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ENVIRONMENTAL LEGISLATION,
MULTILATERAL RELATIONS & FUNDING
OPPORTUNITIES

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ECOLOGY AND ENVIRONMENTAL PROTECTION

ENVIRONMENTAL LEGISLATION, MULTILATERAL RELATIONS AND FUNDING OPPORTUNITIES

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POSITIVE INFLUENCE OF THE BUCHIM'S COPPER LEACHING FACILITY TO THE MAJOR DRAINAGE SYSTEM AROUND THE BUCHIM COPPER MINE AND THROUGH THE LAKAVICA RIVER

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ABSTRACT

Buchim Mine has been built 35 years ago on the well-known porphyry copper deposit Buchim. During these three and half decades of continuous production around the Buchim Mine were created surface waste dump where have been stored more than 130 Mt of waste and hydrotailing dam with more than 110 Mt of tailing. These secondary landfills for years have been considered as basic sources of anthropogenic influences and contamination of air, soils and especially waters. In this paper we would like to present ours latest findings in regards to copper contamination around the Buchim copper mine drainage system and adjacent copper leaching facility. Namelly, several so-called polluting hot-spots around the Buchim copper mine have been determined, which manifested pronounced acidic character of mine waters (pH 3.6-5.5) and increased copper concentrations of up to 800 mg/l Cu. After the leaching facility and closed water system were built, the influence of pollutants to surface and ground waters significantly decreased. Positive effects in regards to environmental pollution following their construction were indicated by the results of the 2012 monitoring and especially by the results of the 2013, 2014 and 2015 monitoring. According to the monitoring in 2013, copper values ranged from <0.01 to 1.6 $mg \cdot l^{-1}$ Cu while 2014 monitoring have shown even better results from 0.01 to 0.98 $mg \cdot l^{-1}$ Cu and pH 4.50÷8.40 and during 2015 from 0.1 to 0.38 $mg \cdot l^{-1}$ Cu for piezometers and from 0.01 to 0.05 $mg \cdot l^{-1}$ Cu for ground and surface waters, which itself speaks about the positive effects achieved with constructions of the copper leaching facility and engulfed drainage waters.

Keywords: leaching, Buchim copper mine, oxide ore, monitoring, contamination.

INTRODUCTION

The copper production from the Buchim Mine for over three and half decades produced significant waste matiral piles: surface waste dump where have been stored more than 130 Mt of waste and hydrotailing dam with more than 110 Mt of tailing. Here we would like to stress out that there are several areas at the Buchim Mine system that are of particular environmental concern: the open pit, the heap leach pad, waste dump, tailing dam and the system of underground fractures that control groundwater movement. Within the waste dump even today there are zones with >0,1% Cu as well as abundance of pyrite that continuously contributes as main acid mine drainage source to the draining streams of Jasenov Dol and outflow of Bucim's Lake, contaminating Madenska and Topolnicka River waters in prolonged period of time. Short term environmental concerns include the presence of cyanide and metal rich solutions in the leach pad, while the long term environmental concern is acid mine drainage. Although acid drainage is commonly associated with the extraction and processing of sulfide-bearing metalliferous ore deposits, acidic drainage can occur wherever sulfide minerals are excavated and exposed to atmospheric oxygen [1]. In regards to the secondary landfills (waste dump and hydrotailing dam) they for years have been considered as basic sources of anthropogenic influences and contamination of air, soils and especially waters. Here we would like to stress out that the Buchim Mine was is especially prone to the environment danger of acid mine drainage because all of the rocks there have lost their capability to buffer acids due to acid sulfide hydrothermal alteration and contrary to the fact that rocks of Buchim deposit contain less than 7%, sulfides, since no carbonates are present to counteract the acid waters, the pH remained very low. The acid mine drainage has the most potential to affect water quality in the downstream agricultural and wetland areas of the Damjan Field and Kriva Lakavica Valley. Suposed process of contamination lasted since 1979 until 2011 when below the waste dump was built copper leaching facility that for its process completely engulfed drainage waters in the area and Madenska River and river flows below were completely decontaminated. Some of the preliminary publications that have studied the issues of mine pollution at the territory of the Republic of Macedonia, including area around the Buchim Mine, can be found in [2], [3], [4], [5], [6] and [7]. After that period studies around the Buchim Mine have been intensified and have been set monitoring points for particular hot spots around waste dump and tailing dam with associated water drainage, ambiental dust monitoring, monitoring of soil contamination etc. Considering that issue there have been completed some significant studies of soil contamination such are [8], [9], [10].

