Heavy Metal Pollution Index of Surface Water and Groundwater Around Tongon Mine (Côte d’Ivoire)

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Abstract: Water is a valued resource, which is increasingly being threatened by mining activity. Monitoring of surface water and groundwater quality around gold mine is essential in terms of heavy metals and toxic substances. The northern zone of Côte d’Ivoire where located Tongon is a highly mineralised zone, with extensive mining of gold. The quality of water resources in this region may be affected by the activity of the Tongon mine, which is the main gold mine in the region. The objectives of this study were to determine the concentration of heavy metals and the Heavy Metal Pollution Index (HPI) in surface water and groundwater around Tongon mine. The concentrations of As, Zn, Pb, Cd, Cr, Cu, and Mn have been evaluated at 21 surface water and 16 groundwater sampling stations. The concentration of these metals were analysed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for heavy metal pollution indexing. The concentrations of As, Pb, Cr, Cu and Mn in surface water were found to be above the highest desirable limit of WHO drinking water standard with mean concentrations of 5.761, 0.016, 0.178, 2.939, and 0.684 mg/L, respectively. Excepted As (2.95 mg/L) and Mn (0.67 mg/L), the metal concentrations in groundwater were well below the permissible limits of WHO drinking water standard. The Heavy Metal Pollution Index was used to evaluate surface water and groundwater quality. The results showed that, in the groundwater samples, HPI values (48.56-72.49) were less than 100, indicating a low-level heavy metal. Concerning surface water, HPI values of Poungbe River are well below the index limit of 100, which suggest that it is generally not contaminated with respect to these metals. The mining activity of Tongon is carried out while protecting water quality against heavy metals. The quality of water resources in the area must be regularly monitored to avoid any dramatic situation.

Keywords: Surface Water, Groundwater, Heavy Metal Pollution, Tongon, Gold Mine

1. Introduction

Water is vital to the existence of all living organisms [1-4]. However, this valued resource is increasingly being threatened by human population’s growth and anthropogenic activities such as mining activity. This is why it is necessary to monitor its quality [1]. Mineral extraction and processing is likely to contribute to the contamination of surface water and groundwater [2]. For example, waste water from non-ferrous metal ore mining and smelting, electroplating and other industrial production process is an important contamination source of heavy metal [5]. The heavy metal contamination has the characteristic of the high toxicity, and difficult to degrade, and its migration brings about a broader range of hazards. The research indicated that mining and the smelting activities caused great destruction to the water environment. The heavy metals are difficult to clear away from the natural environment, or even form a secondary pollution [3-5].

Heavy metals can cause adverse effects to human health when their contents exceed the permissible limit in surface
Thus, heavy metals assessment in surface water and groundwater used for drinking purpose is very significant from the human health viewpoint [7]. Heavy metals are usually present in trace amounts in natural water but many of them are toxic even at very low concentration though many of the metals are essential components of the biological system [8]. Heavy metals such as As, Pb, Cd, Cu, Cr, Zn and Mn are highly toxic even in minor quantity. Contaminated surface water when used for irrigation purpose affects soil quality and crop health of the agricultural system [7].

The pollution parameters monitored for the assessment of the quality of any system give an idea of the pollution with reference to these parameters individually. Quality indices are useful to obtain an idea of the synergistic action of all measured pollution parameters. They make it possible to synthesize the various data in the form of a single value. [9]. Quality indices use a set of quality criteria in a reproducible form and compile all pollution parameters in a simple approach, for evaluation of water quality contamination, the Heavy Metal Pollution Index (HPI) was developed [7, 9]. This index is used to assess the level of pollution of water resources by combining several water pollution parameters [7].

In Côte d’Ivoire, Tongon mine is located in north of the country. With an annual production of 8.5 tons of gold per year, the Tongon mine is the largest gold mine in Côte d’Ivoire. Its gold mine reserve is estimated at 3.16 million ounces, or more than 98 tons [10]. Mining in Tongon is an important source of income for Côte d’Ivoire, but it can affect the environment around the mine. In fact, the surface and groundwater around the Tongon gold mine is an important water resource, which is used for crop irrigation and drinking water. Pollution of these waterways would have harmful consequences for populations. Unfortunately, to date, there are no data in the literature on surface and groundwater quality indices around the Tongon gold mine. Thus, it seems essential to assess the quality of these waters in terms of heavy metals. The main objective of this study is to assess the contamination of surface and groundwater around the Tongon gold mine by the Heavy metal Pollution Index (HPI).

