THE PROBLEM OF HEAVY METAL POLLUTION IN THE REPUBLIC OF ARMENIA: OVERVIEW AND STRATEGIES OF BALANCING SOCIOECONOMIC AND ECOLOGICAL DEVELOPMENT

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Abstract. The presence of heavy metals in environment has been a subject of great concern due to their non-biodegradable nature. It is therefore important to continuously carry out environmental impact assessment and audit in order to evaluate the effects of these metals on the environment and meanwhile to design balanced and sustainable schemes of local industry development. The paper presents overview of heavy metal pollution in Armenia, especially in the regions, where mining industry recently is developed and where indices of heavy metal pollution are very high. Mining industry is the main source of heavy metal pollution in Armenia. Is developed a strategy of modeling of socio-economical and ecological balance of heavy metal impact and a concept of integrated model is presented.

Keywords: Heavy metals, pollution, mining industry, modeling

1. Background

Contamination with heavy metals comes from localized sources mostly from industries, agriculture, sewage, combustion of fossil fuels and road traffic. Heavy metals such as Zn, Cu, Pb, Cd, Mn, etc. are prominent components of industrial effluents, which are discharged into the environment and consequently pollute the aquatic ecosystem. The National strategy of sustainable

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development of the Republic of Armenia in the twenty-first century presupposes a planned, stable socio-economic growth of the country, taking into account the reasonable use of nature resources and conservation of the favorable environment for present and future human generations. The transition to a sustainable development should in the long run solve the problem of parity between the socioeconomic and ecological development, elevation of human life quality. Contamination of the environment by ions of heavy metals can bring forth the most unfavorable consequences. There are several investigations around heavy metal pollution in Armenia, which shows the remarkable level of heavy metal pollution in soil, atmosphere and watersheds and also the influence of heavy metals on the health of adults and children.

2. Overview of Heavy Metal Pollution in Armenia

Ions of lead and cadmium cause decreases of crop yields, changes of plants chemical content, accumulation of cadmium and lead. Lead content in atmospheric air of Yerevan makes 1.2–1.3 of Maximum Allowable Concentration (MAC), while at busy high-ways it reaches 16–19 MAC (Jugaryan, 2000). In the atmospheric air of Vanadzor city the concentration of lead exceeded MAC 15–20 times, while in Alaverdi town exceeding was 10-fold (Jugaryan, 2000; Deroyan, 1957). In soils at the territory of Alaverdi mining metallurgical combine and at a distance of up to 2 km aside from this combine the content of lead exceeded MAC 20–40 times, at a distance of 3–5 km exceeding made 10–15 times (Jugaryan, 2000). According to some sources, soils from the vicinity of this combine lead content exceeded the norm 81–109 times (Unanyan, 1987). There are a number of scientific publications on the content of heavy metals, in particular lead, cadmium and mercury in plants and food stuffs (Avakyan et al., 1984, 1987; Evoyan, 1974; Grigoryan and Galstyan, 1980). In plants from polluted areas in the vicinity of Alaverdi combine the content of lead exceeded MAC 25 times, in apples – 15 times, in peaches 2–5 times. In grapes and peaches grown near the Ararat cement plant lead concentration there was 7–9 fold exceeding, in tomatoes, pepper and aubergine - 2.5–3 times.

Lead exposure is a significant but largely unexamined public health issue. The first comprehensive blood lead level (BLL) survey in the Republic of Armenia was performed in 1996 (Saryan et al., 1996). Over 300 venipuncture blood samples obtained from adult workers at four establishments, and from children living in various districts of Yerevan, have been analyzed for lead content. Armenian children studied between 1992 and 1995 were shown to have low to moderate lead absorption (mean ± SD: 6.5 ± 3.4 mcg/dL, highest value 18 mcg/dL, n = 198 samples). None of the Armenian children fell into the CDC "medical evaluation" range (≥20 mcg/dL).

Questionnaire and interview performed to assess level of knowledge on lead of parents of children and the workers, exposed to lead via life-conditions or at work place, as well as teachers and medical personnel has shown low level of their awareness (Babayan et al., 2004). The analysis of data has shown positive correlation between presence of a factory worker in a family and the level of lead in blood of children. Correlation of socioeconomic status and a level of knowledge about lead is revealed.

In 1986 the coefficients of cadmium content in solid wastes (slag and dust flow) of Alaverdi mining and metallurgy combine made 923–7,692. In soils at a distance less than 2 km from the combine cadmium content exceeded the control levels 2–5 times; at a distance of 3–5 km 2-fold, at 7–8 km – 1.1 to 1.7 times (Avakyan et al., 1987). Cadmium content in plants exceeded the MAC 50-fold. In husbandries of the zone of severe contamination (Alaverdi combine) the crop yield in 1983–1987 made 25–30% of control; while in a zone of moderate pollution it was 80% (Avakyan et al., 1984, 1987).

