GIS Data assessment for Region II of Chile – Implications for international Water Resource Databases

GIS in Water Resources (CE 394K) Term Paper
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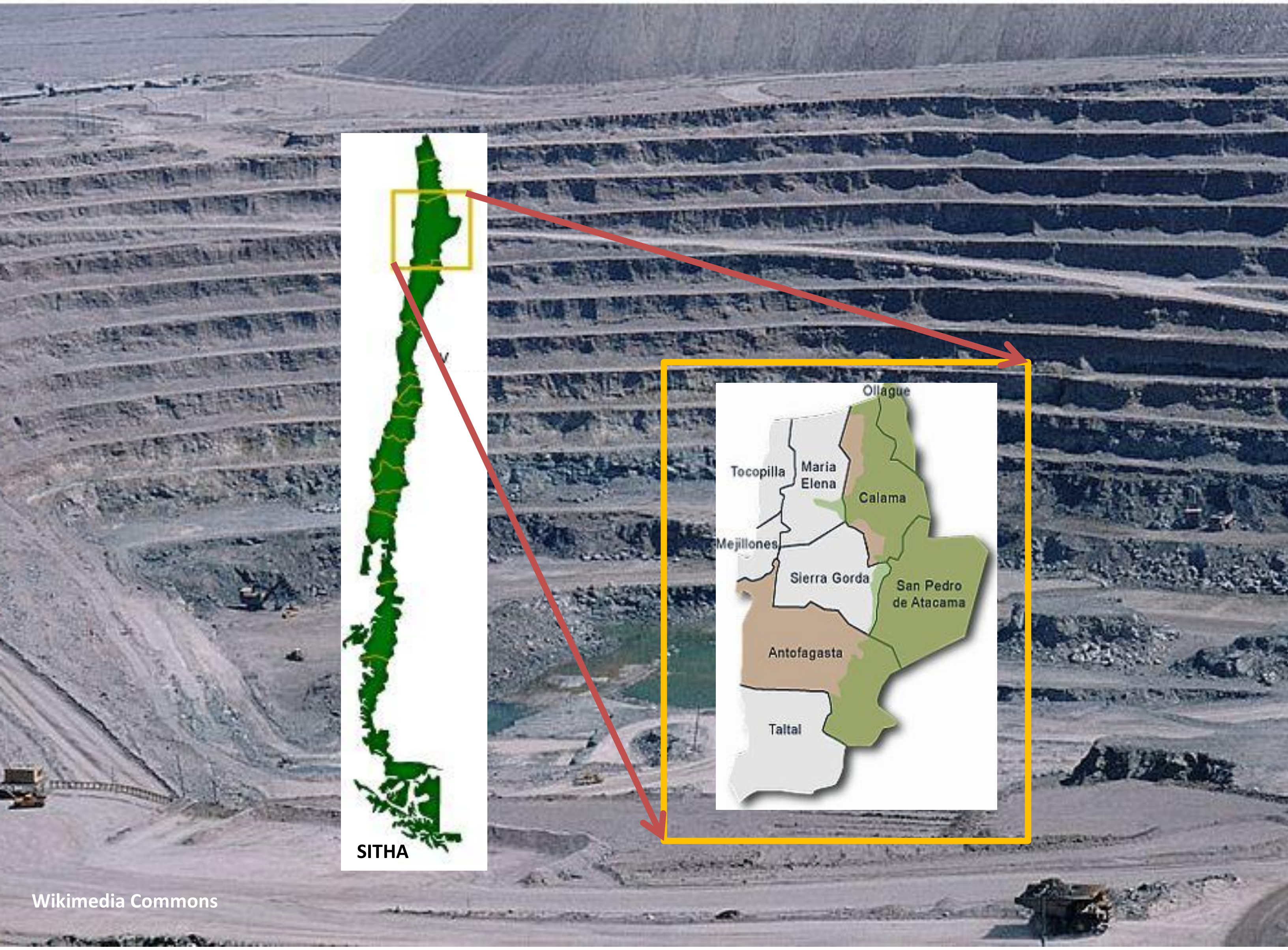


Part 1 – General Spatial Analysis of Region II of Chile

I. Outline

Region II of Chile, or the Antofagasta Region, is found in Northern Chile, and is one of Chile's primary 15 regions. The region is dominated by the Atacama Desert, and is one of the driest places on earth. As a result of the water-limited conditions within the region, this project hopes investigate surface water resources throughout the entire region.

