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ANTHROPOGENIC INFLUENCE ON THE WATER QUALITY IN THE LAKE POOPÓ AREA, BOLIVIA

Mänsklig inverkan på vattenkvalitén i området kring sjön Poopó, Bolivia

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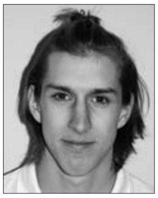

Abstract

Mining in Bolivia has been an important part of the economy for centuries, particularly in the Altiplano area. However, the mining activities have a negative effect on both the environment and the health of the people living in this area. This study summarizes knowledge of the historical as well as current environmental condition in four river basins of the area north-east of Lake Poopó. Data from year 2001 to year 2013 was used. A field study was performed in June 2013. The concentrations of ions and heavy metals are close to or above WHO guideline values for drinking-water during the entire study period in the area in every sampling site. In the Antequera River, up to 95 % of the cadmium contamination could originate from anthropogenic sources such as mining. A clear trend for all four studied rivers is the constantly elevated concentrations of cadmium that is neither increasing nor decreasing up to June 2013. Future studies should include a toxicology research, a social study and a mining study. Measures such as restructuring mining organizations and building waste-water treatment should be implemented as soon as possible.

Key words – Bolivia, Antequera, Surface Water, Drinking-water, Mining, Heavy Metals, Cadmium, WHO Guideline Values

Sammanfattning

Gruvdrift har varit en viktig del av Bolivias ekonomi i århundraden, särskilt i området Altiplano. Men gruvverksamheten har en negativ inverkan på både miljön och hälsan hos de människor som bor i detta område. Denna studie samlar kunskap om de historiska så väl som de nuvarande miljöförhållandena i fyra avrinningsområden i området nordost om sjön Poopó. Data från 2001 och framåt används. En fältstudie genomfördes i juni 2013. Koncentrationerna av joner och tungmetaller är nära eller över WHO:s riktvärden för dricksvatten under hela studietiden i området i varje provtagningsställe. I floden Antequera kan upp till 95 % av föroreningen av kadmium komma från antropogena källor, såsom gruvdrift. En tydlig trend för samtliga fyra undersökta vattendrag är de ständigt förhöjda halter av kadmium som varken ökar eller minskar fram till juni 2013. Framtida studier bör inkludera en toxikologisk studie, en socialantropologisk undersökning och en närmre studie av gruvdriften. Åtgärder såsom omstrukturering i gruvorganisationer och byggande av rening för avloppsvatten bör genomföras så snart som möjligt.

Introduction

Bolivia is a financially weak country rich in natural resources and biological diversity, situated in the middle of South America. The country is located in the tropical zone, with the Andes in the west and the lowland in the east. The studied area lies in the Altiplano, in the mountains of Bolivia. The climate is characterized by a rainy season from November to March and a dry season from April to October (Encyclopaedia Britannica, 2013). The

Altiplano has a semi-arid climate with extreme temperature variations, from –10°C to 14°C in winter and from –2°C to 18°C in summer (García, 2006).

Bolivia has a long-standing mining tradition dating back as far as 2000 BC, when first the Tiwanaku and then the Inca civilizations started extracting minerals. As part of the Andean cultures, indigenous people have always respected the nature. When the Spaniards conquered the Inca Empire the extraction grew to new proportions. From then on, large amounts of different minerals have been extracted with a significant environmental impact as a result. For example, high concentrations of heavy metals have been found in crops and marine life. These metals may accumulate and negatively affect the human population and animals. The harsh climate that characterizes the Altiplano also has a negative effect on the environment (García, 2006).

The rivers in this area receive natural contamination from the Andean Cordillera in the west. This is due to the geological composition of the bedrock and soils. Thermal springs, high in alkalinity, also affect the chemical composition of the waters (García, 2006). Several villages and farms are situated in the basins of the rivers. They also affect the water quality since many lack proper waste water treatment. Some villages lead their drinking water in pipes from high upstream in the river, before any mining activity has affected the water (Blanco, 2013).