METHODOLOGY

Samples were collected during the continuous monitoring in period from 2007 to 2010 and lately in 2013, 2014 and 2015 from the most environmentally threatening hot spots within the Buchim mine drainage system outlined below. Water was collected in polythene syringes, passed through a 0.45μm filter and transferred into polythene tubes. Water was acidified with 0.4 ml of 50% nitric acid. Conductivity and pH were measured in the field for all water samples. Samples were stored in a cool and dark place until they were returned to the laboratory analysis. Solutions were analysed by ICP-AES or ICP-MS, depending on concentrations. A large number of analytes were determined but only those that are likely mining related and environmentally significant are presented and discussed here. The concentrations were compared to reference guidelines (Maximally Allowed Concentrations-MDK) to assess their significance.

MAJOR WATER CONTAMINANTS AROUND THE BUCHIM MINE AND SAMPLING LOCATIONS

In the adjacent vicinity of the Buchim Mine have been located the few important hydrological objects, waste dump, tailing dam, leaching factory and closed circuit water system (Figure 1). Draining waters from the mine waste are composed of meteoric waters flowing from upper parts above the mine waste pile (mine yard and Buchim village area) and passing through the mine waste, rain waters passing though the mine waste dump and flowing further downstream and ground waters infiltrating through the mine waste dump. Buchim Dol (Buchim Lake)-before the start of mine production it was built drainage system/collector, with channels around the location perimeter planned for the mine waste dump, draining into the Madenska River (Figure 2).

Figure 1. Topographic map of the Buchim Mine area with monitoring points

Also, the hydrotailing dam is one pollutant, which drainages through the Topolnicka River.

a) *b)*

Figure 2. Madenska River before the construction of the leaching facility (a) and Madenska River after construction of the leaching facility (b)

The negative influences of the Buchim pollutants clearly can be seen at the Figure 2a where the water in Madenska River is absolutely blue as a direct result of pollution.

RESULTS AND DISCUSSIONS FROM THE MONITORING IN 2013, 2014 AND 2015

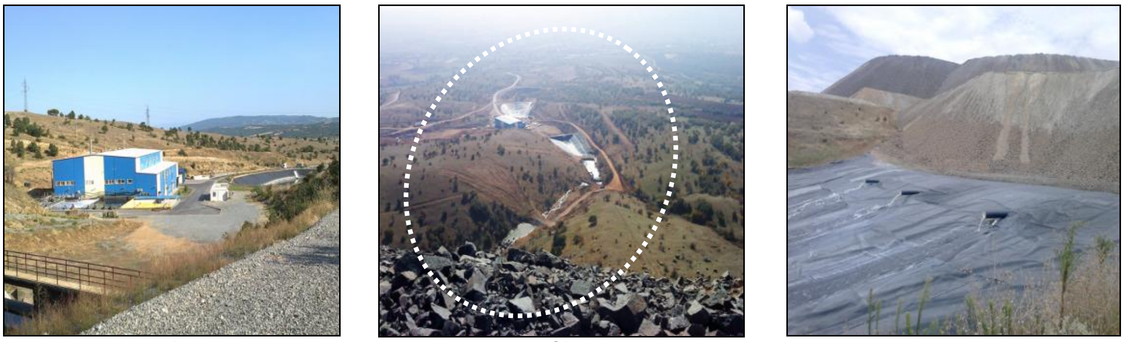
In Table 1 are shown measured copper concentration values by months through the period 2007-2010 in samples from 5 sampling points. The highest concentrations of copper were determined at the monitoring points VP-2 (Topolnica River, under the bridge on the Radovis-Stip road, 9.8÷207.0 $mg{\cdot}l^{-1}$ Cu), S-1 (Buchimski Dol, outflow from Buchim Lake, range 8.8÷69 $mg{\cdot}l^{-1}$ Cu) and S-5/6 (Jasenov Dol creek, outflow from the mine waste dump, range 16.5÷551 $mg{\cdot}l^{-1}$ Cu). At these particular sampling points pollution used to be severe and thousand(s) of order higher than MDK Class III reference value. At VP-2 sampling point pollution was higher than standard values from 196 up to 4140 times, at S-1 from 176 up to 1380 times, while at the S-5/6 they were of highest order, from 330 up to 11010. All of them with ease can be attributed to the anthropogenically introduced factors-sources (ore excavation, waste disposal, etc.).