Data is distributed amongst various ministries of the Chilean government. However, a central database open to the public does not exist. However, a database does exist specifically for Region II, from a wetland restoration program called SITHA. However, much of the data is outdated because SITHA must request data from the Chilean government to update their database. Since data is scattered, and usually outdated in the region, this project hopes to assess what type of analysis can be performed given the distribution of data for the region. This study is made up of two parts: 1) A broad scale analysis of water resources throughout Region II and 2) a local-scale investigation of water quality within the western part of Region II (Calama) where the landscape is dominated by extensive mining operations.

I. **Data Collection**

Data collection was the primary obstacle in GIS analysis for this project. Data for Region II of Chile is not only difficult to find, but also difficult to obtain. This is likely due to a combination of various factors, including the remoteness of the region, personal unfamiliarity with the region of investigation, language-barriers in searching for data, separation of data amongst various ministries of the government of Chile, and most importantly the lack of a single database open to the public.

Data was primarily collected from SITHA, which is provides a set list of data for region II, including a 30 m aster DEM, climate data, and data related to mining operations. However, in order to obtain important hydrologic features such as flowlines and basins Chilean ministries had to be contacted via e-mail in my second language, using rusty Spanish. Some responses were helpful; however, rather than receiving data useful for GIS analysis, images of maps that had previously been made for the region were received. The various organizations from which data was requested are shown in Figure 1. SITHA is shown as the primary data source since this is where most data was collected. Since most data from SITHA was outdated, further data was requested from “Direccion de Aguas” (DGA), which is where SITHA collects its data from. DGA provided important data sets such as basins and aquifers throughout the region; however, DGA redirected me to the “Ministerio del Medio Ambiente,” to collect data necessary for spatial analysis such as stream lines. Data necessary for water quality evaluation was also requested from the “Ministerio de Mineria” and the “Ministerio de Energia,” but a response was not received from these government entities.