2. Materials and Methods

2.1. The Studied Area and Sampling

Tongon gold mine is located at 9°57’5.76’’ N and 5°42’13.68’’ W (Figure 1). The mean temperature in this region is 27.6°C and the annual precipitation for the entire area is reported to be 1400 mm on average [11]. The sampling network consist of 37 sites, 21 of them surface water and 16 groundwater. The sampling sites are marked by a red point and numbered in Figure 1. Totally, 375 surface water and ground water samples were collected monthly from March 2017 to October 2018. The samples were collected in separate polyethylene bottles. Samples were collected and stored according to the method prescribed in the American Public Health Association manual [12]. A volume of 2 mL of 65% HNO$_3$ was added to prevent metal precipitation.

![Figure 1. Location and sampling sites around Tongon mine, Côte d’Ivoire.](image)

2.2. Analytical Methods

The concentrations of heavy metals were determined by Inductively Couple Plasma Mass Spectroscopy (NexION 2000 ICP-MS, USA), after the samples were concentrated and digested. The minimum limit of detection (LOD) for each heavy metal is resumed in Table 1.
3. Results and Discussion

3.1. Distribution of Heavy Metals in Water

The heavy metal concentrations of the surface water and groundwater samples collected in different sampling sites are given in Table 3 and Table 4, respectively.

The metal concentrations (mg/L) in surface water samples ranged from 0.009 to 53.508 for As, 0.005 to 0.625 for Zn, 0.001 to 0.228 for Pb, <LOD to 0.0403 for Cd, 0.006 to 2.505 for Cr, 0.004 to 14.275 for Cu, and 0.021 to 10.9 for Mn, respectively (Table 3). The heavy metal concentrations of all surface water samples were (5.761 ± 19.099), (0.081 ± 0.252), (0.016 ± 0.123), (0.0004 ± 0.0017), (0.178 ± 0.889), (2.939 ± 6.751) and (0.684 ± 2.325) mg/L, for As, Zn, Pb, Cd, Cr, Cu, and Mn respectively (Figure 2). Based on these results, it was observed that concentrations of As, Pb, Cr, Cu and Mn were above the highest desirable limit of WHO drinking water standard (Table 3). It has been observed that concentrations of heavy metals such as Cd and Zn were well below the permissible limits of WHO drinking water standard. The high concentrations of heavy metals in the samples could be explained by the release of heavy metals from mining waste throughout the Tongon mine area. Concerning the groundwater samples (Table 4), the metal concentrations (mg/L) ranged from 0.002 to 0.263 for As, 0.019 to 0.071 for Zn, 0.002 to 0.034 for Pb, <LOD to 0.00019 for Cd, 0.017 to 0.040 for Cr, 0.005 to 0.198 for Cu, and 0.008 to 4.025 for Mn, respectively (Figure 2). The mean concentrations of all groundwater samples were (0.036 ± 1.12), (0.037 ± 0.48), (0.009 ± 0.25), (0.000024 ± 0.000152), (0.021± 0.026), (0.010 ± 0.117) and (0.662 ± 1.283) mg/L, for As, Zn, Pb, Cd, Cr, Cu, and Mn respectively (Figure 3). Excepted As and Mn, the metal concentrations were well below the permissible limits of WHO drinking water standard (Table 3).
### Table 3. Concentration of heavy metals in surface water samples (mg/L).

