Assessment of heavy metal concentrations in streams and economic effects in Haut-Katanga province of the Democratic Republic of Congo

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《**Abstract**》

The Central African Copper belt located in Zambia and the Democratic Republic of Congo constitutes one of the important copper and cobalt deposits in the world. In Haut-Katanga, mining companies discharge into streams both solid and liquid wastes from their industrial plants that pollute the soil and water of streams. The paper analyzes water as samples collected from streams around the cities of Lubumbashi, Likasi, and Kafubu in August and September 2012. This paper aims to assess the concentration of heavy metals in streams of Haut-Katanga. The concentration levels of six metals including copper, cobalt, iron, cadmium, and manganese were assessed by the Inductivity Coupled Plasma Mass Atomic Emission Spectrometry (ICP-AES). The results show that the mean concentrations of Mn, Co, Cu, Zn, Fe, Ni, Cd, As, Pb and Cr were 19106.31, 9935.75, 4353.86, 501.64, 33.79, 33.46, 11.41, 3.24, 0.36, and 0.11μg/L, respectively. High concentration of cadmium in the Buluo stream and Kafubu stream were 79.1 μg/L and 0.2 μg/L respectively. The polluted water of streams and rivers poses a threat to human health, fish and wildlife that depend on it for drinking and farming. The contaminated water may

increase the cost of medical treatment as well as reducing economic income for people living around the mining area.

Keywords: Heavy metals, environmental pollution, Katanga, economic effect

1. Introduction

The supply of both drinking water for workers and plenty of water for metallurgical purposes has played an important role in the mining industry (Rickard 1932). Many industrial sites are constructed near the streams[1)] and rivers. Also, the flotation technique for metal processing, as a preliminary treatment after crashing and washing the ores, requires many tons of water to settle the heavier valuable particles away from the light and poorer material before the concentration process (Moil 1904). The basic problems connected with man's use of water rise from sharp upward trends in the needed quantity and in demands for water for both industry and irrigation (Shelton and Shelton 1966).

The effects of global warning and climate change have increased the scarcity of the fresh water that policymakers deal with to achieve sustainable economic growth. Expansion of the metals output should be planned by innovating the production process while protecting the environment around the industrial sites. The twenty-first century has begun with a widespread imbalance between demand and supply of a good quality water around the world, leading some countries to develop new technology, to import, and to build long-distance facilities for water supply

1) A stream is a flow that may be as small as a brook or as large as a river. Many streams have their sources in mountains.

(Ashton and Haasbroek 2002). Previous research shows the evidence that people recognize that the world's fresh water supply represents a scarce and vital resource that is also extremely vulnerable to human activities (Biswas 1993). Indeed, since water cannot be substituted, neither biological diversity nor social and economic development can be achieved in its absence (Priscoli 1998).

The Haut-Katanga[2)] province is well known for its copper and cobalt reserves. During the early 2000s, a boom of mining projects in Katanga brought again hope for a better future to Congolese people. This study tries to answer the following research questions: What are the concentrations of heavy metals and metalloid in water of streams? What is the economic effect of pollution? The copper industry is the most important sector for economic growth of the region.

1.1 Background of copper industry

At the early phase of extraction in the mining industry, managers tend to focus on addressing profit maximization than preserving the environment. Environmental pollution is an important issue to integrate into mining projects for economic development of the Haut-Katanga province of DR Congo. This country plays an important role in the world market as a supplier of strategic metals such as cobalt, industrial diamond, Colombo-tantalite, oil, and copper (Saquet 2000). However, this country has a low growth rate of gross domestic product (GDP), high poverty rate, and inequality (Noble 1994). The historical analysis shows that the availability of mineral resources itself does not always assure economic development.

The output recovery of copper and cobalt observed from the fiscal year

2) Katanga province was divided into four new provinces including Haut-Katanga, Lualaba, Haut-Lomami, and Tanganyika.