Table 1. Mointoring of copper concentrations in waters around the Buchim Mine, 2007-2010

Parameter	**pH**	**Copper** ($mg \cdot l^{-1}$)	**MDK Class III** ($mg \cdot l^{-1}$)
VP-1	5.7÷7.5	0.0075÷0.05	0.05
VP-2	4.1÷5.9	9.8÷207.0	0.05
S-1	4.1÷5.0	8.8÷69.0	0.05
S-5/6	3.8÷4.8	16.5÷551.0	0.05
S-7	5.8÷6.7	0.002÷1.3	0.05

Note: VP-1 Hydrotailing collector; VP-2 Topolnica River, under the bridge on the Radovis-Stip road; S-1 Buchimski Dol under the dam; S-5 Jasenov Dol earthen embankment (left side); S-6 Jasenov Dol easrthen embankment (right side); S-7 Drinking water well.

The latest monitoring of the ground and surface waters around the Buchim mine has been established after the construction of the copper leaching facility (Figure 3). The leaching facility has been located under the main waste dump of the Buchim mine and encompasses all the drainage surface waters from the waste dump and the Buchim mine (Figure 3) where closed circular system for treated waters and surface waters completely encompasses them (Figure 3).



a) b)

Figure 3. a) Cu-leaching facility at the Buchim Mine the construction of the leaching facility; b) Panoramic view of the leaching facility; c) Cu drainage from an oxide ore pile

Studied monitoring sites of established piezometers have shown significantly lower values for copper and other parameters measured in 2013 (Table 2) and 2014 (Table 3) than those in period 2007-2010 (Table 1).

Table 2. Mointoring of the copper concentrations in waters around the Buchim Mine (2013)

	March, 2013 ($mg \cdot l^{-1}$)	**June, 2013** ($mg \cdot l^{-1}$)	**September, 2013** ($mg \cdot l^{-1}$)	**December, 2013** ($mg \cdot l^{-1}$)	**MDK Class III** ($mg \cdot l^{-1}$)
VP-1	0.15	0.01	0.01	0.01	0.05
VP-2	0.01	0.01	0.08	0.01	0.05
S-1	0.01	0.23	0.01	0.65	0.05
S-2	1.6	0.95	0.9	0.53	0.05
S-3	0.6	0.7	0.65	0.3	0.05
S-4	0.05	0.05	0.03	0.01	0.05
S-5	0.4	0.57	0.52	0.45	0.05
S-6	0.09	0.05	0.05	0.47	0.05
S-7	1.5	0.48	0.02	0.01	0.05

Note: VP-1 Hydrotailing collector; VP-2 Topolnica River, under the bridge on the Radovis-Stip road; S-1 Buchimski Dol under the dam; S-2 Damjan Field at the end of the Buchimski Dol; S-3 Confluence of Jasenov Dol creek into Topolnicka River; S-4 Copper leaching facility; S-5 Jasenov Dol earthen embankment (left side); S-6 Jasenov Dol earthen embankment (right side); S-7 Drinking water well.

From the data in table above it can be seen that in the majority of analyzed water samples have been determined higher concentrations than the maximally allowed concentrations (MDK) for copper in class III waters. However, we have to point that measured values given in the Table 2 above were amazingly lower than those obtained in period 2007-2010. For example values at point VP-2 were in the range 0.1 to 0.08 $mg \cdot l^{-1}$ Cu, which is a decrease in comparison to period 2007-2010 of at least 122 to 2587 times. Quite similar were improvements at sampling point S-1 with newly measured 0.01 to 0.65 $mg \cdot l^{-1}$ Cu, which is at least 13 to 106 times lower than previous, as well as at sampling point S-5/6 with newly measured 0.09 to 0.57 $mg \cdot l^{-1}$ Cu, which is at least 29 to 967 times lower than previous. Also, that there is a correlation between the measuring points and obtained copper concentrations in different periods of 2013, can be seen at the diagram below (Figure 4).