| Station | As       | Zn       | Pb       | Cd       | Cr       | Cu       | Mn       |
|---------|----------|----------|----------|----------|----------|----------|----------|
| Mean    | 0.068    | 0.054    | 0.060    | 0.035    | 0.002    | 0.0004   | 0.0005   |
| SD      | 0.022    | 0.029    | 0.023    | 0.025    | 0.011    | 0.0006   | 0.0005   |
| 1       | 3.265    | 7.062    | 0.219    | 0.011    | 0.012    | 0.0001   | 0.0005   |
| 2       | 0.152    | 0.376    | 0.017    | 0.001    | 0.020    | 0.00000  | 0.00000  |
| 3       | 0.016    | 0.012    | 0.037    | 0.021    | 0.011    | 0.00031  | 0.00021  |
| 4       | 0.027    | 0.033    | 0.002    | 0.025    | 0.000    | 0.00001  | 0.00000  |
| 5       | 0.232    | 0.030    | 0.001    | 0.001    | 0.012    | 0.00001  | 0.00000  |
| 6       | 0.021    | 0.025    | 0.021    | 0.020    | 0.011    | 0.00000  | 0.00000  |
| 7       | 0.022    | 0.036    | 0.016    | 0.026    | 0.012    | 0.00000  | 0.00000  |
| 8       | 0.025    | 0.014    | 0.017    | 0.001    | 0.000    | 0.00001  | 0.00000  |
| 9       | 0.053    | 0.018    | 0.001    | 0.001    | 0.001    | 0.00000  | 0.00000  |
| 10      | 0.060    | 0.020    | 0.017    | 0.001    | 0.000    | 0.00002  | 0.00000  |
| 11      | 0.013    | 0.006    | 0.041    | 0.013    | 0.006    | 0.00000  | 0.00000  |
| 12      | 0.008    | 0.001    | 0.025    | 0.001    | 0.000    | 0.00000  | 0.00000  |
| 13      | 0.025    | 0.002    | 0.017    | 0.001    | 0.000    | 0.00000  | 0.00000  |
| 14      | 0.026    | 0.001    | 0.002    | 0.001    | 0.000    | 0.00000  | 0.00000  |
| 15      | 0.010    | 0.012    | 0.029    | 0.002    | 0.001    | 0.00000  | 0.00000  |
| 16      | 0.012    | 0.030    | 0.001    | 0.001    | 0.000    | 0.00000  | 0.00000  |
| 17      | 0.011    | 0.010    | 0.023    | 0.001    | 0.000    | 0.00000  | 0.00000  |
| 18      | 15.862   | 12.024   | 0.220    | 0.025    | 0.002    | 0.00032  | 0.00058  |
| 19      | 10.800   | 4.525    | 0.008    | 0.001    | 0.023    | 0.00000  | 0.00016  |
| 20      | 9.172    | 8.567    | 0.054    | 0.011    | 0.000    | 0.00022  | 0.00037  |
| 21      | 53.508   | 54.914   | 0.817    | 0.228    | 0.455    | 0.00403  | 0.00596  |

**Figure 2.** Heavy metal concentrations of all surface water samples.

**Figure 3.** Heavy metal concentrations of all groundwater samples.
The analysis of variance was performed using metal data to compare heavy metal concentrations in surface water samples with those in groundwater. It was observed that concentrations of As, Zn, Cd, Cd, Cr, and Cu in surface water samples were statistically higher than those in groundwater (Table 5). This difference is due to the absorption of metals by the different components of the soil and sediments such as carbonates, oxides and organic matter.

Table 5. ANOVA test for significance between surface water and groundwater (difference are significant at P<0.05).

| Location                      | As  | Zn  | Pb  | Cd  | Cr  | Cu  | Mn  | p     |
|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-------|
| Surface water and groundwater | 150.36 | 9.68 | 1.32 | 1.05 | 1.05 | 1.05 | 1.05 | 0.05  |
| Milliariers Bay               | 20.00 | 10.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 0.05  |
| Bierti Bay                    | 150.36 | 9.68 | 1.32 | 1.05 | 1.05 | 1.05 | 1.05 | 0.05  |
| Surface and ground water      | 150.36 | 9.68 | 1.32 | 1.05 | 1.05 | 1.05 | 1.05 | 0.05  |

Table 6 gives the reported concentration range of metals in surface water and groundwater by various studies conducted in Cote d’Ivoire. It can be seen that the concentrations of heavy metals reported in the present investigation are below the high concentration range reported by Bakary et al., and Coulibaly et al [17, 18]. It is observed that the concentration range of Zn, Cd and Pb are similar to the low concentration range reported by Namnita et al [16].