The area northeast of Lake Poopó has been studied for many years and much of the mining activities are situated there. In the present study, the occurrence of heavy metals in four river basins is studied. Data from previous studies are also compared and a historical comparison and evaluation of the changes in heavy metal concentration is made. During a two-month visit to Bolivia the samples were gathered, analyzed and evaluated.

The main objective is to gather knowledge of the present environmental condition of the Poopó, Pazña, Urmiri, and Antequera River basins, with focus on heavy metal concentrations in superficial waters. Also, to increase the understanding of how the heavy metal concentrations have changed during the years of studies conducted in the area.

The questions to answer include:

- What are the concentrations of the heavy metals cadmium, copper, zinc, manganese, iron, arsenic, and lead in the Poopó, Pazña, Urmiri, and Antequera River basins?
- Do the heavy metal concentrations change over time?
- How much of the heavy metal concentrations are caused by anthropogenic and natural contamination, respectively?
- How is the water quality compared to the health-based WHO guidelines for drinking-water?

Previous studies

The first environmental evaluation project in the Lake Poopó region was the Oruro Pilot Project. This started in 1993, partially funded by the Swedish International Development Agency (SIDA) (Oruro Pilot Project reports 9701, 1997). The project focused on the mining and industrial sectors and the aim was to generate an Environmental Master Plan. The publications from this project inform about mining activities, the socio-economic situation, hydrology, flora and fauna of the region (Oruro Pilot Project reports PPO 9401, 1994). In 1996, Troëng and Riera performed geological mapping of the entire area around Lake Poopó (Troëng and Riera, 1996).

Since 2001, research in the Lake Poopó region has been carried out at the Higher University of San Andrés, La Paz, Bolivia. This research is financed by SAREC (the research department within SIDA). One important part of this research is the exchanging of doctoral, master, and bachelor students between Bolivia and Sweden.

Several Master's theses have been conducted in the region of Lake Poopó. Amongst them; Lilja and Linde (2006) who analyzed the concentration of heavy metals in the sub basins in the Poopó region, Mikaelsson and Ny (2009) who investigated the ground- and surface water quality in the same sub basins, and Rosenberg and Stålhammar (2010) who, also in the same sub basins, evaluated heavy metals in water influenced by mining activities.

Between 2007 and 2011, a cooperative project funded by the European Commission, CAMINAR, took place in the Lake Poopó sub-catchment area. The objective of the project in Bolivia was to evaluate the water resources in areas influenced by mining in the Lake Poopó catchment area as well as to present a plan for sustainable management in the area. Studies including analysis of heavy metal concentrations were performed on a regular basis in the study area throughout the period of the project, during dry as well as rainy season (Quintanilla et al, 2012).

Materials and Methods

Data Sampling

The sites for data sampling were selected from a number of standardized sampling sites with predefined GPS-coordinates (table 1). An overview of the study area can be seen in figure 1. In figure 2, the north part of the study area is shown while the south part is visualized in figure 3. Geographical information, pictures and measurements are made with Google Earth. Four different

Table 1. *UTM coordinates (zone 19K) for sampling sites.*

Sampling site	Easting	Northing
BODI1	0725275	7956447
TOTV2	0725130	7954922
TOTR1	0724722	7954208
TOTR2	0723994	7953177
AVR2	0723257	7950256
AVR1	0721868	7948248
CUCC1	0720880	7952031
AVR3	0720873	7945302
URR2	0729626	7948149
URR1	0727604	7944725
URC1	0724127	7944804
URV1	0724168	7944495
URR3	0721998	7943603
PAZR1	0720514	7941971
PALR2	0718183	7942031
CABT1	0717889	7965957
MAD1	0715384	7966183
POR3	0713497	7965977

(Quintanilla et al, 2012).

rivers are studied that are all different in length from first to last sampling site at each river; Antequera River (16635 m), Urmiri River (13995 m), Pazña River (5215 m), and Poopó River (5233 m). The first three are seen in figure 2 while Poopó River is seen in figure 3.

