As             | 0.043   | 0.027   | 0.019   | 0.004   | 0.002   | 0.002   |
| B              | 1.198   | 1.443   | 1.838   | 0.068   | 0.035   | 0.042   |
| Ba             | 1.213   | 0.039   | 0.019   | 0.006   | 0.006   | 0.004   |
| Be             | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   |
| Cd             | 0.019   | 0.004   | 0.011   | 0.002   | 0.001   | 0.001   |
| Co             | 0.007   | 0.014   | 0.012   | 0.004   | 0.002   | 0.002   |
| Cr             | 0.691   | 0.147   | 0.823   | 0.06    | 0.02    | 0.03    |
| Cu             | 0.040   | 0.026   | 0.039   | 0.02    | 0.02    | 0.03    |
| Fe             | 0.754   | 0.863   | 1.435   | 0.36    | 0.24    | 0.28    |
| Li             | 0.074   | 0.069   | 0.069   | 0.004   | 0.002   | 0.001   |
| Mn             | 0.107   | 0.079   | 0.045   | 0.08    | 0.03    | 0.05    |
| Mo             | 0.011   | 0.019   | 0.012   | 0.006   | 0.002   | 0.001   |
| Ni             | 0.033   | 0.151   | 0.027   | 0.004   | 0.002   | 0.002   |
| Pb             | 0.045   | 0.033   | 0.043   | 0.02    | 0.01    | 0.01    |
| Sb             | 0.029   | 0.020   | 0.014   | 0.008   | 0.004   | 0.003   |
| Se             | 0.029   | 0.036   | 0.026   | 0.002   | 0.000   | 0.000   |
| Sn             | 0.078   | 0.049   | 0.116   | 0.002   | 0.001   | 0.001   |
| Zn             | 0.145   | 1.242   | 0.693   | 0.067   | 0.032   | 0.048   |
samples, Pearson correlation analysis of wastewater and borewell water samples was performed. The results are given in Table 6.

**Discussion**

All three ponds exceed standards for parameters except temperature which is primarily due to the addition of salt and chemicals to the pond from domestic sewage and commercial drainages entering the wastewater pond. Alkalinity was above the permissible range in some of the 32 samples. The pH values increased during the day due to the consumption of CO$_2$ by algae during photosynthesis. Conversely, the release of CO$_2$ during the night by algae will decrease pH values. The increase in conductivity is due to the salts and minerals carried out from the sewage adjacent to the wastewater pond. The mean of the samples indicates that DO was within acceptable limits. However, in certain sites it was found to be in a range of 0.3 to 2.1, indicating that these ponds are rich with organic matter, where the bacteria present utilize oxygen for biodegradation, indicating the presence of organic pollutants.

Meanwhile, sampling results from the three ponds revealed that DO was increased (Pond 1 < Pond 2 < Pond 3), indicating the effective treatment of organic pollutants at each stage.

In borewell samples, among the four variables, pH, DO and temperature were within acceptable limits. However, the EC of all three samples exceeded acceptable limits. The fact that ground water is rich in mineral salts may explain the increase in EC.

According to Table 4, aluminum (Al), beryllium (Be), cobalt (Co), copper...
(Cu), lithium (Li), manganese (Mn), nickel (Ni), lead (Pb), tin (Sn) and zinc (Zn) concentrations in most of the wastewater samples collected from Pond 1, Pond 2, and Pond 3 were within permissible limits. The results of magnesium (Mg), sodium (Na), calcium (Ca), phosphorus (P), silver (Ag), arsenic (As), boron (B), barium (Ba), cadmium (Cd), chromium (Cr), molybdenum (Mo), potassium (K), antimony (Sb), and selenium (Se) concentrations in wastewater samples collected from the three ponds exceeded permissible limits. The presence of Ag might result from small-scale photography, household products such as wood polish and from domestic water treatment devices.\[^{35,36}\] In urban effluents and sewage sludge, As is present as dimethyl arsenic acid (DMAA) and as arsenite (As (III)).\[^{37}\] In the present case, As might have originated from household products such as washing products, medicines, garden products, wood preservatives, old paints and pigments.\[^{18}\] The presence of Cu might result from corrosion and leaching of plumbing, fungicides (copper (II) chloride), pigments, wood preservatives and antifouling paints.\[^{24}\] As a potentially toxic metalloid, Se is found in urban waste waters in low concentrations.\[^{19}\] Selenium comes from food products, food supplements, shampoos, cosmetics, old paints, and pigments.\[^{25}\] The remainder of the elements might originate from the small-scale industries whose function are unrecognized/unknown located around the vicinity of Taiz city. Calcium, Mg, Ag, B, Ba, Cd and Cr exceeded permissible limits in borewell water samples. There are a few reasons for the increase in concentrations of these elements. First, there may not be a proper lining to the base of the wastewater/stabilizing pond. Improper lining can lead to the percolation of wastewater, thereby contaminating the aquifer or the groundwater channels. Second, wastewater is used for agriculture purposes around Taiz city. The use of wastewater rich in heavy metals can also lead to contamination of the water table through percolation. The third possibility involves the geology of the area. Beneath the ground surface, mineral or heavy metal-bearing rocks could also be a cause of increased concentrations of these elements in borewell water. The consumption of borewell water for drinking purposes might present a hazard to human health.\[^{40,41}\] To understand the relationship between wastewater and borewell water, Pearson correlation was performed.