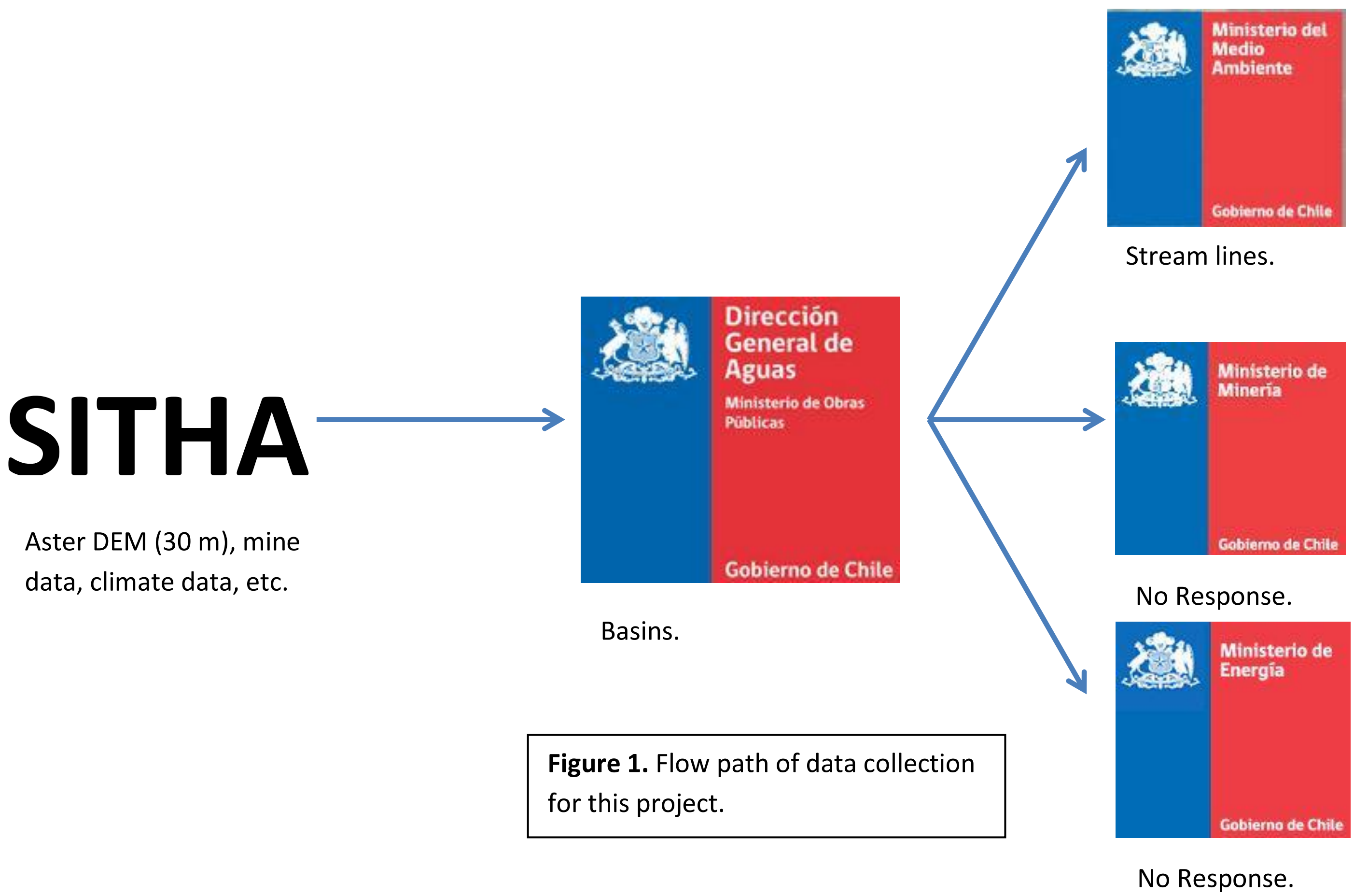


Figure 1. Flow path of data collection for this project.

The convoluted manner in which data had to be requested individually from various ministries of the government of Chile made data collection difficult. Furthermore, the only open public database, SITHA, provided helpful information; however much of their data is not continuously updated, resulting in old datasets.

II. General Spatial Analysis

Since I have never been to the study area in which this project is located, general spatial analysis was performed in order to familiarize myself with the region. The original goal of this project was to delineate watersheds; however, various problems were encountered in attempting to delineate watersheds. All data was projected in WGS_1984 UTM_Zone_19S.

Initial spatial analysis demonstrates that the elevation is highly variable throughout the region, ranging from 0 to 6,685 m (Figure 2a). Flat lying regions correspond to Salars, or salt flats, whereas higher elevations (with steeper slopes) correspond to volcanic mountain chains that run N-S along the eastern section of Region II (Figure 2b, 2c).

