POTOSI MINING DEVELOPMENT AND THE CAUSE OF CULTURE COLLAPSE IN BOLIVIA

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KEY WORDS: Archaeology, Cultural Heritage, DEM, Environment, GIS, Pollution, Simulation

ABSTRACT:

Potosi mine in Bolivia was the largest one of silver, where mercury amalgam method was used in 16th to 18th century. The total amount of used mercury was estimated at 7500 tons, which is 12 times as much as in Minamata, Japan. First, the atmospheric diffusion of mercury at Potosi was calculated with the atmospheric dispersion model. The fall mercury distributed in the normal distribution over a radius of 100 km. From this result, 75% of the total mercury might distribute for the watershed of Rio Paraguay, 20% for the Amazonia, and 5% for the Uyuni lake. High concentration areas distributed more than 100km from Potosi. Finally, the total victims were estimated at about 24 thousand in the watersheds, which corresponds a few % of the total population in the Mojos Plane. In the pre-Inka period, many mines were dug and the heavy metals and sulfide discharged into the rivers. Probably, these mining activities might cause the culture collapse before the contact period in the same way.

1. INTRODUCTION

Potosi is the mine in the Andes, Bolivia. In 1545, silver ore was discovered and Spanish invaded there to obtain the mine, and had occupied till the independence for 250 years. In 1572, mercury amalgamation was introduced and the productivity of silver increased greatly. As a result, till 19th century mercury pollution had occurred in the surround of Potosi and Indians suffered seriously from health damages. On the other hand, in the Amazonia the collapse of cultures occurred and depopulation continued in the communities. Here, this research aimed at obtaining the range of mercury pollution and its distribution using the atmospheric dispersion model. Next, the risk analysis was carried out for mercury pollution from Potosi to the surround in the era of Spanish colonial period.

Figure.1 Study area: Potosi and its watersheds

2. MATERIALS AND METHOD

2.1 Potosi mine

Potosi mine was located on the Andes with the altitude of more than 4000m, where Rio Grande of the Amazon branch flows on the north, Rio Pilcomayo of the Plata branch on the south, and Rio Desaguadero near the Uyuni salt lake on the west. It is on the borders of the three rivers as shown in Fig.1. Over the site the south and north winds are dominant. Besides, tin, zinc, lead, antimony, and iron are produced from the same mine.

In the prime time of Potosi mine, much mercury was consumed for silver refinement for 250 years. Because of highland, the vegetation is a little for fuel in Potosi and then mercury amalgamation was introduced, which requires a little fuel. Amalgam is a mixture of mercury and another metal, from which without any fuel silver is extracted by evaporation of mercury. Therefore, mercury evaporates into the air and pollutes the surround greatly. Especially, in the water body, inorganic mercury is changed to organic mercury that might cause Minamata disease. The total amount of mercury is consumed several times as much as produced silver. At that time, Potosi produced the most silver of the world and consumed the most mercury as well. Moreover, from the mine, sulfuric acid water flowed and sulfur dioxide gas puffed. In the affected areas, heavy metals including mercury, sulfuric acid solution, and sulfur dioxide gas might occur extensive pollution against the air, water, and soil spheres. Undoubtedly, the surrounding Indians might suffer from serious health disorder.

2.2 Data used

Satellite data used were Terra/ASTER for land use classification and DEM. Also, SRTM by NASA was available for DEM. From DEMs the stream systems and their watersheds were generated. Meteorological data were monthly wind velocity at La Paz, Humaita, Port Velho, and Rio Branco (Nova et al., 1976), and seasonal wind directions (IBGE, 1989). The annual amount of mercury consumption in 1572 to1820 was referred from Hylander (2003).

2.3 Atmospheric dispersion model

As a atmospheric dispersion model, the next plume model was used for more than 1 m/s of the mean wind velocity [Nakanishi, 2007].

$$C_0 = \frac{q}{\sqrt{2\pi}\sigma_y U h} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \quad (1)$$

where C0: concentration, q: emission intensity, U: wind irection y is the next velocity, h: mixing height, y: a distance in a direction perpendicular to a direction x.

The dispersion width in a direction y is the next equation.

$$\sigma_y = \tan(\sigma_{wd})x + \sigma_{yp} + \sigma_{y0} \quad (2)$$

where σ_{wd}: the standard deviation of wind direction fluctuation (20_o), x: a downwind distance from the ypes source, σ_{yp}: the dispersion width of the Pasquill diagram, σ_{y0}: the initial dispersion width (2500m). The mixing height h was selected from three types of the atmospheric stability by Pasquill. In this case, types A, B, and G were selected.

