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Environmental Impact of Placer Gold Mining Activities on the Surface Water Quality in Mongolia: Zaamar Goldfield

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Хураангуй

Төв аймгийн Заамарын хөндийд сүүлийн 20-иод жилд уул уурхайн үйлдвэрлэлийн цар хүрээ эрчимтэй тэлж, олон арван уурхай шинээр нээгдэн ашиглалт явуулснаар тус бүс нутгийн гадаргын усны чанарт сөрөг нөлөө үзүүлэх болсон. 2014 оны 9 сард Туул гол, ёроолын хагшаас хурдас болон уурхайнуудын тунгаагуурын уснаас сорьч авч шинжлэхэд бичил элементүүд болох хар тугалга (Pb), зөөлөн цагаан (Cd), хром (Cr)-ын агууламж харьцангуй их илэрсэн. Бохирдуулагч үзүүлэлтүүдээр усны чанарын индексийг тооцож үзэхэд "Угалз гол" ХХК, хувиараа алт олборлодог "Ундрах" компаниудын хаягдал усанд харьцангуй өндөр илэрсэн талаар энэхүү өгүүлэлд дэлгэрэнгүй тусгасан болно.

Түлхүүр үг: Усны чанарын индекс, хүнд металлын бохирдол, Туул гол

Introduction

In Mongolia, mining industry is considered as one of the important source of economic development of the nation, like many other developing countries including Ghana, Indonesia, China and Tibet. As cited by Naranhuu stated that Mongolia is one of the top 10 destinations for the mineral exploration due to the exploration expenditures in years 2004 and 2006 [1]. The World Bank Group report, Economic Update (2013) mining sector is a major contributor to the national economy and it represented 18% of GDP [2].

The mine revenue from the placer gold deposits in Zaamar are of vital importance to the national economy of Mongolia. For the last two decades, gold have been extracted a massive amount in Zaamar mining area. As of today more than 60 tons of gold is exploited in this area and paid to the State bank and Treasury fund. In the past 20 years, Zaamar soum of Tov province have faced enormous environmental problems and it has been damaged badly caused by mining industry and human wrong activities.

There are many studies considering at water quality of the Tuul River Basin and its chemical composition quite well. In the Zaamar gold mining zone, the water used for washing sand with gold and mining waste water is not completely treated before discharge into the river. This effects negatively not only in the life of inhabitants, but also in the river's biological life and the growth of the river fish. The river were seriously polluted due to use of old-fashioned mining methods and technologies. The results and findings of previous research reported that sedimentation test revealed presence of dangerous chemical elements [3], a large increase in suspended sediment [4;5], [5] a high level of heavy metal loads [6] and heavy metal concentration higher in surface water [7]. Grayson, 2004 indicated that artisanal or informal miners wash gold in rivers and other natural bodies and it is a severe impact on the hydro ecology [8].

Moreover, open pit mine in the Zaamar Goldfield, mining operations has influenced the quality of surface water. Thus, the region faced with major water quality problems that needs to be addressed immediately. Therefore, induced from the existing problems, this research tries to determine pollutants and reveal sources of pollutants that contribute to poor water quality emanating from gold mining activities, and try to fill the apparent knowledge gap of the negative effects caused by the mining explorations on the abundant surface water resources on the Zaamar valley.

Materials and methods

Study area

The Zaamar Goldfield is situated along the east side bank of Tuul river valley floodplain and surrounded by terraces and hills. Its length is over 50 km and width ranging from 10 to 20 km. The Zaamar Goldfield is about 230 km away from northwest of Ulan bator, Mongolia's capital city (Figure 1). The Tuul river is the fifth longest river (784 km) in Mongolia. The distance from the Zaamar Goldfield to Zaamar soum is approximately 30 km and located southwest of Oil Zaamar range.