Water Analysis

Heavy Metals

The laboratory analysis of the water included concentrations of copper (Cu), cadmium (Cd), manganese (Mn), zinc (Zn), iron (Fe), lead (Pb) and arsenic (As). An AAnalyst 200 atomic absorption spectrometer was used to quantify the concentrations of Cu, Cd, Mn, Zn, Fe. For Pb and As, generally present in lower concentrations, the analysis was made using equipment with a lower detection limit, namely an AAnalyst 100 atomic absorption spectrometer with a HGA850 graphite furnace.

Field Parameters

Measurements of temperature, pH, conductivity, specific conductivity, TDS, salinity, ORP, and DO were made in the field using a HI 9828 Multiparameter meter. The value of ORP was recorded as the first value attained by the meter. The rest of the values were obtained

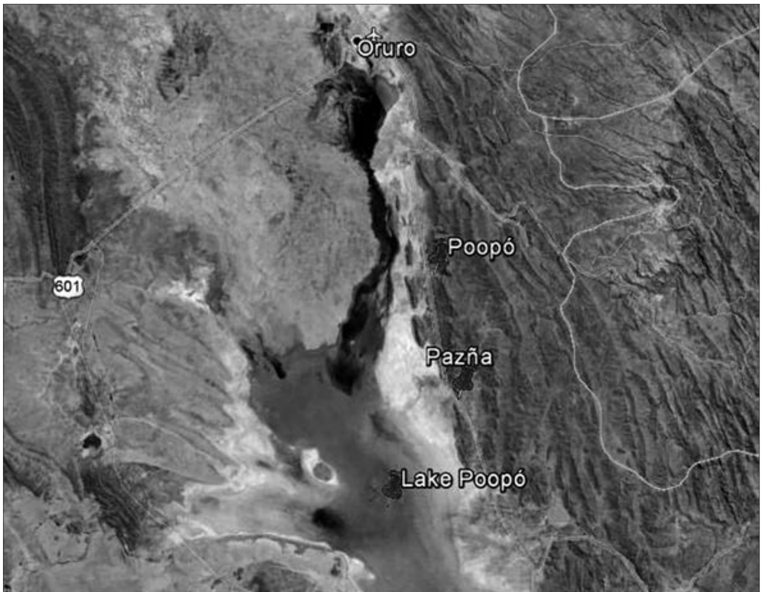

Figure 1. *Overview of the study area, with villages Poopó & Pazña as well as Lake Poopó marked.*

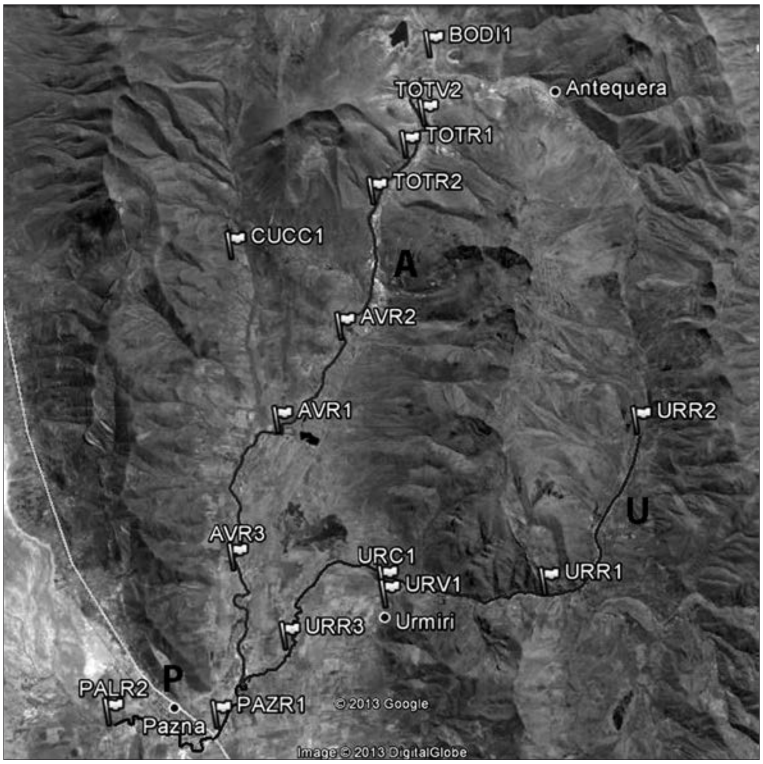

Figure 2. *South part of the study area with Urmiri River (U), Antequera River (A) and Pazña River (P). Pazña village is seen at the bottom left in the picture.*