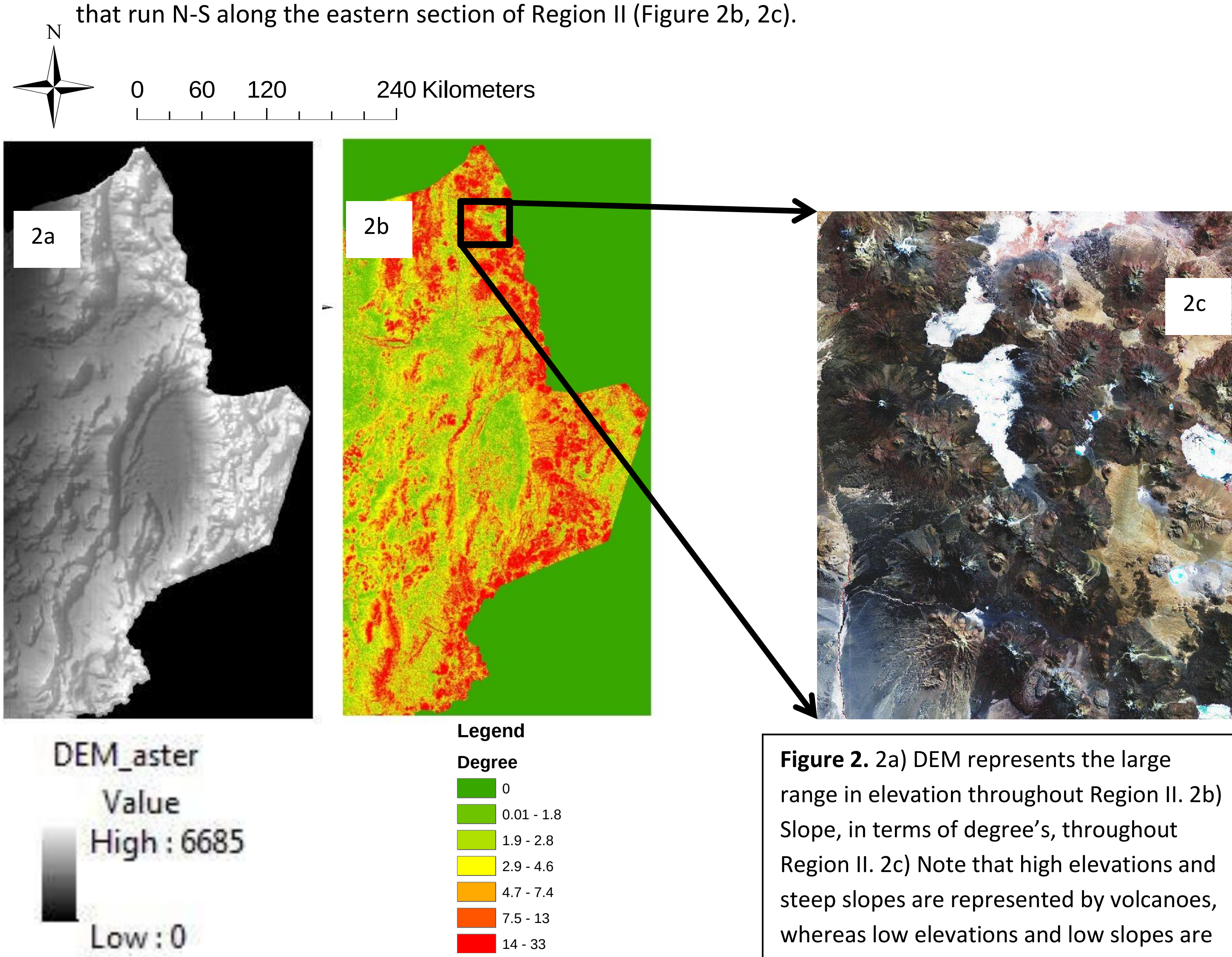


Figure 2. 2a) DEM represents the large range in elevation throughout Region II. 2b) Slope, in terms of degree's, throughout Region II. 2c) Note that high elevations and steep slopes are represented by volcanoes, whereas low elevations and low slopes are represented by salars (salt flats).

The mean annual precipitation and evapotranspiration throughout the region of study was investigated to demonstrate the arid conditions within the study area (Figure 3 and 4). The precipitation regime throughout Region II indicates that in the higher elevations to the east receive a greater amount of precipitation (ranging from 31 to 200 mm). While in the flatter areas to the west, precipitation ranges from 1 to 30 mm.