2006 in the copper industry in Haut-Katanga province has increased environmental degradation around the production sites. The mining activity has considerably altered the quality of the environment, to such level that to live becomes a permanent concern (Reeve 2002). Mining industry generates huge quantities of tailings, acid mine drainage, solid and liquid wastes that pollute the soil, the air, and water around the mining sites (Eggert 1994). Once these contaminants are discharged into nature, they constitute a threat to human health, fish, and wildlife.

The Central African Copper belt located in Zambia and the DR Congo constitutes one of the important copper deposits in the world (Mikesell 1979). Since the colonial era, the Haut-Katanga province has been producing metals such as copper, cobalt, zinc, uranium, iron, and manganese (Kalenga 2014). In the 1980s, DR Congo produced about 6% and 40% of the world's total output of copper and cobalt respectively (Prasad 1989). These mining companies built many open pits and underground mines on vast concessions to extract ores (Mulumba 1974). In addition, the companies have built concentrators, smelters, and hydrometallurgical plants around the mines to produce metals. Ntengwe found that industrial wastes from extraction and processing activities constitute a source of environmental pollution in the copper belt region (Ntengwe 2006). For decades, mining companies in Haut-Katanga did not pay much attention to the environmental impact of their activities. Since 1992, the World Bank and the International Monetary Fund required that all Congolese mining companies willing to borrow from these institutions should implement environmental protection measures (Kalenga 2013b). From that period, mining companies began to implement policies that reduce pollution and degradation of the environment.

The mining policy of 2002 required the companies to integrate environmental protection at all stages of mining projects. The expected outcome of this policy was to ensure that workers on site and population around mining plants work and live in a clean environment. This policy also defines the standards for assessing the contaminants due to mining activities into the air, the sediment, and the water (Congo 2003). Heavy metals occur naturally in the earth's crust at a low level of concentration (Loka Bharathi, Sathe, and Chandramohan 1990). Their quantity into the environment is increased by human activities through the extraction and processing of these metals. Sakata found that the mining activities were the main source of pollution of rivers around the industrial plants in Katanga (Sakata 2009). Furthermore, Weghe et al. estimated that the concentration level of heavy metals was above two to ten folds the international standard in two rivers of Katanga (Weghe et al. 2006). Banza et al. found that in people living around the Kafubu Kolwezi area had a higher concentration of cobalt in urine (Banza et al. 2009).

This paper tries to follow up the trend of pollution due to the high concentration level of heavy metals into five rivers around the cities of Likasi, Lubumbashi, and Kafubu. From the colonial era, the mining sector has constituted the cornerstone of Congolese wealth. The mining industry has been the most important source of foreign exchange and government budgetary support. In the late 1980s, DR Congo was the world's largest producer of cobalt, the third largest producer of industrial diamonds, and the fifth largest producer of copper (Smith 1994). In terms of quantity of copper output, Gecamines takes the leading position as a government-owned enterprise founded after the independence in 1967 to replace the former colonial company, the Union Miniere du Haut-Katanga[3).

3) Union- Minière du Haut-Katanga was the Belgian company created in 1906 by Leopold II to extract and process metals in Katanga.

Gecamines[4] has been producing about 90 percent of the country's copper and total output of cobalt, zinc, and coal. The second enterprise was the Sodimico[5] that processed the remainder, about 10 percent of copper output.

From the fiscal year 2006, the copper industry was recovering in Haut-Katanga. The output of cobalt and copper accounted for 108,888 tons and 522,133 tons respectively in the fiscal year 2011 (Congo 20 Janvier 2012). During this period of recovery, some cases of toxicity and pollution have been reported in the mining industry. The paper assesses the environmental policy that sets the thresholds of concentration levels that the operating companies should apply to avoid toxicological harm around the mining sites then followed by the economic effects of stream pollution.