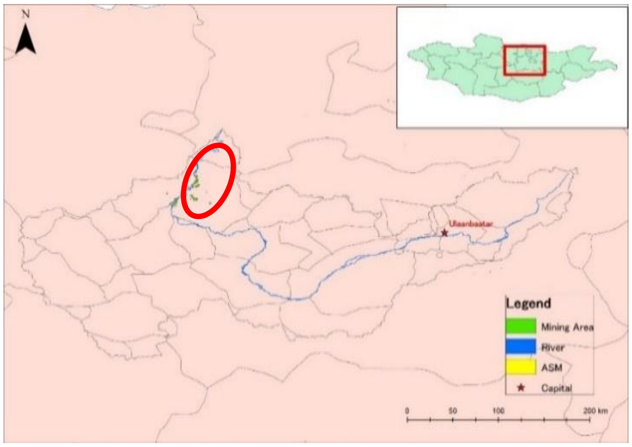

Figure 1. Study area: Thick circled line indicates Zaamar Goldfield

Various stages of exploration program found that gold placer reserves along the river Tuul continues almost 50 km and each valley (Upper Zaamar, Bumbat, Toson, Ar Naimgan, Khailaast, Ar khundii) hosts significant amount of gold. The area is agriculture area with nomadic animal husbandry and lies within the semi-arid climate zone. Meteorological data from a weather station of Lun, Altanbulag shows a mean annual precipitation of 227.3 mm and annual air temperature in winter -19^{0}C-24^{0}C, whereas summer is relatively warm and dry, with temperatures between 18^{0}C-25^{0}C. 80% of the rain fall between June and August. At the weather station of Zaamar also indicate that heavy rain fall (67.6 mm) occurred in June, 2008 because of the summer rainy period. The placer gold mining is fully dependent on surface water from the Tuul river, which is used for the separation of gold from sediment.

The Tuul river water in the Zaamar area was toxic seepage water originating the poorly managed tailings previously used as local drinking water. Nowadays, groundwater from wells is the main drinking water resource for people in Zaamar goldfield (662 household). In the long run, this groundwater can be at risk due to contamination by toxic seepage water originating from the poorly managed tailings and piles, as well as from contaminated river sediment.

Sampling sites

Fieldwork was conducted in early September, 2014 in and 24 sampling sites were chosen for collection of water and sediments from the Tuul River in Tuv aimag, near Zaamar soum's gold mining region, starting from downstream to the upstream point of the river (Figure 2). Water samples (number of samples are 14) were collected from the mining sites which is located along the river.

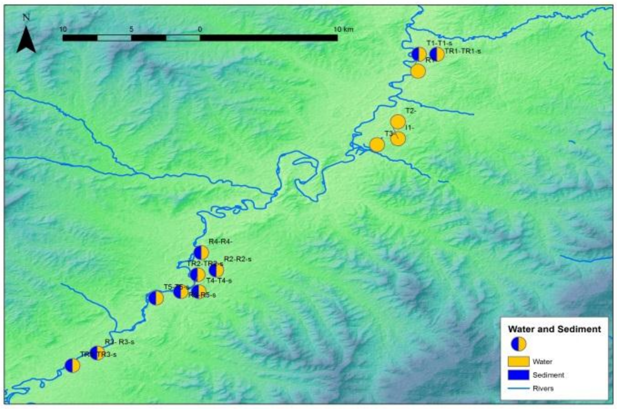

Figure 2. Map showing sampling sites near the Zaamar gold mine.
(TR-Tuul river water, T-tailing water, I-infiltrated water, R-gold wash water)

Three water samples were taken in the upper, middle, and downstream of the Tuul River water (TR1-TR3) five sample are from the goldmining settling ponds (R1-R5), taken at the ponds in which is the water used for the gold washing processes, one is from discharge points (I1), taken at the lake deposit where the water after the gold washing processes goes into and eventually discharged back to the river, and 5 samples are tailing water (T1-T5), which is no more used in left after mine closure. A total of ten sediment samples were also collected; two from the Tuul River water (TR1-s, TR2-s), two from the tailings (T1-s, T5-s), one from the discharge point (I1-s), and five from gold washing water (R1-R5-s). Sampling sites for sediment sample are marked with a suffix (-s) on Figure 2.