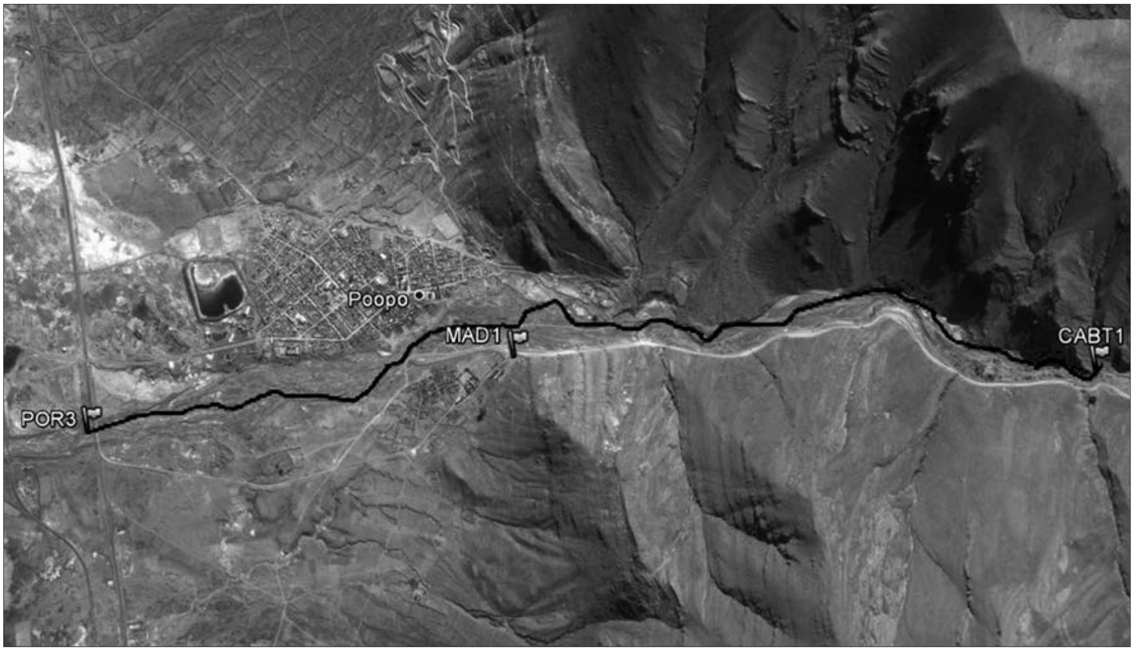

Figure 3. *North part of the study area with Poopó River marked in black.*

as the stabilized values provided. Alkalinity was measured in the field through titrating pre-filtered samples with HCl until the added indicator solution precipitated. Alkalinity was only estimated for samples with a higher pH-value than 5.4.

Bicarbonate and Carbonate

During the field study, alkalinity was measured by titration of the samples with hydrochloric acid using an indicator to determine the point where all the content of bicarbonate and carbonate had combined with the acid. The ions bicarbonate and carbonate were assumed to account for all of the alkalinity. The pK_a-value of HCO_3^- was estimated as a constant 10.32. By combining the definition of alkalinity (eq. 1) with the dissociation formula of bicarbonate into carbonate (eq. 2), the concentration of bicarbonate (eq. 3) was estimated, whereafter the concentration of carbonate was estimated with equation 2:

$$Alk = [HCO_3] + 2[CO_3^{2-}] = [CaCO_3] \qquad (1)$$

$$[CO_3^{2-}] = \frac{[HCO_3^-]}{10^{pK_a - pH}} \qquad (2)$$

$$[HCO_3^-] = \frac{0.5 * Alk * 10^{pK_a - pH}}{1 + 0.5 * 10^{pK_a - pH}} \qquad (3)$$

where pK_a is the dissociation constant of bicarbonate into carbonate (assumed at standard conditions) and pH the pH of the specific sample.