**Correlation test**

The results of the correlation analysis between the wastewater and borewell water samples are given in Table 6. Correlation analyses for the results obtained using ICP-OES were performed to understand the relationship between wastewater and borewell water samples. Correlation analysis is employed to resolve the degree of the linear relationship between two variables, with a range between -1 to 1. If the values obtained are closer to 1 or -1, this indicates that there is a strong positive linear relationship between the correlated variables. If the values are nearer to 0, this indicates that there is no linear relationship between the two variables. The present analysis indicated a strong correlation between wastewater and borewell water samples at a 0.01 and 0.05 level of significance. The analysis demonstrates the presence of a relationship among all of the elements/heavy metals present in wastewater and borewell water, suggesting that the elements/heavy metals present in wastewater might have percolated through the soil beds and might have reached the groundwater table.

This could have led to the presence/increase of some parameters in borewell water, thereby making it unsafe for domestic purposes.

Some heavy metals play important roles in the body’s physiological and biochemical processes, while others can be toxic to humans.\[^{52-54}\] Continued use of groundwater from the borewells around Al-Buraihi stations might lead to acute or chronic toxicity in humans and animals. In the interest of public health, regulatory authorities should adequately handle the wastewater at Al-Buraihi station so that contamination of groundwater and soil is reduced. However, due to Yemen’s civil war, this will not be possible in the foreseeable future.

**Conclusions**

Systematic analyses of wastewater and borewell water samples were performed. The ICP-OES analysis indicated that pH, EC, DO and temperature and elements such as Ag, As, Al, Ba, B, Cd, Cr, iron (Fe), Mo, Ni, Se and Zn exceeded permissible limits recommended by international standards. Similarly, some of the elements exceeded permissible limits in borewell water samples. The results indicate a strong relationship between the elements present in wastewater and borewell water. The use of wastewater as a source of nutrients for irrigation has become common practice in Yemen, especially in Taiz, because of the water crisis in this city. The results of the present study showed that the treated sewage wastewater in Taiz city, Yemen is not suitable for irrigation as the elements/heavy metals get accumulated in soil/plants and could become accumulated in humans and animals through bio-accumulation. Finally, these heavy metals could reach the water table and aquifers through percolation, thereby polluting groundwater quality.
Acknowledgments
The authors of this article would like to thank all those who have directly or indirectly contributed to this work. This study was funded as part of employment.

Copyright Policy
This is an Open Access article distributed in accordance with Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0/).