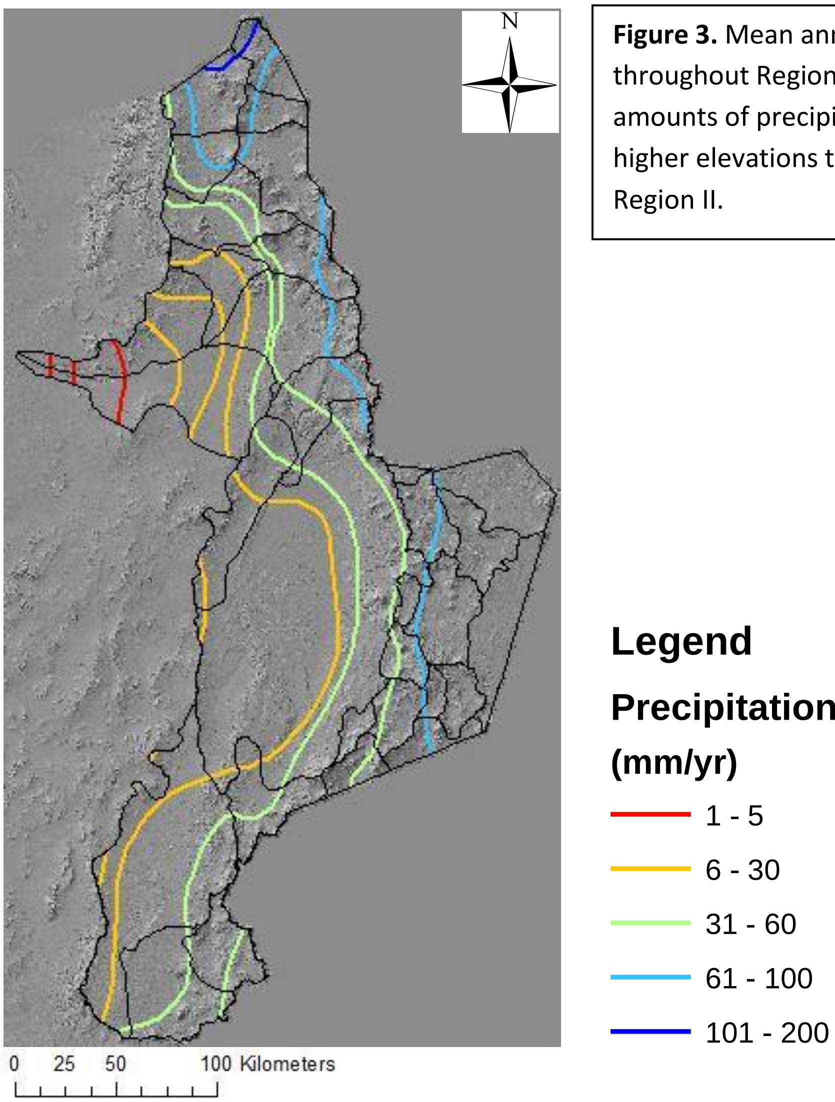
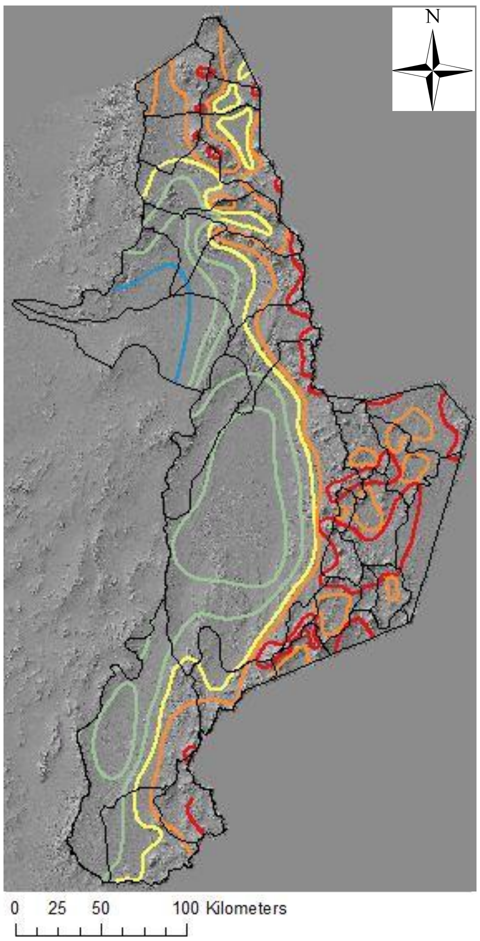


Figure 3. Mean annual precipitation throughout Region II. Greater amounts of precipitation occur at higher elevations to the east of Region II.

As expected, the greater amounts of evapotranspiration throughout the region coincide with areas that have greater amounts of water from precipitation. The mean annual evapotranspiration throughout Region II indicates that all precipitation inputs are taken up by evapotranspiration. Furthermore, it should be noted that greater amounts of evapotranspiration are associated with greater vegetation cover to the east of Region II.



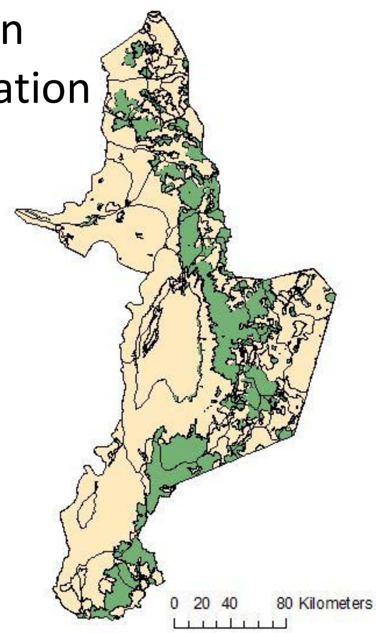


Figure 4. Mean annual evapotranspiration throughout Region II. Note that a greater amount of evapotranspiration is associated with greater vegetation cover.