Table 6. Concentrations of heavy metal in groundwater samples (mg/L).

| Station | As  | Zn  | Pb  | Cd  | Cr  | Cu  | Mn  |
|---------|-----|-----|-----|-----|-----|-----|-----|
|         | Mean | SD  | Mean | SD  | Mean | SD  | Mean | SD  | Mean | SD  | Mean | SD  | Mean | SD  | Mean | SD  |
| 22      | 0.006 | 0.007 | 0.029 | 0.023 | 0.002 | 0.005 | 0.00002 | 0.00004 | 0.017 | 0.017 | 0.016 | 0.019 | 0.096 | 0.014 |
| 23      | 0.002 | 0.003 | 0.019 | 0.016 | 0.003 | 0.006 | 0.00002 | 0.00006 | 0.017 | 0.017 | 0.009 | 0.009 | 0.113 | 0.033 |
| 24      | 0.003 | 0.003 | 0.023 | 0.017 | 0.002 | 0.001 | 0.00001 | 0.00004 | 0.018 | 0.017 | 0.007 | 0.003 | 0.261 | 0.249 |
| 25      | 0.006 | 0.005 | 0.023 | 0.015 | 0.013 | 0.012 | 0.00002 | 0.00006 | 0.017 | 0.018 | 0.023 | 0.062 | 2.474 | 0.409 |
| 26      | 0.024 | 0.027 | 0.071 | 0.138 | 0.006 | 0.003 | 0.00001 | 0.00003 | 0.034 | 0.020 | 0.009 | 0.008 | 0.075 | 0.080 |
| 27      | 0.004 | 0.005 | 0.034 | 0.032 | 0.002 | 0.002 | 0.00004 | 0.00011 | 0.023 | 0.017 | 0.010 | 0.003 | 0.312 | 0.642 |
| 28      | 0.263 | 0.291 | 0.034 | 0.029 | 0.034 | 0.078 | 0.00019 | 0.00054 | 0.040 | 0.077 | 0.198 | 0.408 | 1.013 | 0.978 |
| 29      | 0.098 | 0.046 | 0.050 | 0.044 | 0.025 | 0.031 | 0.00001 | 0.00003 | 0.022 | 0.018 | 0.023 | 0.037 | 1.687 | 0.294 |
| 30      | 0.002 | 0.057 | 0.058 | 0.022 | 0.001 | 0.001 | 0.00000 | 0.00000 | 0.018 | 0.017 | 0.009 | 0.006 | 0.008 | 0.008 |
| 31      | 0.025 | 0.079 | 0.045 | 0.034 | 0.008 | 0.004 | 0.00001 | 0.00003 | 0.020 | 0.016 | 0.013 | 0.007 | 0.113 | 0.132 |
| 32      | 0.078 | 0.195 | 0.045 | 0.057 | 0.006 | 0.005 | 0.00003 | 0.00009 | 0.020 | 0.019 | 0.013 | 0.014 | 4.025 | 2.523 |
| 33      | 0.003 | 0.004 | 0.033 | 0.035 | 0.002 | 0.002 | 0.00001 | 0.00000 | 0.018 | 0.018 | 0.007 | 0.000 | 0.014 | 0.011 |
| 34      | 0.009 | 0.019 | 0.039 | 0.039 | 0.003 | 0.003 | 0.00001 | 0.00000 | 0.017 | 0.016 | 0.009 | 0.006 | 0.010 | 0.006 |
| 35      | 0.005 | 0.003 | 0.041 | 0.034 | 0.019 | 0.020 | 0.00002 | 0.00004 | 0.019 | 0.018 | 0.005 | 0.002 | 0.269 | 0.802 |
| 36      | 0.009 | 0.014 | 0.036 | 0.027 | 0.016 | 0.023 | 0.00002 | 0.00006 | 0.018 | 0.017 | 0.009 | 0.011 | 0.021 | 0.024 |
| 37      | 0.007 | 0.012 | 0.022 | 0.024 | 0.007 | 0.006 | 0.00001 | 0.00001 | 0.017 | 0.017 | 0.006 | 0.003 | 0.065 | 0.153 |

A number of significant correlations were obtained in the Study (Table 7). The correlation at 5% level of significance (P<0.05) shows significant correlation between the following pairs As and Zn, Pb, Cd, Cu, and Mn; Zn and As, Pb, Cd, Cr and Mn; Pb and As, Zn, Cd, Cr, and Mn; Cd and As, Zn, Pb, Cr, and Mn; Cr and As, Zn, Cd and Mn; Mn and As, Zn, Cd, and Cr. Cu shows significant correlation with As. Overall the convergent results indicated that the significant correlation was correlated with a common source. The source of these elements is the gold mining activity.