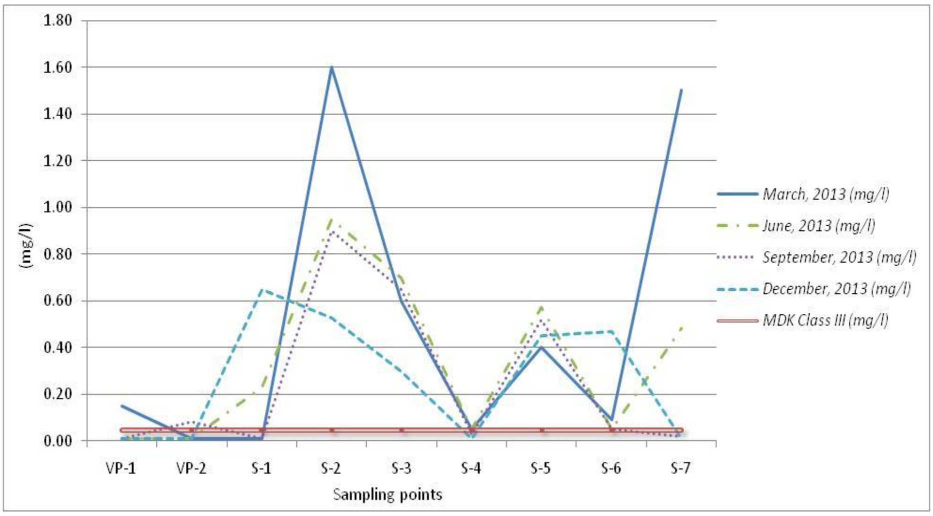


Figure 4. Diagram of copper distribution in the monitored mine drainage system waters around the Buchim copper mine throughout 2013

The very next monitoring of the ground and surface waters around the Buchim mine was performed throughout 2014 (Table 3).

Table 3. Mointoring of the copper concentrations in waters around the Buchim Mine (2014)

	March, 2014 (mg/l)	May, 2014 (mg/l)	September, 2014 (mg/l)	December, 2014 (mg/l)	MDK Class III (mg/l)
VP-1	0.03	0.01	0.01	0.01	0.05
VP-2	0.03	0.01	0.01	0.05	0.05
S-1	0.03	0.01	0.01	0.01	0.05
S-2	0.94	0.95	0.97	0.98	0.05
S-3	0.56	0.75	0.83	0.23	0.05
S-4	0.04	0.01	0.01	0.05	0.05
S-5	0.08	0.53	0.33	0.1	0.05
S-6	0.42	0.01	0.01	0.11	0.05
S-7	0.45	0.52	0.24	0.2	0.05

Note: VP-1 Hydrotailing collector; VP-2 Topolnica River, under the bridge on the Radovis-Stip road; S-1 Buchimski Dol under the dam; S-2 Damjan Field at the end of the Buchimski Dol; S-3 Confluence of Jasenov Dol creek into Topolnicka River; S-4 Copper leaching facility; S-5 Jasenov Dol earthen embankment (left side); S-6 Jasenov Dol earthen embankment (right side); S-7 Drinking water well.

As can be seen from data in table above it can be seen that in the majority of analyzed water samples have been determined higher concentrations than the maximally allowed conce-ntrations (MDK) for copper in class III waters, but now we have at several sampling locations values below the standard. Also, we would like to point out that decrease trend noticed in 2013 continues in 2014 meaning that measured values given in the Table 3 above were still amazingly lower than those obtained in period 2007-2010. For example values at point VP-2 were in the range 0.1 to 0.03 $mg \cdot l^{-1}$ Cu, which is a decrease in comparison to period 2007-2010 of at least 326 to 6900 times. Quite similar were improvements at sampling point S-1 with newly measured 0.01 to 0.03 $mg \cdot l^{-1}$ Cu, which is at least 293 to 2300 times lower than previous, as well as at sampling point S-5/6 with newly measured 0.01 to 0.53 $mg \cdot l^{-1}$ Cu, which is at least 31 to 1039 times lower than previous. Also, previously noticed correlation (2013) that there is a correlation between the measuring points and obtained copper concentrations in different periods of 2014, was confirmed one again and can be seen at the diagram below (Figure 5).