Reliability of basins that were investigated in order to determine if they would be reliable for watershed delineation of the region. This was determined by overlaying their boundaries on a hillshade map of Region II. Since basins are separated by topographic highs, or volcanic mountain chains, the basins were considered reliable (Figure 5).

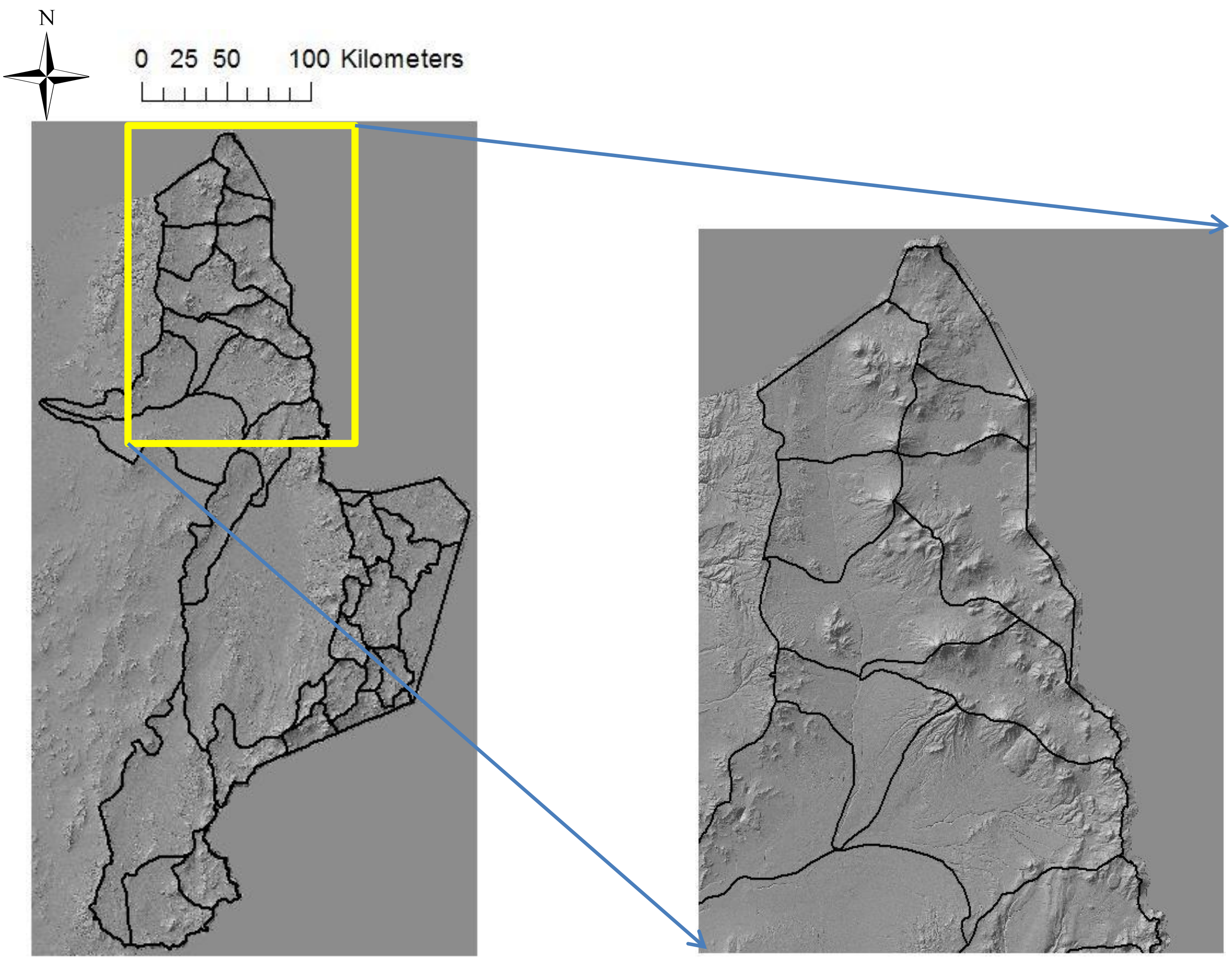


Figure 5. Basins are separated by topographic highs as they should be. This indicates that the data collected from DGA for basins is reliable, and may be used for general watershed delineation.