Table 7. Correlation matrix between heavy metals (bold correlations are significant at P<0.05).

| As     | Zn    | Pb    | Cd    | Cr    | Cu    | Mn    |
|--------|-------|-------|-------|-------|-------|-------|
| As     | 1.00  | 0.85  | 0.48  | 0.89  | 0.88  | 0.39  |
| Zn     | 1.00  | 0.48  | 0.47  | 0.91  | 0.90  | 0.39  |
| Pb     | 0.48  | 0.47  | 1.00  | 1.00  | 0.99  | 0.67  |
| Cd     | 0.89  | 0.91  | 1.00  | 1.00  | 0.99  | 0.66  |
| Cr     | 0.88  | 0.90  | 1.00  | 0.99  | 1.00  | 0.66  |
| Cu     | 0.39  | 0.93  | 0.05  | 0.05  | 1.00  | 0.66  |
| Mn     | 0.63  | 0.63  | 0.39  | 0.67  | 0.66  | 0.01  | 1.00  |
3.2. Heavy Metal Pollution Index

Mean concentrations of the analysed metals were used to calculate the HPI values. The HPI values of surface water sampling sites ranged from 50.03 to 794.51 (Table 8). Sampling sites N° 10, 18, 19, 19, 20 and 21 have HPI values higher than the critical HPI threshold value (100). These sampling sites are contaminated. The higher values of HPI may be attributed to the gold mining activity [13]. The water in these sampling sites come from directly the mine plant, the artificial dam, and the artificial lake, which is created to collect runoff water during rainfall in the mine. It is important to note that the Tongon mine has a water reusing system. This system uses the contaminated surface water in the processes of the mine plant. The sampling site N°8 is located at the site where the mine water is discharged into the environment. The HPI value of the sampling station N° 8 was below 100 (Figure 4). It is far below the critical HPI threshold value (Table 8). It indicates that the sampling site N° 8 is not contaminated by the heavy metals studied. It shows that the water reusing system in the Tongon mine is operating. It is confirmed by HPI values of the sampling station N°12, 15 and 16 which were below 100. These sampling stations are located at the Pounge River.

![HPI map of surface water around Tongon mine.](image)

**Figure 4. HPI map of surface water around Tongon mine.**

**Table 8. Heavy metal pollution index of surface water sampling stations.**

| Station | Qi-As | Qi-Zn | Qi-Pb | Qi-Cd | Qi-Cr | Qi-Cu | Qi-Mn | Wi×Qi-As |
|---------|-------|-------|-------|-------|-------|-------|-------|----------|
| 1       | 145.00| 146.98| 8.78  | 148.00| 64.49 | 199.42| 101.50| 2.90     |
| 2       | 8137.50| 148.03| 7.43  | 140.00| 53.06 | 630.00| 110.00| 162.75   |
| 3       | 111.58| 147.88| 7.72  | 150.00| 70.17 | 198.47| 110.00| 1.08     |
| 4       | 709.75| 148.44| 8.18  | 143.13| 64.03 | 198.95| 97.00 | 539.50   |
| 5       | 11.88 | 147.50| 8.67  | 146.25| 26.02 | 198.88| 108.13| 6.81     |
| 6       | 340.50| 149.56| 9.36  | 149.00| 71.43 | 199.20| 111.13| 32.36    |
| 7       | 1617.92| 147.07| 9.14  | 137.92| 31.46 | 198.24| 106.46| 332.00   |
| 8       | 16600.00| 149.77| 9.92  | 147.50| 90.82 | 197.58| 2600.00| 332.00  |
| 9       | 4.09  | 148.25| 8.49  | 150.00| 76.81 | 199.15| 71.56 | 0.08     |
| 10      | 2.88  | 147.99| 10.28 | 150.00| 77.55 | 199.63| 105.00| 0.06     |
| 11      | 3.21  | 148.55| 9.56  | 150.00| 68.92 | 199.27| 103.46| 0.06     |
| 12      | 521.29| 148.24| 9.96  | 141.54| 68.76 | 199.39| 109.30| 10.43    |
| 13      | 303.96| 148.22| 8.97  | 142.08| 70.41 | 199.32| 70.65 | 6.08     |
| 14      | 240.81| 147.93| 8.82  | 142.50| 68.54 | 199.32| 25.40 | 4.82     |
| 15      | 1.50  | 148.31| 10.00 | 147.92| 65.48 | 199.51| 101.63| 0.03     |
| 16      | 39628.85| 144.66| 8.83  | 134.23| 28.89 | 1153.92| 117.42| 792.58   |
| 17      | 26975.00| 149.65| 1.67  | 150.00| 55.10 | 1227.50| 125.00| 539.50   |
| 18      | 22903.85| 147.97| 9.54  | 139.23| 43.96 | 1164.62| 43.50 | 458.08   |
| 19      | 133745.83| 118.75| 242.75| 51.25 | 5010.71| 752.58| 1554.50| 2674.92  |
Table 8. Continued.