Sampling, sample preparation and analysis

Collecting and handling samples were conducted in accordance to the standard methodology for the analysis of the analyzed parameters. Water samples were collected in 500 ml polypropylene (PP) plastic bottles washed and cleansed with deionized water. Water sample were collected, and were analyzed for chemical properties DO, EC, TSS in-situ on unfiltered water using portable pH, EC, and turbidity meter and free cyanide (CN), chemical oxygen demand (COD), ammonium ($NH4^+$), nitrite ($NO2^-$), nitrate ($NO3^-$), and phosphorate ($PO4^-$) were measured with “Pack Test” manufactured by Kyoritsu Chemical Check Lab Corp. At each sampling area, the bottom sediment deposits (0-10cm depth) were collected with sediment sampler and transferred into 200 ml polyethylene containers and labeled. The sediment samples were sun-dried for about 24 hours in order to remove moisture and sieved through 2 mm and analyzed for five heavy metal concentrations of Ni, Pb, Zn, Cr, and Cd using Atomic Absorption Spectrophotometer (AAS), at the Laboratory of the Institute of Geology, MAS. Exact location of sampling sites were collected using a The Germin Global Positioning system (GPS) device on a satellite image obtained from Google Earth.

Water quality index

Water quality index (WQI) is provides a single number (like a grade) that expresses overall water quality at a certain location and time based on several water quality parameters. The WQI uses categories from very clear to dirty to rate the quality of the water, with dirty being the highest possible grade. These categories used for the water quality assessment are listed in Table 1.

Once the overall WQI grade is known, it can be compared against a ratio to determine how healthy the water is on a given day. In this study water quality assessment made using WQI is calculated in order to assess the level of impact of the pollutants on the environment in the surface water.

The WQI is based on the results of seven chemical/physical tests: dissolved oxygen (DO), chemical oxygen demand (COD), free cyanide (CN), ammonium ($NH4^+$), nitrate ($NO3^-$), nitrite ($NO2^-$) and phosphorate ($PO4^-$). These parameters were chosen because they significantly impact aquatic organisms and are inexpensive to conduct. WQI is based on the following formulae:

$$WQI = \frac{\sum_i \left[\frac{Ci}{Pli}\right]}{n}$$

Where:

WQI is the overall water quality index

Ci is concentration of i-th pollutant

Pli is the maximum permissible level of i-th pollutant

n is the total number of pollutants.

In this study, water quality assessment was made using above mentioned WQI, the National Standards for water quality (MNS 4586-1998) were used for Pli.

Table 1. Water quality type based on WQI ranges

WQ classification	WQ index
Very clear	≥0.3
Clear	0.31-0.89
Slightly polluted	0.9-2.49
Polluted	2.5-3.99
Very polluted	4.0-5.99
Dirty	≥6.0

Heavy metal contamination in sediment

To assess metal contamination in sediments, Muller classification were applied in the calculation of to the sediment quality assessment due to the lack of sediment standards in Mongolia. The sediment quality classified into six categories from “unpolluted” to “extremely polluted” according to the Muller classification and is given in Table 2.

Table 2. Muller classification for bottom sediment metal concentration, mg/kg

Classification	Cd	Cr	Pb	Ni	Zn
Unpolluted	0.00045	0.135	0.03	0.102	0.1425
From unpolluted to moderately	0.0009	0.27	0.06	0.204	0.285
Moderately	0.0018	0.54	0.12	0.408	0.57
From moderately to strongly polluted	0.0036	1.08	0.24	0.816	1.14
Strongly polluted	0.0072	2.16	0.48	1.632	2.28
From strongly to extremely polluted	0.0144	4.32	0.96	3.264	4.56

Results

Quality of the water sample

The results of the water quality classification (WQC) for each water sample of the study area and concentration equation of each parameters, the water quality index (WQI) are presented and illustrated in Table 3 and Figure 3. According to the WQI and WQC of Tuul river valley in Zaamar mining area, was mainly assessed as slightly polluted and polluted. In a few cases WQI was clear and very polluted. In this study, upper part of Tuul river water (TR3) is the reference site of all sampling sites which is not affected by mining activities. Therefore, upstream indicates that mining activities have less impact on water quality environment.