3. Mining Industry in Armenia and Heavy Metal Pollution

Nowadays heavy metal pollution is a key problem for the Republic of Armenia. Armenia is situated in the South of the Caucasus and occupies only 29.8 km^2. The total land in Armenia is 2,974,300 ha. Soil and water pollution by heavy metals is a concern in urban and industrial areas. Mining industry is the main source of heavy metal pollution in Armenia. Copper and gold mining operations in the republic were heavily polluting soils. In Armenia about 30,000 ha of land is polluted by copper, lead and molybdenum due to mining operations in Northeast and South of the republic. The volume of accumulated industrial wastes reaches several hundred millions cubic meters. Land surrounding the Alaverdi copper-molybdenum plant, in radius of 3 km is polluted by heavy metals 20–40 times above norms. Similar enterprises are located in Kadjaran, Kapan, Megri and Agarak, and their surroundings are also polluted by heavy metals (statistical data are not available).

Total 26 polymetallic mines are being developed in Armenia. Among them there are truly giants such as Kajaran Copper-Molybdenum Mine. It is known that its borders stretch so far that whole Kajaran Town is located above rich copper and molybdenum reserves. Next to Kajaran Copper-Molybdenum Mine is the Shahumyan gold-polymetallic deposit, Kapan central deposit. Because of the negative impact of such a number of mining and industrial objects in the whole region of Syunik, including Kapan Town, Kajaran, and Agarak Town, adjacent communities are in a really hard condition close to ecological and social disaster. In some samples taken from the soil, water and agricultural products the content of heavy and toxic metals, such as copper, molybdenum,

mercury, arsenic, vanadium, cadmium, selenium etc exceeds MPC (maximum permissible concentration) by ten times, sometimes, by hundreds times.

An important issue for Armenia is the problem of optimal management of water resources and prevention of watersheds from heavy metal pollution. Water resources play important role in the economic development of Armenia. Because of the economic crisis and inoperability of industrial enterprises were seem improvement of surface water quality. Pollution of surface waters, not complete management of water resources are really problems in the field of water resources management in Armenia.

The pollution of the Armenian rivers is conditioned by two main factors. This is the absence of purifying system for municipal sewer, including in big towns, and pollution with industrial flows and ore waters. According to the State Statistical Service, the discharge of sewage in 2008 made up 205 million cubic meters (www.armstat.am).

One of the most polluted rivers is considered to be Voghji transboundary river (southern boundary with Iran) exposed by big enterprises, Kapan Ore Processing Combine and Zangezour Copper and Molybdenum Combine. The breakdown emissions of the Artsvanik tailing, the ore water from Shahumyan and Qajaran Mines also are discharged into this river. On average, the samples taken from the Voghji River exceed the MPC as follows: ammonia – from 3 to 4.6 times, sulphate ions – from 1.6 to 2.5 times, aluminum – from 1.6 to 8 times, vanadium – 3 times, manganese – from 3 to 3.5 times, copper – 6–7 times. The Akhtala River, a tributary to the Debed transboundary river (the northern border with Georgia), is also a highly polluted river. The drainage of the Akhtala Ore Processing Factory flows into this river. According to the data submitted by the Monitoring Center of the Ministry of Nature Protection of RA (www.mnp.am), in the ore water of the Akhtala River the content of copper, zinc and manganese exceeded MPC by 9,199.0–10,656, 363.1–397.6 and 580.9–642.3 times, respectively. One of the main sources for the river pollution is the Akhtala tailing which is already overfilled and doesn't fulfill the functions of a hydraulic cleaner. The Debed river watershed basin is one of the important economical centers of Armenia, as is characterized with rich natural resourses, and stands out with developed industry and agriculture. All of these cause serious ecological and environmental problems, especially when the waste management mainly absents in the area of watershed basin.

Investigations of the level of pollution with heavy metals and possible risks related to Debed river watershed basin is one of the important ecological issues in Armenia. Around the problem was made research for the period from 2004 to 2008 with the aim to discover the matter of pollution with heavy metals from big residential areas of the watershed basin and the clean-self possibilities of waters of the rivers (Danielyan, 2008). On 2005 in the waters of the river

Pambak exceeds of MPC for culture-municipal water use are observed from toxic metals for the iron (MPC-0.5 mg/l) and for the copper (MPC-0.01 mg/l). On 2006 in the river Pambak the exceeds of MPC have been mentioned also for the manganese (MPC-0.1 mg/l), aluminum (MPC-0.5 mg/l), lead (MPC-0.03 mg/l), zinc (MPC-1 mg/l) and for cadmium (MPC-0.01 mg/l). On 2006 compared with 2005 were observed remarkable increases of heavy metals' concentrations in waters of the river Pambak. In waters of the river Debed exceeds of MPC have been mentioned for the iron, cooper, manganese, aluminum and for the zinc. On 2006 exceeds of MPC have been mentioned also for the lead. It is distinctive that concentration of cooper has exceeded the MPC in the river Debed, where is developed the metallurgical industry in area of the watershed basin.