| Station | Wi×Qi-Zn | Wi×Qi-Pb | Wi×Qi-Cd | Wi×Qi-Cr | Wi×Qi-Cu | Wi×Qi-Mn | ΣWi×Qi | HPI |
|---------|----------|----------|----------|----------|----------|----------|--------|-----|
| 1       | 0.03     | 6.14     | 44.40    | 1.29     | 0.20     | 2.03     | 56.99  | 53.71 |
| 2       | 0.03     | 5.20     | 42.00    | 1.06     | 0.63     | 2.20     | 213.87 | 201.54 |
| 3       | 0.03     | 6.35     | 44.19    | 0.91     | 0.09     | 0.74     | 235.38 | 221.81 |
| 4       | 0.03     | 5.40     | 45.00    | 1.40     | 0.20     | 0.88     | 55.15  | 51.97 |
| 5       | 0.03     | 5.73     | 42.94    | 1.28     | 0.20     | 2.15     | 66.52  | 62.68 |
| 6       | 0.03     | 6.07     | 43.88    | 0.52     | 0.20     | 2.16     | 53.09  | 50.03 |
| 7       | 0.03     | 5.52     | 42.00    | 0.35     | 0.20     | 1.94     | 51.11  | 48.16 |
| 8       | 0.03     | 6.55     | 44.70    | 1.43     | 0.20     | 2.22     | 61.94  | 58.37 |
| 9       | 0.03     | 6.40     | 41.38    | 0.63     | 0.20     | 2.13     | 83.12  | 78.32 |
| 10      | 0.03     | 6.94     | 44.25    | 1.82     | 0.20     | 52.00    | 437.24 | 412.02 |
| 11      | 0.03     | 5.95     | 45.00    | 1.54     | 0.20     | 1.43     | 54.22  | 51.10 |
| 12      | 0.03     | 7.19     | 45.00    | 1.55     | 0.20     | 2.10     | 56.13  | 52.90 |
| 13      | 0.03     | 6.69     | 45.00    | 1.38     | 0.20     | 2.07     | 55.44  | 52.24 |
| 14      | 0.03     | 6.97     | 42.46    | 1.38     | 0.20     | 2.19     | 63.65  | 59.98 |
| 15      | 0.03     | 6.28     | 42.63    | 1.41     | 0.20     | 1.41     | 58.03  | 54.69 |
| 16      | 0.03     | 6.18     | 42.75    | 1.37     | 0.20     | 0.51     | 55.85  | 52.63 |
| 17      | 0.03     | 7.00     | 44.38    | 1.31     | 0.20     | 2.03     | 54.98  | 51.81 |
| 18      | 0.03     | 6.18     | 40.27    | 0.58     | 1.15     | 2.35     | 843.14 | 794.51 |
| 19      | 0.03     | 1.17     | 45.00    | 1.10     | 1.23     | 2.50     | 590.53 | 556.47 |
| 20      | 0.03     | 6.68     | 41.77    | 0.88     | 1.16     | 0.87     | 509.47 | 480.09 |
| 21      | 0.02     | 169.93   | 15.38    | 100.21   | 0.75     | 31.09    | 2992.30 | 719.73 |

The HPI values of groundwater ranged from 48.56 to 72.49 (Table 9). All groundwater-sampling sites have HPI values below the critical HPI limit value (Figure 5). It shows, in general, that the groundwater samples are not contaminated with respect to heavy metals pollution.
4. Conclusion

In this research, the heavy metal concentrations were first evaluated, and then a Heavy Metal Pollution Index (HPI) was calculated for surface water and groundwater around the Tongon gold mine. The findings of the present research are summarized as follows:

i. The concentration of As, Pb, Cr, Cu and Mn has been found more than the highest desirable limit of WHO drinking water standard in the majority of sampling stations for surface water.

ii. The surface water of the sampling site, which has the HPI values above the critical index value of 100 was used by the water reusing system of the mine.

iii. In general, the groundwater is not contaminated with respect to heavy metals pollution.

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