2. Materials and Method

This paper assessed the concentrations of heavy metals and metalloid in samples of water as the principal material for investigation and their economic effects on provincial community. For environmental pollution, samples of water were collected during the field research from streams of Kafubu, Lubumbashi, Buluo, and Kimpulande stream from Likasi to run experiments in the laboratory. These samples were collected within the week of September 12 to September 17, 2012 in three cities of Kipushi, Lubumbashi, and Likasi of Haut-Katanga province. These cities are the centers of the copper industry in Haut-Katanga. Two inspectors from the

4) La Générale des Carrières et des Mines (Gecamines) is the government owned company created in 1967 after the nationalization of the Union Minière du Haut-Katanga.

5) La Société de Développement Industriel et Minier du Congo (Sodimico) is the government owned company originally created as joint company with Japanese consortium in 1969. It was renamed as Sodimiza under the Mobutu regime of Zaire.

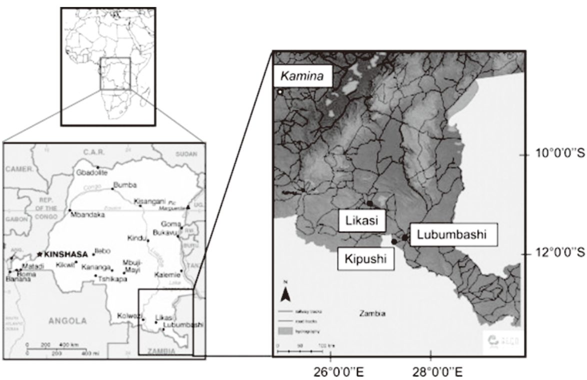
Provincial Division of Ministry of Environment participated in the sampling process in Kipushi, Likasi, and Lubumbashi. These samples of water were assessed at the Laboratory of Toxicology by the Inductivity Coupled Plasma Mass Atomic Emission Spectrometry (ICP-AES).

2.1 Sampling points and process

The points of sampling were randomly chosen in Haut-Katanga province, especially in the cities of Likasi, Kipushi, and Lubumbashi. These three locations constitute the centers of mines and processing plants to produce metals. Figure 1 shows the study area where points of sampling of water were conducted.

The climate in Haut-Katanga is characterized by two principal seasons: a rainy season from November to April, and a dry season from May to October. Total precipitation in the Haut-Katanga province is about 1,546.8 mm and falls mostly in the rainy season (Mukena 2004). Therefore, the discharge in streams and rivers is highly variable, with a large difference

Figure 1 Map of study area and sampling points in Katanga



Source: Banza et al., 2009. "High human exposure to cobalt and other metals in Katanga, a mining area of the Democratic Republic of Congo." Environmental Research no. 109 (6):747.

between the rainy and dry season. The sampling was conducted in August and September 2012 during the dry season. This period corresponds to the worst scenario due to seasonal rainfalls. The quantity of water discharged into the river diminishes in dry season than in the rainy season and the effect of dilution does not affect significantly the concentration of heavy metals discharged into streams and rivers.

In Haut-Katanga province, Lubumbashi (S11^{0}35'20.7"; EO 27^{0}28'33.3") has been the center of copper processing since the colonial era (D'Ydewalle 1960). Mining companies constructed industrial plants to process copper ore from mines. Tailings from these plants are huge in Lubumbashi city. Near Lubumbashi, the oldest underground mine of Kipushi is the most significant Zn-(Cu)-Pb carbonate-hosted deposits in the central African Copper belt (Kampunzu et al. 2009). The Likasi city (S10^{0}59'42.4"; EO 26^{0}46'36.8") constitutes the central part of the copper belt concession for copper extraction and processing (Katanga 1957). Kolwezi city located in the western area of the concession has the largest reserves of copper and cobalt. Kolwezi produces about 75% of total copper and cobalt output.

2.2 Determination of heavy metals

The water samples were analyzed to assess the concentration of heavy metals using Inductivity Coupled Plasma Mass Atomic Emission Spectrometry (ICP-AES) at the laboratory of veterinary medicine of Hokkaido University in Japan.