4. Modeling and Optimal Control

The problem is focused on the establishment sustainable mining strategies in Armenia. Mining is one of the main branches of industry in post-soviet Armenia. Armenia nowadays has resource based economy and mining industry generates notable part of GDP in Armenia. From the other hand mining regions mostly are polluted with heavy metals, what has its social consequences. Solutions for secure policymaking must be obtained under one "social-ecological-economical" system. In order to balance economic development with environmental and social sustainability it is necessary to realize multifaceted analysis. Sustainability concerns not only economic, but also social systems and it is extremely important not to separate social processes from economic activities. Integration of economic, ecological and political values into decision making is the mail condition. According to above mentioned, in order do develop environmentally sustainable strategies and realize optimal control of heavy metal pollution, social and economical factors must be considered in the same framework.

A concept of a model system (integrated model) for obtaining optimal strategies of development of mining industry in Armenia was developed (Figure 1). The main idea of the concept of integrated model is the definition of influence of economic activities on child morbidity and working out of socially optimal economical strategies in mining regions of Armenia. Social influence of economic development could be calculated directly. Such classic approach is being widely used in modeling practice. There is a new approach in the presented model, which is based on the definition of intermediate assessment and is presented with the help of "built-in" function. The model integrates social, ecological and economical factors of heavy metal pollution and includes three phases-assessment, intermediary assessment and optimal control.

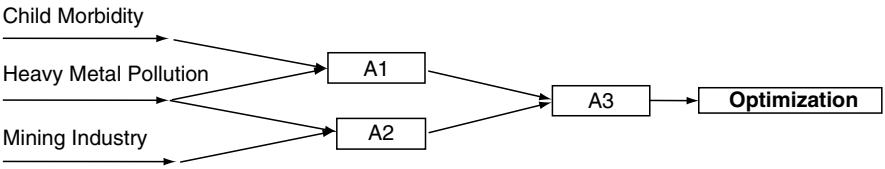

Figure 1. Concept of a Model System for Definition of Optimal Strategies of Development of Mining Industry.

Assessment phase consists from two econometric models – A1 and A2.

A1 presents environmental assessment of mining industry in corresponding regions and definition of the following pollution function

$$P = f(E) \tag{1}$$

where, P – index of heavy metal pollution, E – mining production index.

A2 presents social assessment of heavy metal pollution and definition of social function:

$$M = z(P) \tag{2}$$

where, M – index of child morbidity, P – index of heavy metal pollution,

The idea of the second phase is social assessment of economic activities thru environmental factor (pollution) and working out of intermediary assessment function based on built-in environmental function.

$$M = s(P),\ M = s[f(E)] \tag{3}$$

Calculation of parallel influence of production index and pollution index on morbidity could be realized by power function model:

$$M = APx1Ex2 \tag{4}$$

where x1 and x2 are elasticity coefficients of pollution and production.

As a methodological base of optimization optimal control model will be more acceptable. Function of optimal control of heavy metal pollution is based on the result, which was developed in the model A3, during the second phase.

5. Concluding Remarks

In order to develop socioeconomical and ecological sustainable solutions, currently there is a need, to investigate, the influence of industrial development, as a main source of heavy metal pollution, on the morbidity. Econometrical investigations showed that there is a definite correlation between heavy metal

pollution and indices of child morbidity. A scheme of models was constructed to reveal optimal solutions for development mining industry in Armenia.

Analysis of the situation with heavy metal pollution in Armenia have revealed following conclusions:

- There is a notable level of heavy metal pollution of air soil and especially watersheds in Armenia,
- Heavy metal pollution remarkable influence on the morbidity of adults and children in Yerevan and regions with developed mining industry,
- Municipal and industrial wastes are the main sources of heavy metal pollution in Armenia. Was revealed the influence of municipal and industrial wastes of cities Vanadzor and Alaverdy on formation of heavy metal concentrations of chemical composition of the rivers Pambak and Debed.
- During last 5–6 years were observed remarkable increases of heavy metal concentrations in waters of the main rivers, which could be related with development of the economy in that area.
- Condition of the water environment directly or indirectly reflects to other components of investigated rivers watershed environment, because the close linkages and interactions between them (atmosphere, land and biodiversity).

Overexploitation and pollution of water and degradation of aquatic ecosystems directly affect human well-being too, as human well-being and environmental sustainability are interconnected. Especially in the case of pollution with heavy metals there are real risks related to the agricultural lands and food contamination with heavy metals, to the rise of water treatment cost, related to the rises of chronic diseases.

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