Physicochemical quality of surface water: background study prior of the Milky river sub-basin, Abitibi, Canada.

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Abstract

In spite of its economic benefits, the mining industry can have many negative impacts on the environment, more specifically, on surface water quality. The evaluation of the impact of the mining activity must therefore be addressed adequately with a background study prior to mining operation areas. Thirteen active and past producing mines are located inside the sub-basin of the Milky. These mining sites may contribute to the water mineralization of the surface waters and sediments of the Milky river system. In the present study, nine metals including As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were measured at thirty (30) surface water locations during two years in the catchment area of the Milky river. The data collected served to calculate the Metal pollution index (MPI) and the Metal index (MI) to evaluate the surface water quality. The MI values suggest that all the samples are contaminated, while only some of the samples are considered contaminated according to the MPI values. However, it is impossible to discriminate the origin of this contamination between the natural enriched geochemical background of this sub-basin and the anthropic activities. This discrepancy between the two pollution evaluation methods demonstrate that their interpretation needs to be adapted to the context of mining districts that have both a high natural geochemical background and are affected by past and present mining activities.

Keywords: Surface water, Metals, Metal pollution index, Metal index.

1 Introduction

In this study, we shall consider as metals arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn). Seven of these metals such As, Cd, Cr, Cu, Ni, Pb, and Zn are considered toxic for human health and are seen as a major environmental problem [1]. Following the oxidation of sulphides, the leachate is acidified, therefore solubilizing metals [15, 2, 7]. Subsequently, toxic acidic water contaminated with metals negatively impacts aquatic environments [17]. In Quebec, surface water is evaluated according to the *Quality criteria of surface water in Quebec* [12] in view of the protection of aquatic organisms as well as human.

2 Materials and Methods

2.1 Description of the study area

The study area is in the Canadian Shield which consists of volcanic rocks of the precambrian era, more specifically within the Superior geologic province (2.5 - 4 MA), in the geologic sub province of Abitibi. The sub-province has the vastest area of Archean volcano-sedimentary rocks in the world and is known for its of gold, silver, copper, and zinc deposits [13, 21]. The study area is located inside the sub-basin of the Milky river. Thirteen active and past producing gold mines are located inside this sub-basin: Canadian Malartic, Goldex, Kiena, Camflo, Midway, East Malartic, Kierens, Malartic Goldfields, Malartic Hygrade, Marban, Norlartic, Siscoe, and Sullivan lie within a 15 kilometer radius. Two main river systems are present within the Milky sub-basin: the Kierens river in the north and the Piché river in the south. These two streams cross the study area from west to east. The Vassan and De Montigny lakes are the two biggest lakes in the north and south of the area, respectively (Fig. 1). The present study was initiated in order to evaluate the level of metallic concentrations of the surface waters within the milky river sub-basin.