Anions and Cations

The concentrations of sulfate and nitrate were estimated using a Hach DR 2800 portable spectrophotometer using specific Permachem reagents for sulfate and nitrate, respectively. The technical supervisor estimated the concentration of chloride independently.

The analyses of potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg) were made with an AAnalyst 200 atomic absorption spectrometer independently by the technical supervisor.

Sources of Error

One source of error is the difficulty of determining the point of time at which the meter can be considered to supply stabilized values. This was especially difficult regarding ORP where the value never stabilized. To mitigate the error, Efraín Blanco (2013) assumed that the primary value of the meter was the most accurate. Therefore the values of ORP for each sampling point were obtained as the first value that the meter supplied. Additionally, the sampled water might not be fully homogenous in terms of TDS, salinity and conductivity. Errors might also have been introduced during the sampling as some bottles, though not previously used, were not sufficiently pre-washed before being filled with water samples.

A large source of error is the dilution that had to be made to the samples. As the samples had very high concentrations of heavy metals and ions, they had to be diluted up to 10 000 times in order to decrease the concentrations below the maximum detection limit of the specific analysis equipment. The final dilution factor is dependent on the preciseness of the adjustable pipettes used for measuring volumes, which is why the calculated dilution factor might differ from the actual dilution factor. Also, the ion analysis in the laboratory took place during the months of July and August. This may lead to ion concentrations that differ somewhat from the concentrations at the time of sampling (14–15 June). The change in concentration is explained by chemical reactions that may take place between the different chemical species in the samples.

Results – Current Situation

In table 2, the heavy metal composition of the water samples from the four rivers is presented. Values exceeding the parametric values according to WHO health-based guideline value for drinking-water are marked with bold font (World Health Organization, 2011).

Antequera River

The water quality of the Antequera River is poor. Nitrate, cadmium and arsenic exceed WHO health-based guideline values for drinking-water. A particularly interesting sampling site is AVR2. AVR2 is situated downstream the highly contaminated TOTR2, which is surrounded by tailings. This might explain the concentration peak of arsenic seen at AVR2. Interestingly, the arsenic concentration at the next sampling site, AVR1, is significantly lower despite the vast input of arsenic to the Antequera River at AVR2. The decrease of arsenic concentration may be explained by the drop in pH (by 0.71) taking place between the sampling sites. The arsenic concentration determination is also highly dependent on the oxygen reduction potential (ORP) of the water. In the Antequera River the ORP is increasing downstream, potentially leading to a decrease of measured arsenic concentrations due to arsenic-iron precipitation. The hypothesis that the drop in arsenic concentration after AVR2 is explained by pH is strengthened by the fact that the iron concentration at AVR1 also has decreased severely.

Cadmium most probably originates from the mine waste water influenced BODI1, where cadmium con-

Table 2. *Heavy metal concentrations for the four rivers studied.*

River	Sampling site	Date	As µg/l	Pb µg/l	Cd µg/l	Cu µg/l	Fe µg/l	Zn µg/l	Mn µg/l
Antequera	BODI1*	2013-05-14	<5	<5	**980**	<100	**23494**	**81500**	**4745**
	TOTV2	2013-05-15	<5	<5	**59**	<100	127	423	<70
	TOTR1	2013-05-15	<5	<5	**932**	111	**2174**	**122400**	**6880**
	TOTR2	2013-05-15	9.29	9.01	**936**	494	**8660**	**126761**	**6680**
	AVR2	2013-05-15	**929**	9.43	**791**	1860	**51130**	**119219**	**7614**
	AVR1	2013-05-15	<5	<5	**433**	484	1051	**55263**	**14250**
	CUCC1*	2013-05-15	<5	<5	**59**	<100	143	57	<70
	AVR3	2013-05-15	<5	<5	**381**	423	444	**95000**	**11832**
Urmiri	URR2	2013-05-14	<5	<5	**62**	<100	131	45	<70
	URR1	2013-05-14	<5	<5	**67**	<100	132	46	107
	URC1	2013-05-14	<5	<5	**57**	<100	188	50	101
	URV1*	2013-05-14	<5	<5	**56**	<100	128	47	72
	URR3	2013-05-14	<5	<5	**54**	<100	127	47	<70
Pazña	PAZR1	2013-05-14	<5	6.04	**305**	302	277	**29500**	**8100**
	PALR2	2013-05-14	<5	<5	**301**	300	207	**66897**	**8275**
Poopó	CABT1	2013-05-14	<5	<5	<30	<100	173	79	<70
	MAD1*	2013-05-14	**2458**	**618**	**10310**	1790	**3296000**	**1274000**	**17477**
	POR3	2013-05-14	<5	<5	**95**	<100	179	2128	**407**
WHO guideline:			10	10	3	2000	2000	3000	400