3. Result of metal concentrations and industrial output

The results of the analysis show that the concentrations of cadmium, cobalt, manganese, copper, iron, arsenic, lead, chromium, nitrogen, and

Table 1 Concentrations of heavy metals and metalloid in streams in microgram / liter

Metal Sample sites	Mn Conc. [ppb]	Co Conc. [ppb]	Cu Conc. [ppb]	Fe Conc. [ppb]	Cd Conc. [ppb]	Zn Conc. [ppb]	As Conc. [ppb]	Cr Conc. [ppb]	Ni Conc. [ppb]	Pb Conc. [ppb]
P_1	60748.2	86264.6	57127.1	1.8	79.1	5464.7	5.3	0.0	328.8	2.5
P_2	41278.1	6386.2	1227.7	1.3	27.9	360.7	4.4	0.1	23.4	0.8
P_3	9351.0	3358.3	470.6	2.1	3.0	58.2	6.2	0.1	12.4	0.2
P_4	57690.6	11204.6	1606.5	6.5	24.7	397.6	5.0	0.1	48.6	0.7
P_5	6.7	5.1	17.3	3.6	0.0	2.3	0.6	0.0	1.0	0.0
P_6	2781.3	531.4	152.3	31.1	1.2	109.2	9.1	0.3	5.6	0.3
P_7	94260.5	31049.4	89.7	2.5	0.2	11.8	2.8	0.4	35.4	0.0
P_8	10.1	7.5	11.5	3.3	0.0	0.9	1.0	0.3	2.4	<0.000
P_9	121.1	32.9	186.6	65.1	16.6	207.3	2.3	0.1	6.3	0.4
P_{10}	1.0	0.3	1.8	2.6	0.0	1.5	0.6	0.0	0.8	<0.000
P_{11}	4.2	4.2	27.9	2.2	6.3	138.3	2.6	0.0	1.2	0.1
P_{12}	2.3	0.3	4.3	333.4	0.0	4.4	2.4	0.2	0.5	0.0
P_{13}	1144.0	138.6	3.2	16.6	0.0	42.1	0.8	0.0	1.0	<0.000
P_{14}	89.2	117.1	27.5	1.0	0.8	223.9	2.2	0.0	1.1	0.0

Source: Author's collation from data of laboratory analysis.

zinc were higher. The concentrations of metals and metalloid due to industrial wastes constitute the main source of rivers and stream pollution in Haut-Katanga. Table 1 shows the concentration level of metals and metalloid in streams and rivers of Haut-Katanga.

Table 1 shows that concentration of copper, cobalt and manganese is higher than the thresholds set in mining policy at 1.5 μg/l for Cu, 1 μg/l for Co, and 1 μg/l for Mn respectively. The concentrations of heavy metals reveal a threat of diseases and contaminations for people and other species living around these mining sites. The exposition to cadmium and copper above the curve standard at sampling points with coding as P_1, P_2, P_3, P_4, P_6, P_9, and P_{11} may contaminate people and kill other aquatic species that consume water from the streams.

The Congolese threshold standards for heavy metals at discharge points are set as follows (Congo 2003): Cu: 1.5 mg/l; Fe: 6 mg/l; Pb: 0.5 mg/l; Zn: 10 mg/l. Since the levels of Cd, Co, and Mn are not defined in this policy, the international standards will be referred to for these metals. The results of Mn, Cu, Co, and Cd exceed the recommended thresholds constitute a great danger for the community living around the mining sites. The results of copper and manganese are higher than the Congolese threshold standards at all fourteen sampling points. The levels of cadmium are extremely higher at points P_1, P_2, P_4, P_9, and P_{11}, which exceed the World Health Organization (OMS) 2006 known as the international standards for the year 2006 of 0.003 mg/l. The Kafubu stream shows the highest levels of Zinc and cadmium. Table 2 shows the mean values of concentrations of metals in streams.