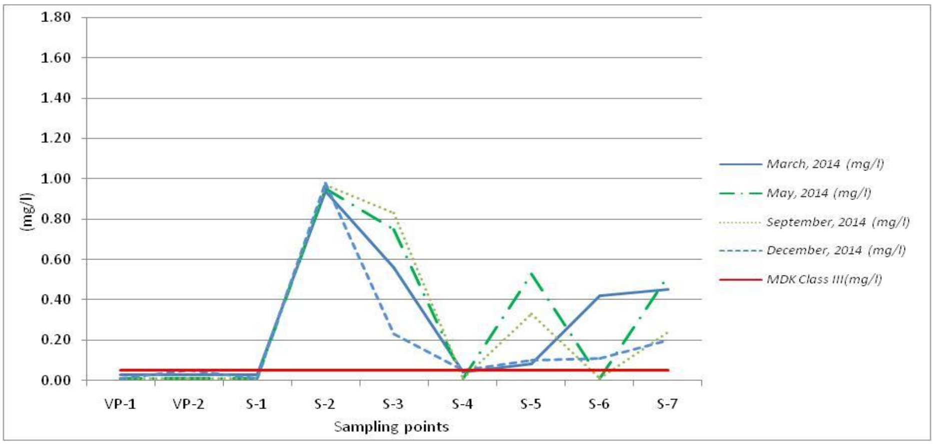


Figure 5. Diagram of copper distribution in the monitored mine drainage system waters around the Buchim copper mine throughout 2014

Namely, there is continuous decrease of values in 2014 compared to those of 2013 while at neither sampling point values haven't been higher than 1 $mg \cdot l^{-1}$ Cu (compared to max. 1.60 1 $mg \cdot l^{-1}$ Cu in 2013), which it must certainly be welcomed in terms of environmental protection and the correct direction of development specified by the management of the Buchim Mine. These results and continuous trend of decrease of values of environmentally concerning copper initiated further monitoring in 2015 at several locations (piezometers S1-S7, Table 4 and Figure 6, and ground VI-1 to VI-3 and surface waters VP-1 to VP-6, plus those at Pilav Tepe locality, Table 5 and Figure 7) around the Buchim Mine's drainage area.

Table 4. Mointoring of Cu concentrations in piezometers around the Buchim Mine, 2015

	July, 2015 (mg/l)	**pH**	**MDK Class III (mg/l)**
S-1	0.10	6.47	0.05
S-2	0.38	4.51	0.05
S-3	0.25	6.02	0.05
S-4	0.10	6.86	0.05
S-5	0.28	6.46	0.05
S-6	0.10	6.88	0.05
S-7	0.18	4.91	0.05

Note: S-1 Buchimski Dol under the dam; S-2 Damjan Field at the end of the Buchimski Dol; S-3 Confluence of Jasenov Dol creek into Topolnicka River; S-4 Copper leaching facility; S-5 Jasenov Dol earthen embankment (left side); S-6 Jasenov Dol earthen embankment (right side); S-7 Drinking water well.

As can be seen from the plot below (Figure 6), there is significant trend of decreased copper values in piezometers during 2015 (see double stacked line) in comparison to values measured in 2014. Also, this trend shows steady approximation to standard values od the MDK class III.