Stream Lines that were collected from “Ministerio del medio ambiente” were also analyzed to determine if they would be useful for watershed delineation. However, DEM reconditioning was not performed since the vector stream information was considered less reliable than the Raster DEM. This is a result of the disconnectedness observed in the stream lines (Figure 6). There are only a few major, perennial streams throughout the region, while the majority of the stream lines are non-perennial. Since mean annual flow values were not available for the non-perennial streams I was unable to determine the periods in which the streams flow. As a result of the complexity of the streams, such as disconnected features, and the likely case that the non-perennial streams flow rarely throughout the year, DEM reconditioning was not performed. Furthermore, the stream lines are not suitable for watershed delineation due to their lack of connectedness.

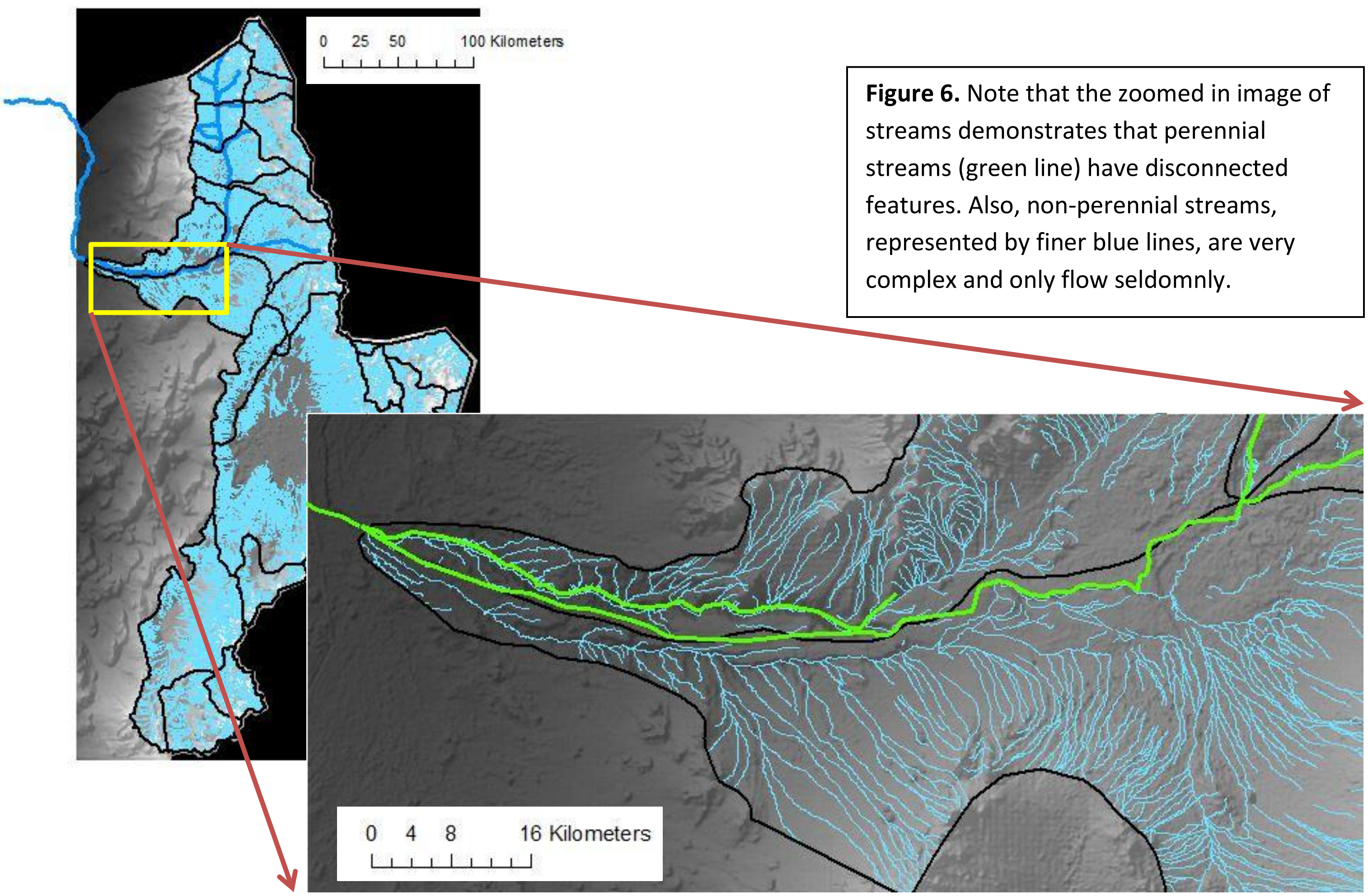


Figure 6. Note that the zoomed in image of streams demonstrates that perennial streams (green line) have disconnected features. Also, non-perennial streams, represented by finer blue lines, are very complex and only flow seldomnly.