The metals may cause cancer disease to human and poisoning for aquatic species. They constitute an imminent threat to people and the other living species that consume water from the Buluo stream. There is a similarity of cobalt concentration in Kafubu stream and Lubumbashi stream with that Mees has found for Kipushi and Likasi areas (Mees et al.). The liquid waste from washing, concentrators, and hydrometallurgical plants are discharged into streams and rivers without retreatment. These contaminants pollute the environment, streams, and rivers. They present a threat of toxicity to aquatic species around the discharge points. These soluble pollutants and toxic are destroying aquatic habitats at significant distances downstream of

Table 2 Mean concentration of heavy metals and metalloid in streams in Haut-Katanga

stats	Mn	Co	Cu	Fe	Cd	Zn	As	Cr	Ni	Pb
mean	19106.31	9935.75	4353.86	33.79	11.41	501.64	3.24	0.11	33.46	0.36
sd	31124.15	23536.39	15197.41	88.03	21.75	1434.67	2.48	0.14	86.30	0.67
kurtosis	3.39	9.24	12.05	11.13	7.86	11.87	3.17	2.52	11.37	8.57
skewness	1.35	2.73	3.32	3.11	2.37	3.28	0.93	0.90	3.16	2.52
max	94260.5	86264.6	57127.1	333.4	79.1	5464.7	9.1	0.4	328.8	2.5
min	1	0.3	1.8	1	0	0.9	0.6	0	0.5	0
N	14	14	14	4	14	14	14	14	14	14

Source: Author's collation from data of laboratory analysis.

streams. The dilution effect may take effect as far as one moves away from mining centers at long distances to more than 200 kilometers, especially when these streams pour into large rivers. During the field research, some companies showed their awareness about environmental degradation due to mining activities.

The Kimpulande stream is heavily polluted by four metals including copper, cobalt, cadmium and manganese, and this pollution may be related to the proximity of the latter stream to the point of discharge of the Shituru Plant. The effect of dilution of heavy metals into the river may not occur because this stream has short distance up to the point of confluence with Buluo stream. The Lubumbashi stream depicts a higher concentration of manganese, copper, cobalt and cadmium. Many industrial wastes from processing plants are discharged in the Lubumbashi stream at different points along the course of water. Fishermen who live along the stream in slum consume on a daily basis this contaminated water to sustain their daily lives. The Lubumbashi stream constitutes an affluent to Kafubu stream, where higher levels of cadmium, cobalt and copper were detected.

4. Discussion of concentration of metals and economic effect

The objectives of this paper were to determine the concentration levels of heavy metals in streams around the mining sites in Haut-Katanga province of the DR Congo and the economic effects. The main findings show that the concentration of Cd, Co, Cu, and Mn was higher in the Buluo stream than other streams of Haut-Katanga. The Kafubu stream has a higher concentration of zinc in comparison to other metals.

The mining policy of March 2018 does recognize the failure of the producing companies in the mining industry to comply with the environmental protection implemented by the mining policy in 2002. Within the local communities, where these companies extract, and process minerals, the damage caused to both humans and the environment around the missing sites has a great consequence for the next generations (République 2018).

The issue of whether there is any opposition between economics and environmentalism needs to be addressed. Unfortunately, the relationship between these two fields is not obvious. In practice, a mining company that produces metals in the unregulated market will create pollution. To economists, pollution represents a situation where a third party is affected by the spillover from production and consumption decisions in which this third party is not directly associated into the original transactions of the market. Pollution is the most social example of negative externalities from industries. The dumping of industrial waste into streams in Haut-Katanga causes pollution. Both the seller and buyer of metals may be perfectly happy, but the third party would be negatively affected by contaminated water due to industrial wastes discharged into rivers.

The historical records of the Belgian Congo revealed that the general government of the colony enacted the first policy to deal with the environmental impact of mining activities in 1953. The law of 12 February 1953 required that all mining companies operating in the Belgian Congo to refrain from discharging wastes that contaminate and pollute the quality of water in streams and rivers around the mining concessions (Belge 1953). In the Belgian Congo, the general government appointed a representative-officer to supervise the activities of mining companies to avoid environmental pollution. In 1974, the government of Zaire transferred the supervisory role to the Zairian Office of Control agency. During this period, the copper producing companies in Haut-Katanga had paid less attention to the environmental protection before the early 1990s.