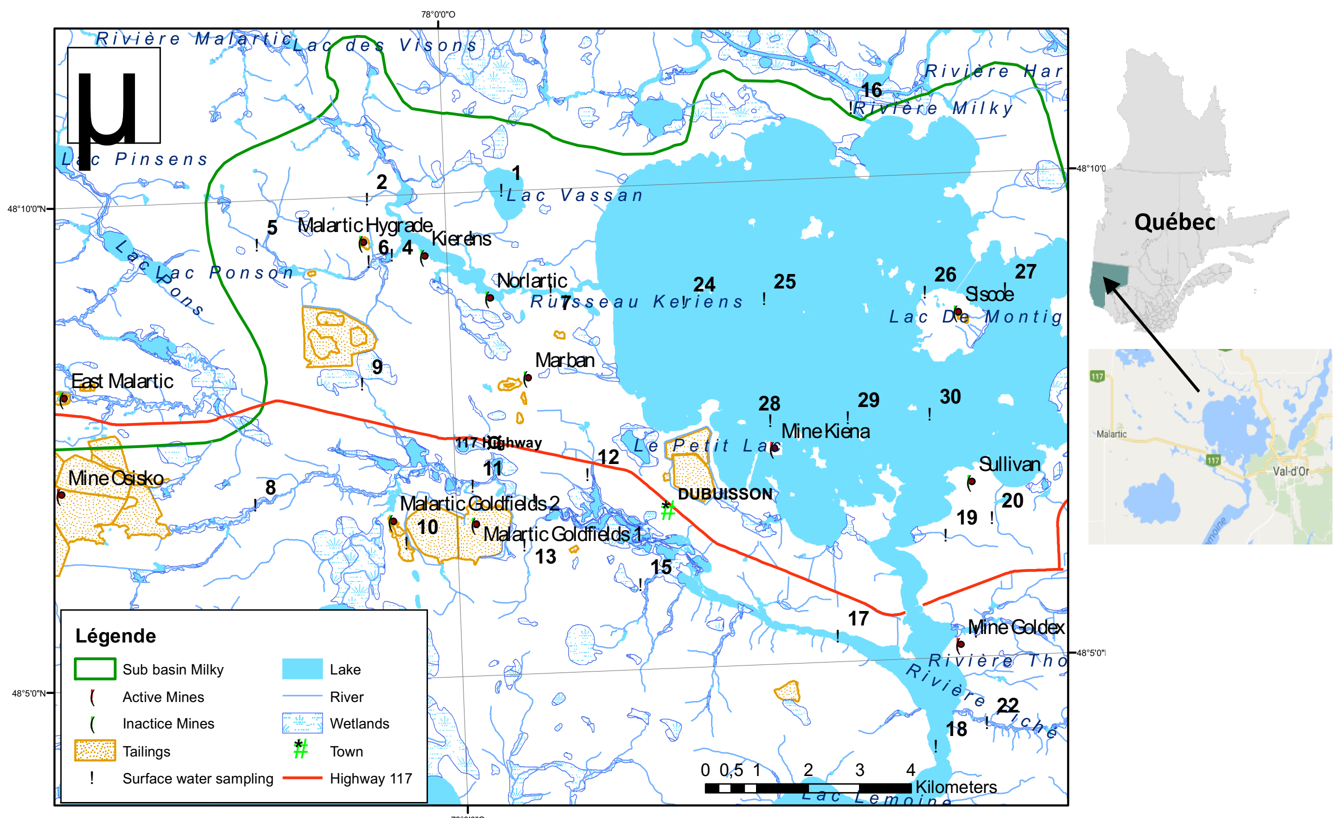

Fig. 1 Surface water sampling locations in the sub-basin of the Milky river

2.2 Laboratory analysis

Thirty (30) surface water samples were collected inside the sub-basin of the Milky River (see Fig.1) and placed into polyethylene bottles (250 ml) preserved by adjusting pH < 2 with 6N ultra-pure nitric acid (HNO_3) [20]. These samples were kept at 4°C in ice-boxes and transported to the laboratory. The analysis of As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn was done using ICP-MS (Inductively Coupled Plasma Mass Spectrometry) in an accredited laboratory.

2.3 Assessment of metallic pollution

In order to estimate the surface water quality within the Milky river sub-basin, two metallic pollution indexes of surface waters were used. These two indexes are described in the following sections.

2.3.1 Metal Pollution Index (MPI)

The Metal pollution index (MPI) is a rating technique that provides the composite influence of individual metals on the global quality of water [14]. The MPI calculation method has been widely used [e.g., 4, 8, 19]. The critical MPI value for drinking water, as given by [16], is 100. Five classes of water qualities have been used to rate them as excellent, good, poor, very poor, and unfit for MPI values respectively between 0-25, 26-50, 51-75, 76-100 and > 100 [5].

The MPI calculation [14] is given by Eq. (1) :

$$\mathrm{MPI} = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \qquad (1)$$

where Q_i is the sub quality index of the i^{th} parameter, W_i is the unit weightage of the i^{th} parameter, and n is the number of parameters considered. The sub quality index (Q_i) of the i^{th} parameter is calculated by Eq. (2) :

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i(-)I_i\}}{(S_i - I_i)}\ x\ 100 \qquad (2)$$

Where M_i is the measured value of metal of i^{th} parameter, I_i is the ideal value (maximum desirable value for drinking water) of the i^{th} parameter, and S_i is the standard value (highest permissible value for drinking water) of the i^{th} parameter. The sign (-) indicates numerical difference of the two values, not algebric difference. W_i is considered as a value inversely proportional to the highest permissible value for drinking water (S_i) of the corresponding parameter.