Table 3. Water Quality Index & Water Quality Classification at sampled points

Points	DO (mg/l)	COD (mg/l)	NH4 (mg/l)	NO3 (mg/l)	NO2 (mg/l)	PO4 (mg/l)	CN (mg/l)	Water Quality Index (WQI)	Water Quality Classification (WQC)
Standard	5	10	0.5	9	0.1	0.1	0.05		
TR1	8.3	8	0.6	0.8	0.02	0.1	0.01	0.7	Clear
R1	7.1	10	0.5	1.6	0.01	0.15	0.01	1.13	Slightly polluted
T1	6.5	10	1	2	0.11	0.12	0.01	2.56	Polluted
T2	5.3	18	2.5	5.1	0.05	2.4	0.02	4.29	Very polluted
I1	7.7	10	0.8	2	0.09	1	0.04	1	Slightly polluted
R2	8.62	5	0.4	4	0.05	0.4	0.01	0.75	Clear
T3	7.54	12	1.5	6	0.06	2.5	0.02	2.57	Polluted
T4	6.42	4	0.7	3	0.2	0.8	0.01	0.9	Slightly polluted
TR2	10.1	8	0.8	2	0.05	1.5	0.o2	2.93	Polluted
R3	8.5	8	0.5	0.6	0.02	0.3	0.01	0.99	Slightly polluted
TR3	9.2	6	0.2	0.2	0.005	0.08	0.01	0.58	Clear
R4	7.53	10	1	1	0.02	1	0.02	4.42	Very polluted
R5	8.12	12	0.8	1.5	0.01	1.2	0.01	0.96	Slightly polluted
T5	6.21	15	1.5	2	0.05	2	0.02	1.98	Slightly polluted

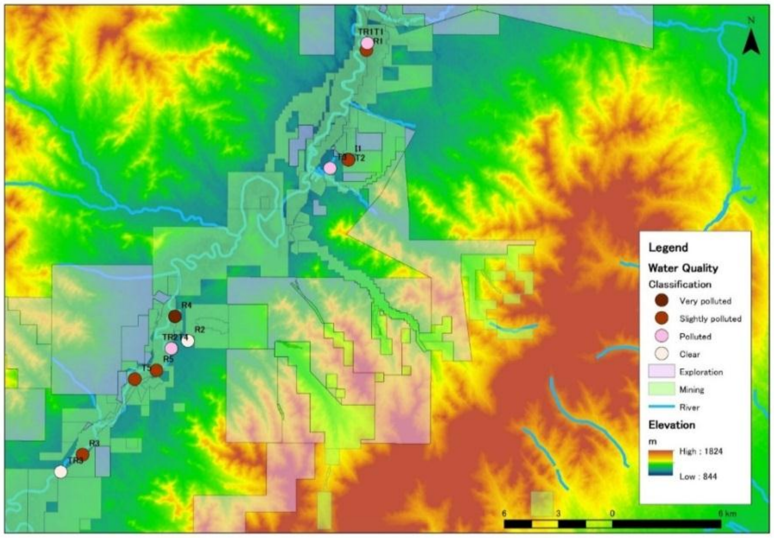

Figure 3. Sampling locations in the river valley and Water Quality Index results.

As seen in Table 3, water quality of six sites out of the fourteen sites in the river valley, graded “slightly polluted” or “bad” water quality as depicted by the water quality index. Three sites were in “polluted” and “clear” condition and two location was categorized as “very polluted”, respectively. From Table 3, it could be seen that both tailing water near Bayangol valley (T2) and gold wash water in "Undrakh" small-scale mine (R4) are in the category of “very polluted” compared to the reference site of TR3 in terms of ammonium, phosporate ion concentrations and chemical oxygen demand. The water used by Ugalz gol mine (I1), dissolved oxygen was high of upper limit and to wash gold ore was discharged back into the Tuul river without undergoing filtration. At site Tuul (TR2) was in polluted categories while both upstream Tuul (TR3) and downstream Tuul (TR1) locations were in “clear”. It might be because middle of the river water is located near I1 points where gold wash waste water flows directly to the Tuul river. Thus, goldmining in the Zaamar region results in pollution of the Tuul river water. Reference site (TR3) have better water quality compared to the all tailing water T spots. Figure 3 demonstrates that in the middle part, water quality was getting worse than the upper part and is included in the “polluted” to “very polluted” category. However, the results should be accepted as questionable, because water quality index gives only information about organic pollution, the companies operation is different, such as small-scale mining has a lack of technology for washing the gold from sediment. It could be water quality is being poor, near the small-scale mine sites.