Although the environmental policy sets the standards for heavy metals to be discharged in the nature, in practice some industrial wastes contained metals that exceeded those thresholds thus polluting the environment.

The results of this paper converge with the preceding study that analyzed the case of Kafubu stream in 2011 (Kalenga 2013a). The situation of environmental protection has not yet been improved to avoid the contamination of water and soil around the mining sites. Heavy metals discharged in the streams near the industrial plants constitute a source of contamination of the streams around these processing plants.

A good quality water is one of the resources that the living species need to sustain their lives. For humankind, the paradox of value shows clearly that the value in use of water is enormous leading to higher total utility because of the huge quantity consumed. The value in exchange or price of water is low, making also its marginal utility low due to the fact that water is naturally an abundant resource (Parkin and Bade 1987). Although the price of water is low, it is impossible to think about life without a good quality water for consumption. But diamond, which is a rare metal, has low value in use because it is bought in small quantity and has a high marginal utility and high value in exchange even though it is not an absolute necessity for life in comparison with water.

In Kafubu stream, the concentration level of Zn at 27 μg/l exceeds 9 folds the international recommended standard of 3 μg/l. This result corroborates with the quantity reported on Weghe's findings (Weghe et al. 2006). The Cd is 0.31 μg/l; Cu is 0.001 μg/l; Co stands at 0.84 μg/l; Fe is 0.001 μg/l and Mn is 0.965 μg/l. The Kafubu stream shows higher levels of Zinc and cadmium. These metals may cause poisoning to human and aquatic species. The pollution of the water and the air due to mining activities occurred in other places around the world. For instance, during the Japanese high economic growth in the 1960s, the industrial pollution has exposed Japanese citizens to diseases. Environmental pollution in Japan exposed people to diseases such as Minamata disease describing the organic mercury poisoning from a chemical factory in Kyushu, the Itai-Itai disease resulting in cadmium pollution in Toyama from Kamioka mine, and the Yokkaichi air pollution from a power and petrochemical plant in Yokkaichi (Yoshida 2012).

Risk assessment is a function of the hazard and exposure that is defined as the process of estimating the probability of occurrence of adverse health effects over a specified time period. The identification of the health effects is divided into carcinogen and non-carcinogenic according to type of heavy metal. The dose-response assessment estimates the amount of chemical that can be affected to human health, including Reference Dose (RfD) used for non-carcinogen risk and Slope Factor (SF) for cancer risk as shown in Table 3 below.

Table 3 The toxicity responses to heavy metals and metalloid as the oral reference dose (RfD) and oral Slope Factor (SF)

Heavy metals/metalloid	Oral RfD (mg/kg/day)	Oral SF (mg/kg/day)
Fe		
As	3.00E-04	1.5
Cd	5.00E-04	0.38
Co	2.00E-02	nd
Cr	3.00E-03	41
Cu	4.00E-03	nd
Mn	1.40E-01	nd
Ni	2.00E-02	nd
Pb	3.50E-03	nd
Zn	3.00E-01	nd

nd:notdetermined

Source: U.S. EPA. IRIS Toxicological Review of Trichloroethylene (Interagency Science Discussion Draft). U.S. Environmental Protection Agency, Washington, DC, EPA/635/R-09/011D, 2011.

Exposure assessment estimates the magnitude, frequency, and duration of human exposure to an agent in the environment.

Cancer Risk for carcinogenic effect is estimated in equation (3) as follows: Exposure X SF (3) where Exposure is ADDs (mg / kg a day) and SF is Slope Factor (per mg / kg-day). If acceptable level is 10-6, means the probability that about 1 cancer patient among 1,000,000 people happen.

Out of six metals analyzed in the Buluo stream, five metals have concentration above the standard, including copper, cobalt, manganese, cadmium and zinc. This concentration level constitutes high risk for aquatic species and humans who consume the water from this stream. Moreover, small scale farmers cultivate vegetables using water from the Buluo stream for irrigation and washing vegetables. The grown vegetables are sold in the markets of the Likasi City for consumption by humans. The vegetables may absorb the environmental contaminants which will be up taken as far as these vegetables are sold and bought by households who cook them as food for their own families or customers who have diners in restaurants. The water containing heavy metals is very harmful to human health.