*Not part of actual river (tributary)

centrations are over 320 times higher than the WHO guideline value. The reason why cadmium peaks at TOTR1 and not at TOTV2, the sampling site right after BODI1, might be because of a decrease in pH that increases solubility of cadmium. The pH decreases from pH 6.92 at TOTV2 to 4.91 at TOTR1. The severe drop of pH from sampling site TOTV2 to TOTR1 might also explain the low concentrations of zinc, manganese, iron and cadmium at TOTV2. A high pH decreases solubility of these heavy metals. Meanwhile, BODI1 has an even higher pH than TOTV2 but still shows high concentrations of heavy metals. This is probably explained by the unusually high amount of heavy metals leaking from the mine at that sampling site. Cadmium shows a constant decrease downstream in the river, implying that no large sources leak cadmium into the river.

Urmiri River

Urmiri River undergoes a rapid change of conductivity after sampling site URR1. This is probably due to underground thermal water that blends with the river once the river starts to flow underground (after URR1). Accordingly, the temperature of URC1, the following sample point, is about 10°C higher than at URR1. Chloride and sodium concentrations also peak at URC1, further strengthening the hypothesis of thermal water leaking into the river. Regarding cadmium, the concentrations are above the WHO guideline values but are at the same time relatively constant throughout the river. This fact indicates that is can be assumed that the cadmium mostly originates from natural leakage from the surrounding bedrock.

Poopó River

The tributary stream with the sampling point MAD1 has great influence on the water in Poopó River. This stream joins the river between the points CABT1 and POR3. When comparing the analyzed values for both heavy metals and ions in these points, it is clear that MAD1 is the main reason for the increased values in POR3. The concentration values for MAD1 are extremely high and all the heavy metals except for copper vastly exceed the WHO guideline values for drinking-water. Especially the concentration for lead is very high at sampling site MAD1.

Pazña River

The concentrations of heavy metals and ions in Pazña River are almost the average values between Urmiri and Antequera River. Urmiri River has high pH and is a relatively non-contaminated river while Antequera River has low pH with both ions and heavy metals exceeding the WHO guideline values. Pazña River has a higher pH than Antequera River but also a significantly lower pH than Urmiri River. Pazña River has higher values for ions and heavy metals than Urmiri, but not as high as the values for Antequera.

Summary

Assuming that the bedrock in Urmiri River basin is similar to the bedrock of Antequera River basin, the characteristics of Urmiri River can in general be used as a measure of the natural contamination of heavy metals in the area. This comparison strengthens the hypothesis of a major anthropological contamination of Antequera River basin due to mining activities. This is especially clear regarding cadmium, where Antequera River is characterized by concentrations more than 300 times above the WHO guideline values for drinking-water. The natural levels (seen in Urmiri River) are only 20 times above WHO guidelines. It is roughly estimated that in the Antequera River, which might represent the current situation in the other rivers, up to 95 % of the cadmium contamination could originate from anthropogenic sources.