Wind Speed[m/s]	Solar Radiation [cal/cm^{2}h]			Cloudiness	Night Time	
	>50	25-49	<25	8-10	Cloudiness>5	Cloudiness<4
<2	A	A, B	B	D	G	G
2-3	A, B	B	C	D	E	F
3-5	B	B, C	C	D	D	E
5-6	C	C, D	D	D	D	D
<6	C	D	D	D	D	D

Table 1 Pasquill's stable grade [Nakanishi, 2007]

Atomospheric Stability	Mixing Height[m]
A	600
B	500
C	400
D	200
E,F	70

Table 2. Mixing Height [Nakanishi, 2007]

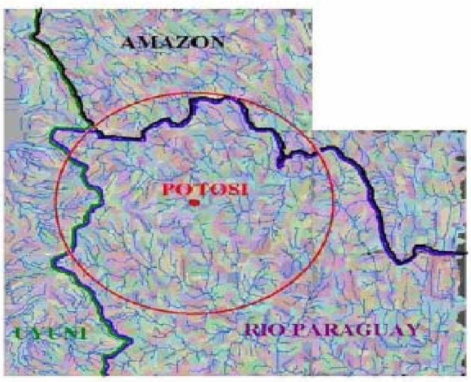

Figure.2 Potosi in a circle with a radius of 100 km and its stream systems

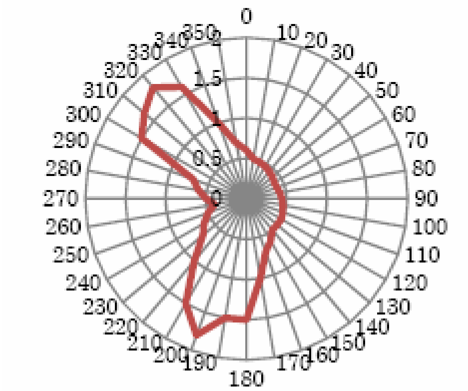

Figure.3 Estimated wind velocity and its directions at Potosi: units are m/s and degrees.

3. RESULTS

Three watersheds made from DEMs are shown in Fig. 2. Potosi was located near the borders of three watersheds. The annual wind velocity and directions are shown in Fig. 3. Through the Andes north and south winds are dominant. The average wind velocity exceeds 1 m/s for any month. Therefore, the south wind might bring mercury vapor over Potosi to the Amazonia watershed.

The spatial distribution of mercury concentration were simulated by the atmospheric dispersion model each atmospheric stability shown in Figs. 4 to 6. The wind velocity was assumed by 1 m/s in these figures. The abscissas are the downwind distance from the source in km. Types A and B are categorized by dry and rain seasons. Type G is night time. As shown in Figs, the profiles of the spatial distributions are the shape between the normal and exponential distributions.

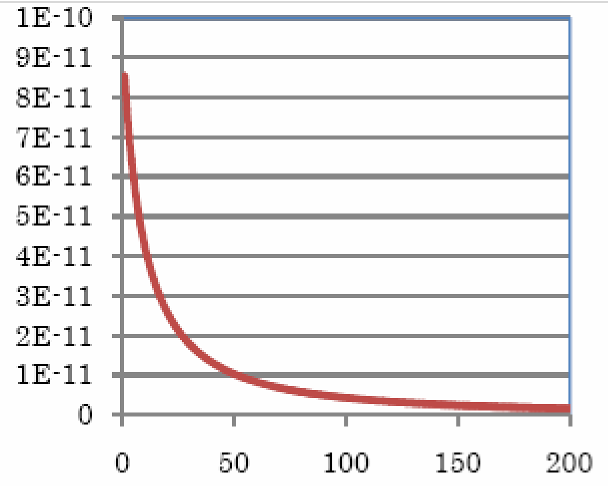

Figure. 4 Mercury distribution from Potosi in Type A, a dry season. The Abscissa unit is km.

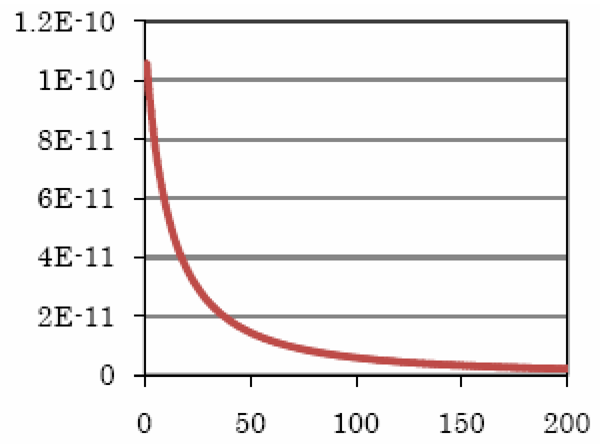

Figure. 5 Mercury distribution from Potosi in Type B, a rain season. The Abscissa unit is km.