In this study, the standard value (S_i) and the ideal value (I_i) for drinking water relative to the considered element derive from the Canadian Council of Ministers of Environment [3] for the protection of the aquatic life.

2.3.2 Metal Index (MI)

The Metal Index (MI) is based on the composite influence of individual metals on the global quality of water [18]. This evaluation method of the drinking water quality addresses the effects of metals on human health. The MPI [18] is calculated according to Eq. (3) :

$$\mathrm{MI} = \sum_{i=1}^{n} \frac{C_i}{(MAC)_i} \qquad (3)$$

where C_i is the concentration of each element and $(MAC)_i$ si the maximum allowable concentration for i. Six classes of water quality have been used to rate as very pure, pure, slightly affected, moderately affected, strongly affected, and seriously affected for MI values of repectively < 0.3, 0.3-1.0, 1.0-2.0, 2.0-4.0, 4.0-6.0 and > 6.0 [10].

3 Results and discussions

3.1 Results of chemical analysis

The mean values, standard values, and ranges of the results of metal analyses are provided in table 1 for the surface water samples. The As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn concentrations were compared with the WHO drinking water standards [6] and the guidelines of the Canadian Council of Ministers of Environment for the protection of the aquatic life [3].

The concentrations of metals were in the ranges of 0-16.7 for Arsenic, 0-1.5 for Cadmium, 0-44.85 for Chromium, 0-41.7, 75-32000 for copper, 10.65-1580.7 for iron, 0.25-33.40 for manganese, 0-35.3 for nickel and 0-165 µg/l for zinc (Table 1). The Cr, Cu, Fe, Mn, Pb, and Zn concentrations exceeded the permissible limits of respectively 20, 4, 300, 50, 7, and 50 µg/l for the protection of aquatic life in Canada [3]. The Cu, Fe, Mn, and Zn mean and maximum concentrations were above the desirable limits [11] and [6] of drinking water.

Table 1 Summary statistics of metal concentrations (µg/l) compared to WHO, MAC and CCME

Metals	*As*	*Cd*	*Cr*	*Cu*	*Fe*	*Mn*	*Ni*	*Pb*	*Zn*
Minimum	0	0	0	0	75	10.65	0.25	0	0
Maximum	16.70	1.50	44.85	41.7	32000	1580.7	33.40	35.3	165
Mean	1.19	0.13	3.33	7.66	4550.3	208.01	7.26	5.11	23.97
Median	0.4	0	1.1	4.4	1200	85.78	3.98	1.3	11.23
Permissible Value (S_i) (CCME, 2007)	50	1.8	20	4	300	50	150	7	50
Highest desirable value (I_i) (CCME, 2007)	-	0.2	2	-	-	-	25	1	-
MAC (2006)	10	5	50	1000	300	50	20	10	5000
WHO (2011)	50	3	10	2000	300	100	70	10	500

3.2 Evaluation of indexes

The As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn mean concentrations were used to calculate the MPI and the MI. The results are provided in table 2.

The MPI value of each of the 30 sampling sites (Table 2) ranged between 9.7 and 258.5 with an average of 70, while the maximum MPI value is illustrated by the error bars (Fig. 2). The MPI values of the 30 sites showed a different degree of pollution on surface water samples. The sites 22 and 23 showed excellent quality (0-25). The sites 1, 3, 11, 13, 15, 16, 21, 24, 25, 26, 27, 28, and 29 showed good quality (26-50). The sites 5, 10, 17, and 30 showed poor quality (51-75). Finally, the sites 2, 7, and 14 showed very poor quality (76-100), while the sites 4, 6, 8, 9, 12, 19 and 20 exhibit unfit quality (MPI>100). These results suggest that the surface waters of the study area are contaminaed. The contamination source could either be explained by the naturally high geochemical backgound or the past mining activities within the Milky river sub-basin.

The Metal index is the second index used to evaluate the metallic pollution of surface waters in the present study. The MI value of the thirty (30) sampling sites were ranged between 1.5 and 140.5 with an average of 20.43. The maximum MI value is illustrated by the error bars (Fig. 2). The MI values of the 30 sites showed different degrees of pollution in the surface water samples. The sites 1 and 23 showed slight effects, while the sites 18 and 22 showed moderate effects. The sites 3, 7, 24, 25, 26, 27, 28, 29, and 30 showed strong effects. Finally, the sites 4, 5, 6, 8, 9, 7, 11, 12, 13, 14, 15, 17, 19, 20, and 21 exhibited serious effects. The different degrees of pollution from slight to serious is caused by individual metal concentrations. These MI values under 1 suggest metallic pollution, which can be due to the presence of Fe and Mn in surface waters with concentrations exceeding the acceptable limits [11].