Meanwhile, the arsenic contamination is probably underestimated for the area since the solubility of arsenic decreases with lower pH, which is especially clear for Antequera River and Pazña River with pH levels as low as 3.65. The arsenic and lead concentrations are especially elevated in Antequera River and at sampling site MAD1. The cadmium concentration exceed the WHO guideline values at all but one sampling site in the whole study area and is vastly elevated in the mine influenced rivers Antequera and Pazña. The same pattern can be seen for the heavy metals iron, zinc and manganese. Manganese and zinc both exceed the WHO guideline values at most sampling sites in the rivers Antequera and Pazña as well as at the sampling site MAD1. Iron concentrations do not exceed WHO guideline values in Pazña River, but they do in both Antequera River and at sampling site MAD1. The solubility of zinc is closely connected to pH, just as for arsenic. In Antequera River, the pH drops under 5 downstream from the sampling site TOTR1, whereby the solubility of zinc increases and starts to leach from the bedrock. This could explain the extremely high zinc concentrations in Antequera River. Regarding the ions; nitrate and sulfate seems to be the most important contaminants that the anthropological activities contribute with.

Results – Historical Situation

Many historical concentration values exceed the WHO guideline values for drinking-water, especially the values for Antequera River. There, cadmium, iron, zinc, and manganese exceed the WHO guideline values almost in every study for every sampling site. The opposite can be seen for the values from the Urmiri River. There, the values almost never exceed the WHO guideline values except for a few times for cadmium and arsenic as well as for one time for lead. This corresponds to the conclusion regarding the current situation, namely that no large mines pollute the Urmiri River, as is the case for the Antequera River.

Many values from the Poopó River also exceed the WHO guideline values, especially for arsenic, lead and cadmium. The highest values can be found from sampling sites POR3 and especially MAD1, downstream the less polluted CABT1. This indicates that the tributary MAD1 pollutes the Poopó River. The same indication was given by the current situation analysis. A clear trend is the constantly high concentrations of cadmium vastly exceeding the WHO guideline value in all four rivers. The cadmium concentrations seem to be neither increasing nor decreasing up to present date, which is true for almost all sampling sites and rivers. Sampling site MAD1 does not follow this pattern but instead has extremely elevated arsenic and lead concentrations up to present date. This could be explained by the fact that MAD1 is situated directly at a mine wastewater outlet from which the contamination has not been decreased.

For sampling sites PAZR1 and POR3, where the data sampling starts as early as 2001, the arsenic and lead concentrations are high above the WHO guideline values until June 2007. Thereafter the levels seem to have stabilized close to or under the WHO guideline values. There is a strong connection between pH, ORP, and the arsenic and lead concentrations. Even though no clear trends can be seen regarding the pH, the ORP in for example POR3 show an increasing trend. Since arsenic binds to iron and precipitates to the sediment under aerobic conditions (high ORP), this indicates that the measured arsenic concentrations in POR3 are lower than actual concentrations. Also, the extremely high values of manganese in sampling sites AVR1, PAZR1 and MAD1 combined with relatively low concentration of arsenic, indicate that manganese absorption of arsenic may have occurred.

Review of Results

Nitrate and sulfate concentrations were estimated using UV-equipment. Lack of reagent solutions to add to the samples led to the analysis of only 14 out of the total 18 samples for nitrate concentration and the analysis of only 5 duplicates for sulfate concentration (where the mean value was utilized as raw data for the current study). Due to lack of reagents, supervision and time, the analysis of cations as well as chloride concentrations was made retrospectively on commission by our technical supervisor at UMSA, Efraín Blanco. No RAD-values were estimated for our results due to lack of laboratory time and equipment/material (such as reagents). Therefore no control of the deviation of the results has been made which might have an effect on the precision of the results. However, we believe that the other sources of error (such as having to dilute up to 10 000 times) are such great sources of error that our laboratory results can only be seen as approximations. On the other hand, it is clear that these approximations often are well above the WHO guideline values, which is perhaps the most important fact to prove.

Discussion

The studied area northeast of Lake Poopó is polluted, both because of the mines and tailings and also because of the villages and farms. The villages and farms most likely lack adequate treatment facilities both for outgoing wastewater and incoming drinking-water. The mining activities contribute to increased concentrations of heavy metals, which is especially clear regarding cadmium. Zink and manganese concentrations are also extremely high in the mining areas. The waste water from villages and farms probably mainly increase the nitrate concentrations. The concentrations of ions and heavy metals are close to or above WHO guideline values during the entire study period, except for copper that never has exceeded the guideline values from WHO. For arsenic and lead, the concentrations seem to have decreased with time, which might be explained by a change in pH.