Every community at the national level, especially in rural areas of Africa, tries to deal with the challenge of providing enough quantities of good quality water to meet the growing needs of its increasing population (Van Wyk 1998). The mineral resources are non-renewable resources that deplete gradually because of the extraction degree. The economic impact on local communities is aggravated by a decline of good quality water supply because of resource depletion and pollution, forcing the rural population to migrate to urban cities without any qualifications for its adaptation in the main cities (Falkenmark 1989).

Traditionally, people in the Haut-Katanga combine both the artisanal mining in the dry season with agriculture during the rainy season. The

Table 4 Comparison of metal concentration by stream with the recommendation

Metal	Buluo	Kimpulande	Lubumbashi	Kafubu	Recommendation
Mn	60748.2	41278.1	2781.3	94260.5	0.4
Co	86264.6	6386.2	531.4	31049.4	10
Cu	57127.1	1227.7	152.3	89.7	1.5
Fe	1.8	1.3	31.1	2.5	6
Cd	79.1	27.9	1.2	0.2	0.003
Zn	5464.7	360.7	109.2	11.8	3

Source: Author's collation from data of laboratory analysis

phenomenon has been observed mainly in zones with less precipitation resulting in the lack of fresh water for farm irrigation. Cultivating fewer cash crops reduces the capacity of local people to earn revenues because they produce basically for their own consumption and less for trade. The situation is correlated to the prevalence of poverty, hunger, and disease. Table 4 depicts a comparison of heavy metal concentration in water by the stream.

The concentration of heavy metals into streams may decrease the income of households and farmers who depend on water for their daily consumption and production of agricultural vegetables and crops that constitute their main source of revenue. In the country such as the DR Congo where the government policy does not distribute equitably the national wealth from the export of the metals, the government should at least protect the environment around the mine sites for those who live and depend on their small scale farms to make their living, their health care, and their incentive to improve the quality of life in their local communities.

The higher levels of heavy metals detected in the samples of water from streams may be related to mining activities in the Haut-Katanga region. Although some companies of the Katanga showed their awareness about environmental degradation due to mining activities during conduction of this study, an effective policy should be implanted to address this issue of pollution around the mining sites.

5. Conclusion

This paper demonstrates that mining projects have both positive and negative impacts on the economy, society and environment. The interaction between the government and the mining industry should lead to enact policies that balance social benefit and cost of pollution to deal with the impact of mining activities on the environment and the national economy. From the economic perspective, zero pollution is not realistic nor useful policy goal. In fact, zero pollution would mean closing most of mining plants and thus reducing most of the sources of wealth for the national economy. This situation would not be sensible in today's global economy. Moreover, pollution has both cost and benefit because it is emitted to produce other goods that people want to buy to satisfy their needs.

The concentrations of metals in streams of the Haut-Katanga show that heavy metals are contaminants that pollute the fresh water. The recovery of output was a good signal for economic growth. This sharp upward trend, however, hides environmental degradation that affects negatively the living species around the mining sites. The pollution of streams around mining plants in Haut-Katanga constitutes a threat to aquatic habitats. Aquatic species and people in the rural areas who drink the contaminated water from these streams are exposed to potential diseases. All these have social and economic effects of mining activities of other agents than the household. Further research should investigate the effects of heavy contaminants on human, wildlife, vegetables produced around mining sites in Haut-Katanga.

Water has become a strategic resource for industrial, human, and agricultural activities. Humankinds around the world need water as a necessity for life. The fact that there is not a substitute for water, it is impossible to think of a development, involving social and economic, without a stable source of supply of water to meet the demand for water by an increasing population and urbanization. Global management of fresh water should lead to a sustainable development to avoid both the pollution and disputes and conflicts that may arise in the arid regions.

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