References
1. Council HR. Annual report of the United Nations High Commissioner for Human Rights. Human Rights Council; 2019.
2. Ministry of Public Health and Population. Nutrition Survey of Taiz Governorate 2016. Office TGH, ed. Yemen: Ministry of Public Health and Population; 2016. Project CIM. CIMP quarterly report. In. Yemen2020.
3. Katko TS, Juuti PS, Vuorinen HS. History of water and health from ancient civilizations to modern times. Water Supp. 2007;7(1):49-57.https://doi.org/10.2166/ws.2007.006
4. Avtar R, Tripathi S, Aggarwal AK, Kumar P. Population–Urbanization–Energy Nexus: A Review. Resources. 2019;8(3).https://doi.org/10.3390/resources8030136
5. Boojhawon A, Surroop D. Impact of climate change on vulnerability of freshwater resources: a case study of Mauritius. Environment, Development and Sustainability. 2020;23(1):195-223.https://doi.org/10.1007/s10668-019-00574-3
6. Tundisi JG. Water Resources in the Future: Problems and Solutions. Estudos Avançados. 2008;22(63):7-16.https://doi.org/10.1590/S0103-40142008000200002
7. Pophare AM, Lamsose BR, Katpatal YB, Navale VP. Impact of over-exploitation on groundwater quality: A case study from WR-2 Watershed, India. J Earth Syst Sci. 2014;123(7):1541–1566.https://doi.org/10.1007/s12040-014-0478-0
8. Amin MT, Alazba AA, Manzoor U. A Review of Removal of Pollutants from Water/Wastewater Using Different Types of Nanomaterials. Adv Mater Sci Eng. 2014;2014:1-24.https://doi.org/10.1155/2014/825910
9. Sharma S, Bhattacharya A. Drinking water contamination and treatment techniques. Appl Wat Sci. 2016;6(3):1043-1067.https://doi.org/10.1007/s13201-016-0455-7
10. Rasalingam S, Peng R, Koodali RT. Removal of Hazardous Pollutants from Wastewaters: Applications of TiO2-SiO2Mixed Oxide Materials. J Nanomater. 2014;2014:1-42.https://doi.org/10.1155/2014/617405
11. Hubbe MA, Metts, J, R., Hermosilla, D., Blanco, M. A., Yerushalmi, L., Haghighat, F., Lindholm-Lehto, P., Khodaparast, Z., Kamali, M., and Elliott, A. Wastewater treatment and reclamation: A review of pulp and paper industry practices and opportunities. Bioresources. 2016;11(3):7953-8091.https://doi.org/10.15376/BIORES.11.3.HUBBE
12. Abedi-Koupai J, Mostafazadeh-Fard B, Alyuni M, Bagheri M. Effect of treated wastewater on soil chemical and physical properties in an arid region. Plant, Soil and Environment. 2006;52(8):335-344.
13. Mejri A, Aziz HA. Effects of municipal wastewater on accumulation of heavy metals in soil and wheat (Triticum aestivum L.) with two irrigation methods. Rom Agri Res. 2011;28:217-222.https://doi.org/10.5897/AMJR-11-1492
14. Miryed NR. Challenges to treated wastewater reuse in arid and semi-arid areas. Environ Sci Policy. 2013;25:186-195.https://doi.org/10.1016/j.envsci.2012.10.016
15. Qureshi AS. Challenges and Prospects of Using Treated Wastewater to Manage Water Scarcity Crises in the Gulf Cooperation Council (GCC) Countries. Water. 2020;12(7).https://doi.org/10.3390/w12071971
16. Valipour M, Singh VP. Global experiences on Wastewater Irrigation: Challenges and Prospects. In: Balanced Urban Development: Options and Strategies for Liveable Cities.Water Trans. 2016:289-327.https://doi.org/10.1007/978-3-319-28112-4_18
17. Sardar K, Ali S, Hameed S, et al. Heavy metals contamination and what are the impacts on living organisms. Greener J Environ Manage Pub Saf. 2013; 2 (4):172-179.https://doi.org/10.15580/GJEMPS.2013.060413652
18. Hashim M, Chu K. Biosorption of cadmium by brown, green and red seaweeds. Chem Eng J. 2004;97:249-255.https://doi.org/10.1016/S1385-8947(03)00216-X
19. El-Sheekh M, El-Naggar A, Osman M, El-Mazaly E. Effect of cobalt on growth, pigments and the photosynthetic electron transport in Monoraphidium minutum and Nitzschia perrminuta. Braz J Plant Physiol. 2003;15(3):159-166.https://doi.org/10.1590/S1677-0420200300003/00005
20. Wuana RA, Okieimen FE. Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. ISBN Ecology. 2011;2011:1-20.https://doi.org/10.5402/2011/402647
21. Chibueke GU, Obiora SC. Heavy Metal Polluted Soils: Effect on Plants and Bioremediation Methods. Applied and Environmental Soil Science. 2014;2014:1-12.https://doi.org/10.1155/2014/752708
22. Sall ML, Diav AKD, Gningue-Sall D, Efremova Aaron S, Aaron JJ. Toxic heavy metals: impact on the environment and human health, and treatment with conducting polymers, a review. Environ Sci Pollut R.2020;27(24):29927-29942.https://doi.org/10.1007/s11356-020-09354-3
23. Nompongong P, Ngila J, Msagati T, Moodley B. Preconcentration of trace multi-elements in water samples using Dowex 50W-x8 and Chelex-100 resins prior to their determination using inductively coupled plasma atomic emission spectrometry (ICP-OES). Phys Chem Earth. 2013;66:83-88.https://doi.org/10.1016/j.pce.2013.08.007
24. Briffa J, Sinagra E, Blundell R. Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon. 2020;6(9):e04691.https://doi.org/10.1016/j.heliyon.2020.e04691
25. Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ. Heavy metal toxicity and the environment. Molecular, Clinical and Environmental Toxicology. 2012;101:133-164.https://doi.org/10.1007/978-3-7643-9340-4_6
26. United States Environmental Protection Agency. SW-846 Test Method 3050A. Acid Digestion of Waters for Total Recoverable or Dissolved Metals for Analysis by Flame Atomic Absorption (FLAA) or Inductively Coupled Plasma (ICP) Spectroscopy. In. 3050A:1992. Accessed [2021 April 30] Available from: https://www.epa.gov/sites/production/files/2015-12/documents/3050a.pdf
27. American Public Health Association. Standard Methods for the Examination of Water and Wastewater. 20th ed: American Public Health Association, American Water Works Association, Water Environment Federation; 1999. Accessed [2021 April 30] Available from: https://www.standardmethods.org
28. World Health Organization. A compendium
of standards for wastewater reuse in the Eastern Mediterranean Region. World Health Organization; 2006. Accessed [2021 April 30] Available from: https://apps.who.int/iris/handle/10665/116515