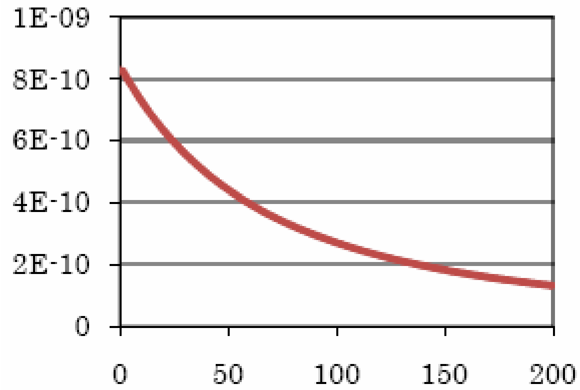

Figure. 6 Mercury distribution from Potosi in Type G, night time. The Abscissa unit is km.

The cross section are the normal distributions. In the case G, mercury vapor flows far from the source in a band.

Thereby, the amount of mercury flying over the bord was estimated depending on the wind velocity. From the results, 75% of the total mercury falls on the Rio Pilcomayo watershed, 20% the Amazon watershed, and 5% the Rio Desaguadero watershed.

Next, the annual amount of mercury consumption is shown in Figure. 7. The fluctuat consumption might depend on the population of the Indians because the output of silver was proportional to the population. The total mercury consumption was estimated by 7500 tons for 250 years. Among the total mercury consumption, 5625 tons of mercury fell down over the Rio Pilcomayo watershed, 1500 tons of mercury over the Amazonia watershed, and 375 tons of mercury over the Rio Desaguadero watershed. High concentration of mercury pollution might occur in the large scale area.

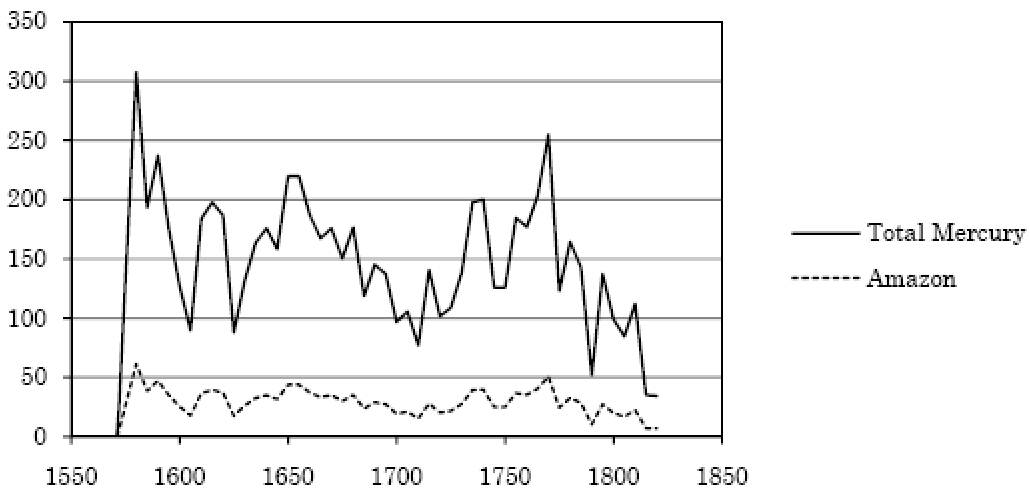

Fig. 7 Historical change of mercury emission from Potosi in tons each year

4. DISCUSSION

In Minamata, 617 tons of methyl mercury emitted into the Shiranui Bay in 1948 to 1965 [Nishimura & Okamoto, 2001]. The annual average amount was 36 tons. As a result, over 2000 of fishermen and their family became Minamata disease by eating polluted fish. However, in Potosi, the annual average amount was 30 tons of mercury and the total amount was estimated by 7500 tons of mercury, which was 12 times as much as Minamata. In each watershed, not only fishermen but also farmers had used polluted water. Therefore, about 24000 of Indians might become Minamata disease. Most of them were serious and died without any evidence. In the eras of Inca and pre-Inca, much gold, silver, and cupper were produced, which means much pollution occurred with sulfuric acid water and sulfur dioxide. The cause of collapse of cultures contributed to the increase of population, the climate change, and Spanish invasion. But, the possibility of mine pollution is high. Especially, in lowland and flood plains, such tragedy might occur.

5. CONCLUSIONS

From the mercury consumption data for the past 250 years, the spatial distribution of mercury was simulated by the atmospheric dispersion model. As a result, the next conclusions were obtained.

(1) Among the total amount of mercury consumption at Potosi in the past 250 years, 75% might fall down over the Rio Pilcomayo watershed, 20% over the Amazonia watershed, and 5% over the Rio Desaguadero watershed.

(2) The total mercury consumption was 7500 tons, which might cause Minamata disease enough, corresponding to 24000 serious patients. This means the possibility of destruction for many tribes and the collapse of cultures.

In near future, by investigating the distribution of mercury in the watersheds, the past unknown history would be solved.

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