According to the results presented from the table 4, the bottom sediment around the mining area contains elements such as Ni, Zn, Cr, Pb and Cd, ranging from 16.1-32.5 mg/kg, 21.5-60.6 mg/kg, 6.6-41.3 mg/kg, 0.5-48.2 mg/kg and 0.003-0.563 mg/kg, respectively. Results of heavy metal concentrations show that, Pb has the highest concentrations at TR2 and lowest concentration at R3. Zn and Ni have the highest concentration at R2 and lowest concentration at TR3 and TR2. As can be seen from table, levels of Cr (41.3 mg/kg) and Cd (0.563 mg/kg) are measured in tailings sample. According to the Muller’s classification all these values can be graded as “Strongly to extremely polluted”. In some cases, heave metal concentration was higher in the tailings water from than in the Tuul river and gold wash water because the water is pollutes from the result of mine closure.

Table 4. The concentrations range of heave metal in bottom sediment

Point	Ni	Zn	Cr	Pb	Cd
TR1	17.7	47.4	6.6	17.1	0.07
TR2	16.3	37.7	23.1	48.2	0.003
TR3	17	21.5	6.6	17.1	0.005
T4	17.8	34.7	41.3	28	0.563
T1	26.9	55.2	14.8	10.1	0.135
R2	40.8	70.7	26.4	23.7	0.003
R3	16.1	41.1	9.2	0.5	0.013
R4	26.6	57.6	28.2	17	0.002
R5	32.5	60.6	15.4	15.8	0.005
T5	31.5	62.1	22.8	30.1	0.121

Discussion

Impact on downstream Tuul River

The original goal of this study was to determine pollutants and reveal sources of pollutants since a recent study [7] of the Tuul river showed that the mining operations in Zaamar valley have an impact on the middle and downstream water quality of the river. This is noteworthy considering the relative strong dilution capacity of the Tuul river. The water samples, collected from tailings 3 and 5, and the gold wash water samples (Figure 3 middle part) show that there is chemical concentrations in the surface water due to the gold mining activities. The sediment profile of the studied heavy metals, including lead (Pb), chromium (Cr), cadmium (Cd), zinc (Zn), nickel (Ni) in the sediments of mining pond, tailings and river water were presented in Table 4. This table shows that the source area of the river valley, Zaamar Goldfield. The contaminations were mainly due to high levels of Zn, Ni, Pb, Cr and Cd. However, in terms of gold wash water quality, Ni contributed the highest concentration, followed by Zn and Cr, and tailings water quality. In the sediments Zn is the main element of environmental concern, followed by Ni and Pb. The content of these tailings and pond water needs to be characterized in order to determining the long term of these heavy metals and their potential impact on the downstream environment [6].

Conclusion

Measurements of the river water reveal a high degree of pollution in the Zaamar goldfield, especially in Khailaast bag near the mining concession. This pollution may depend on variety of factors, such as size of mines, the skill, and technology of mines. The placer gold mining at the Zaamar site has contaminated with chemical concentrations, and heavy metals such as Cd, Zn, Ni, Cr and Cd. The gold mines have contaminated the environment with these elements. These elements can cause on human and livestock health in this area. The dispersion of these elements into groundwater and surface water may also unsuitable for local people and livestock.

There have some problems to make assessment aquatic environment due to have not National standard of heavy metal's acceptable value in sediments for surface water. In terms of environmental concern, it has to be developed.

Therefore the placer gold mining industry naturally has the greatest possibility for negative impacts on the point pollution, there is important to study abroad methodology of treating and neutralizing a point contamination of surface water.

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