Table 2 Calculation of MPI and MI values with mean concentration of metals in surface waters

Sites	MPI	MI	Sites	MPI	MI	Sites	MPI	MI
1	34.83	1.52	11	46.60	8.15	**21**	35.47	17.16
2	77.97	36.70	12	142.75	60.13	**22**	10.77	2.82
3	41.41	5.89	13	27.85	10.63	**23**	9.68	1.83
4	150.48	6.44	14	99.25	11.42	**24**	39.56	5.63
5	55.49	30.20	15	36.54	17.86	**25**	36.79	5.18
6	123.83	6.45	**16**	36.72	4.75	**26**	37.96	5.34
7	92.98	5.38	**17**	60.14	10.35	**27**	37.68	4.50
8	258.48	8.62	**18**	25.15	2.15	**28**	37.60	5.43
9	160.56	140.50	**19**	193.38	114.01	**29**	38.10	5.75
10	71.79	1.84	**20**	256.03	70.70	**30**	54.56	5.44

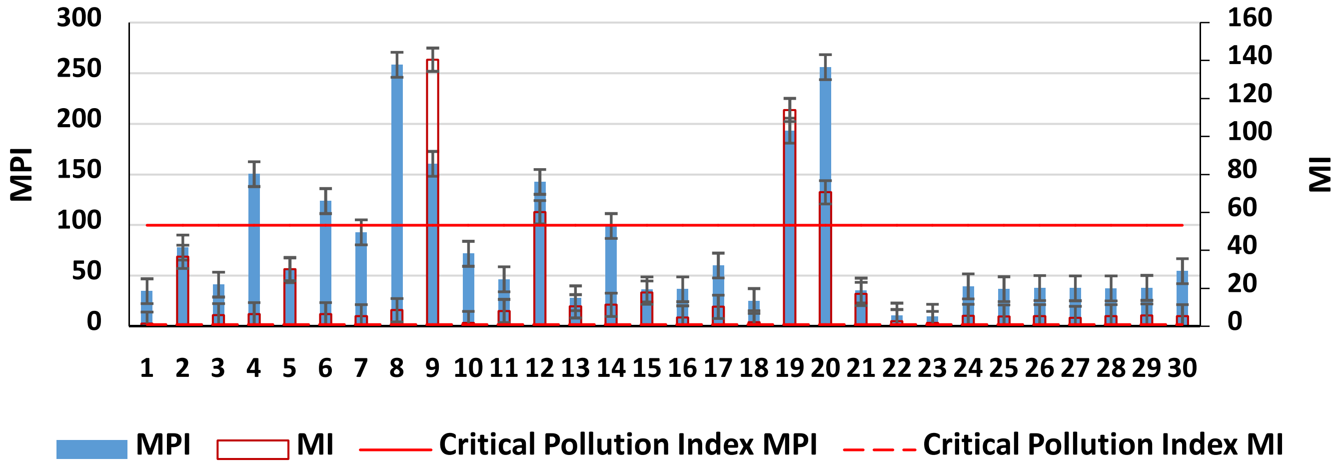

Fig. 2 MPI and MI values for the sampled surface water (error bars represent maximum values)

4 Conclusion

The quality of surface waters within the Milky river sub-basin has been evaluated using the Metal pollution (MPI) index and the Metal index (MI). Thirty (30) surface water samples were collected and the concentrations of As, Cd, Cu, Cr, Fe, Mn, Ni, Pb, and Zn were measured. Seven sites showed MPI values over the critical pollution index (100), while all sites showed MI values above the critical pollution index (1). Surface water samples collected from the sites 4, 6, 8, 9, 12, 19, and 20 were found to be highly polluted and unfit using the MI and MPI indexes. These high MPI and MI values can be attributed to either the naturally high geochemical backgound or the past mining activities within the Milky river sub-basin. These results show that the background metallic levels have to be taken into account before starting new mining operations in order to accurately measure their potential environmental impact on the quality of surface waters.

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