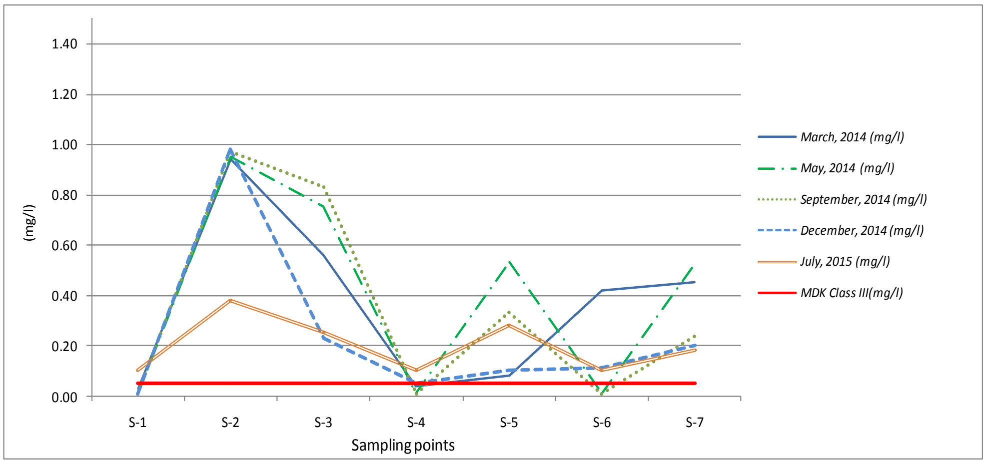


Figure 6. Diagram of copper distribution in the monitored mine drainage system waters (only piezometers) around the Buchim copper mine throughout 2014 and 2015

Further, as we already mentioned, we initiated ground and surface waters analysis along the Kriva Lakavica River draining system (Table 5), where before the establishment of the copper leaching facility was determined significant deteoration in regards to water quality and copper concentrations.

Table 5. Monitoring of Cu concentrations in ground and surface water along Kriva Lakavica, 2015.

	July, 2015 (mg/l)	October, 2015 (mg/l)	MDK Class III (mg/l)
VP-1	0.032	0.027	0.05
VP-3	0.021	0.035	0.05
VP-4	0.012	0.027	0.05
VP-5	0.017	0.016	0.05
VP-6	0.017	0.022	0.05
VI-1	0.050	0.022	0.05
VI-2	0.011	0.032	0.05
VI-3	0.033	0.015	0.05
Pilav Tepe	0.021	0.043	0.05

Note: VP-1 20th km bridge-road to Negotino; VP-2 Separation Kriva Lakavica River; VP-3 Kriva Lakavica River at Lakavica village; VP-4 Side road before the beginning of the new road (near Lakavica village; VP-5 Lake at Kriva Lakavica; VP-6 Under the bridge near the prison; VI-1 20th km well close to the tile production facility; VI-2 Separation well; VI-3 Water pump Lakavica village.

As can be seen from the table above and plot below (Figure 7), there is continuous decreasing of copper concentrations in measured medias and which more important everywhere they were below the standard values of MDK class III.

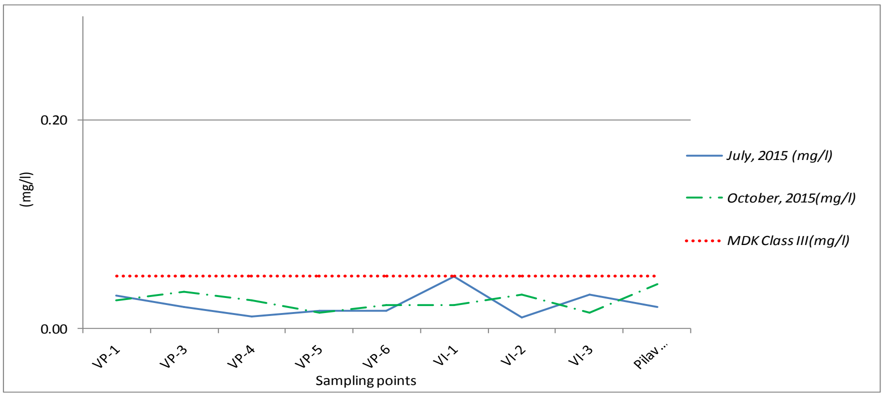


Figure 7. Diagram of copper distribution in the monitored mine drainage system waters (only piezometers) around the Buchim copper mine throughout 2014 and 2015

CONCLUSION

Several pollution hot-spots have been determined in the drainage system around the Buchim copper mine, which manifested pronounced acidic character of mine waters (pH 3.6-5.5) and increased copper concentrations of up to 800 mg/l Cu. After the leaching facility and closed circuit water system were built the influence of pollutants to surface and ground waters dramatically changed in period of few years, which has been confirmed by latest monitoring in 2013, 2014 and 2015. From the review of the monitoring of ground and surface waters, around the Buchim mine for the aforementioned period, it can be concluded that copper concentration at studied sampling points showed continuity of measured values that are slightly higher, but does not drastically differ from the MDK standards and steadily are decreasing over the time since the construction of the copper leaching facility at the Buchim Mine and its closed water circuit.

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