The Antequera River is the most polluted River of the four studied rivers. This is due to the many tailings and mines in the basin of the Antequera River, but also the numerous villages. The estimation that 95 % of the contamination of the river originates from anthropogenic activities should provide enough motivation to implement improvements for the water quality of Antequera River. Urmiri River is the least polluted river. There are neither mining activities with significant impact nor any considerable impact from villages and farms on the water in the river. The Pazña River is more contaminated than Urmiri River, but not as much as Antequera River. The Poopó River runs through the Poopó village. The water quality is fairly good upstream of the tributary MAD1. However, downstream of MAD1 the values for both ions and heavy metals increase. MAD1 is a sampling site situated directly at a mine outlet stream. Probably because the waste water from the mine is not treated correctly, the result is high concentrations of ions and heavy metals in the Poopó River. The Poopó village is situated further downstream of MAD1. Fortunately, the people of the village lead water in pipes taken upstream of MAD1. The waste water from the village may also have a negative effect on the water quality since it probably is not treated in any way.

The mining activities are without a doubt the most important source of contamination in the rivers of the Lake Poopó area. The major sources of heavy metals and ions are the large-scale mining, the small-scale mining and mining waste placed along the rivers. Therefore, the most efficient way of improving the water quality would be to implement cleaner and more environmentally friendly operational procedures in the mines. However, changes are hard to implement due to the poor economic situation, the political situation and the social situation. Since many of the workers in the mines also live in the surrounding villages, it is very important to inform about the risks and what measures that can be taken to improve the water quality and thus the living standard of the people. For example, sedimentation dams could be built and the tailings could be properly closed. One change that would have great effect is to relocate the small-scale mining workers to the large-scale mines. This change is probably hard to implement but would minimize the untreated waste. Especially since larger mines are easier to monitor by the government to ensure compliance with the environmental regulations. Also, installing reservoir tanks in the populated areas could solve the problem of uneven water distribution during the year due to the dry and wet period. The waste-water treatment plants should be examined and improved. A biological treatment of waste-water would also improve the water quality and decrease the high nitrate concentrations. Sufficient amounts of data and information have been acquired to implement these measures as soon as possible.

Further studies

A comparison between values from the dry and wet periods would be of great help for understanding the different influences of the water chemistry. It would also indicate how changes in climate (droughts, rainy periods, etc.) affect the water chemistry. Such a study could include how future climate change might affect the Altiplano area and the leakage of heavy metals. The properties of heavy metals should then also be studied to draw conclusions on whether an increasing drought, which is the most probable scenario for the Altiplano in the future, decreases leakage of heavy metals from the bedrock or not. Further studies of the wells and the groundwater should be carried out and be coupled with our superficial water data. Another interesting factor to study is the amount of organic material in water and sediment, especially since organic material absorbs heavy metals. By studying the organic material content, the reliability of the results from the heavy metal analysis could be estimated as a certain degree of absorption to organic materials occur. This study also lacks statistical tests of the historical changes in field parameters

Also, a study of facilities for cleaning wastewater and incoming drinking-water should be made. Where exactly are the drinking-water wells and the wastewater treatment plants (if any) located, how well do they function and how could one improve the water treatment? An exact definition of the location of the mines should also be made, including how much waste is produced, what type of environmental regulations are implemented, etc. An anthropological study should address the issue of how to deal with the problem of the possibly short lifespan for workers in cooperative mining. This problem is related to the hypothesis that workers might, because of their possibly shorter lifespan, start to care even less for the environment and their own health. The same workers also live in the villages that are polluted by the mining activities. Finally, and perhaps most importantly, a toxicology study should be performed to evaluate how the heavy metals accumulate in different organisms of different food chains. This study should include humans and those current health-issues in the area's population that can be related to exposure to the high levels of heavy metals. Coupled with scientific data from studies such as this one, the anthropological and mining studies would examine the cause of the contamination while an in-depth toxicology study would give a clear answer as to what is the effect of the contamination on the organisms living in the ecosystems of the Poopó area.

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