29. Republic of Yemen. Yemen Standardization, Metrology and Quality Control. http://www.ysmo.org

30. World Health Organisation. Compendium of food additive specificationsThe Joint FAO/WHO Expert Committee on Food Additives (JECFA). In: World Health Organisation ; 2018. Accessed [2021 April 30] Available from: http://www.fao.org/publications/card/en/c/CA2330EN/

31. Bureau of Indian Standards. Indian Standard Drinking water — specification. 2012 Accessed [2021 April 30] Available from: http://cgwb.gov.in/Documents/WQ-standards.pdf

32. Al-Sabahi I. A study of surface water and groundwater pollution in IBB city, Yemen. Electronic Journal of Geotechnical Engineering. 2010;14:1-12. https://doi.org/10.1.1.565.6062

33. Tebbutt THY. Principles of water quality control. 5th Edition, Butterworth-Heinemann Elsevier;1997.

34. Shafer M, Overdier J, Armstrong D. Removal, partitioning and fate of silver and other metals in wastewater treatment plants and effluent-receiving streams. Environ Toxicol Chem. 1998;17(4):630-641. https://doi.org/10.1002/etc.5620170416

35. Adams NW, Kramar JR. Silver speciation in wastewater effluent, surface waters, and pore waters. Environ Toxicol Chem. 1999;18(12):2667-2673. https://doi.org/10.1002/etc.5620181203

36. Thornton I, Butler D, Docx P, Hession M. Pollutants in urban wastewater and sewage sludge. London European Communities; 2001. Accessed [2021 April 30] Available from: https://ec.europa.eu/environment/archives/waste/sludge/pdf/sludge_pollutants.pdf

37. Tangahu BV, Sheikh Abdullah SR, Basri H, Idris M, Anuar N, Mukhlisin M. A Review on Heavy Metals (As, Pb, and Hg) Uptake by Plants through Phytoremediation. International Journal of Chemical Engineering. 2011;2011:1-31.https://doi.org/10.1155/2011/939161

38. World Health Organization. Guidelines for the safe use of wastewater, excreta and greywater In: Vol 4. Geneva 27, Switzerland: World Health Organization; 2006 Accessed [2021 April 30] Available from: https://www.who.int/water_sanitation_health/publications/gsuswg4/en/

39. Gutierrez-Ravelo A, Gutierrez AJ, Paz S, et al. Toxic Metals (Al, Cd, Pb) and Trace Element (B, Ba, Co, Cu, Cr, Fe, Li, Mn, Mo, Ni, Sr, V, Zn) Levels in Sarpa Salpa from the North-Eastern Atlantic Ocean Region. Int J Environ Res Public Health.2020;17(19). https://doi.org/10.3390/IJERPH17197212

40. Zaksas NP, Soboleva SE, Nevinsky GA. Twenty Element Concentrations in Human Organs Determined by Two-Jet Plasma Atomic Emission Spectrometry. Sci World J. 2019;2019:9782635.https://doi.org/10.1155/2019/9782635

41. Engwa GA, Ferdinand PU, Nwalo FN, Unachukwu MN. Mechanism and Health Effects of Heavy Metal Toxicity in Humans. InTech Open. 2018:1-23. https://doi.org/10.5772/INTECHOPEN.82511

42. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. Interdiscip Toxicol. 2014;7(2):60-72.https://doi.org/10.2478/intox-2014-0009