Although stream lines were not reliable, a typical watershed delineation of Region II was attempted. However, various problems arose while performing such analysis. The fill tool did not work, resulting in many sinks in the DEM. Filling was then skipped, and the flow direction tool and flow accumulation tool was used. While the flow direction tool worked, after many hours of computer processing the flow accumulation tool was unable to calculate the flow accumulation grid. The flow accumulation tool may not have worked since GIS could not handle the size of the DEM being processed, or, possibly as a result of the many sinks within the associated DEM. Further watershed delineation was not viable at this point in the project as a result of various problems associated with the data needed to perform such analysis.

III. Conclusions

Various problems were encountered while attempting to perform watershed delineation. While some of these problems may have been possible to work out on GIS, many of the problems were inherently associated with the collected data. Implications from my experiences indicate that more reliable datasets must be made available to the public to allow for the investigation of water resources in remote, water-limited areas such as Region II of Chile. For Chile, this indicates that rather than having to send e-mails to collect data from various governmental entities within their country, a centralized database, with reliable data, should be developed for their Chile that is open to the public.

Furthermore, I believe that a global database is necessary to provide the framework that will allow individuals from afar to perform analysis of natural resources in remote areas, where resources such as water are limited. CUAHSI and ArcGIS Online serve as potential avenues in distributing data and information in an effective way to a wide population. However, these online resources need to be further developed on a global-scale. Furthermore, factors that must be taken into account include the filtering of unreliable data as well as possible language barriers that may arise. One of the major difficulties in obtaining data for this project involved having to communicate with professionals in my second language, which I am not entirely confident in. Furthermore, once data was received, attributes were displayed in Spanish, making data useful only to the extent in which I could understand them. A global database that takes into account language differences would bridge the gap between the difficulties that arise when collecting data on an international-scale. Considering the experiences encountered during basic watershed delineation of Region II, I plan to further develop the conversations that I have had with various government entities in Chile to encourage them to compile their data on a centralized database exchange such as CUAHSI or the USGS Seamless Server.

Part 2 – Copper Mines Influence on Water Quality in Calama of Region II

IV. Background

This part of the project focuses on a local-scale investigation of water quality in the province of Calama in Region II, where the landscape is dominated by extensive mining operations. Chile produces the greatest amount of copper in the world (Table 1). Furthermore, the region in which this study is performed (Calama) produces the greatest amount of copper in all of Chile (Contreras, 2008). The distribution of water samples and mines within the region of study is shown in Figure 8. A total of 31 samples, all falling along the major rivers of Region II, were available for the years 1999 and 2000 (SITHA). All mines within the area for that given time are included within the map. As a result of the temporal resolution of the collected data, this project is roughly 10 years outdated. Nonetheless, analysis was still performed, utilizing available data, to determine if copper mines within the area may affect surface water resources. The region is characterized by uranium-rich source rocks, which may result in high soil radiation levels; however the mines within the region likely enhance the concentration of contaminants due to extraction methods, such as leaching (EPA, 2011).

Rank	Country/Region	2006 Copper production (tonnes)	2009 Copper production (tonnes)
	World	15,100,000	
1	Chile	5,360,800	5,320,000
2	United States	1,220,000	1,310,000
3	Peru	1,049,933	1,260,000
4	China	915,000	960,000
5	Australia	875,000	900,000
6	Indonesia	817,796	950,000
7	Russia	675,000	750,000
8	Zambia	502,998	655,000
9	Canada	606,958	580,000
10	Poland	497,200	440,000

Table 1. Chile is the greatest producer of copper of all of the countries in the world.

The landsat image in figure 8 demonstrates that the location of copper mines within the region is associated with a shift in the composition of soils. Brown colors to the west are rich with porphyry minerals such as copper (EPA). Natural soils are expected to affect water chemistry; however, mines within the area may introduce a influence the concentration of contaminants as well. As such, analysis of water quality was performed to determine if water is potable within Calama and to determine if mines affect the quality of water within the region.

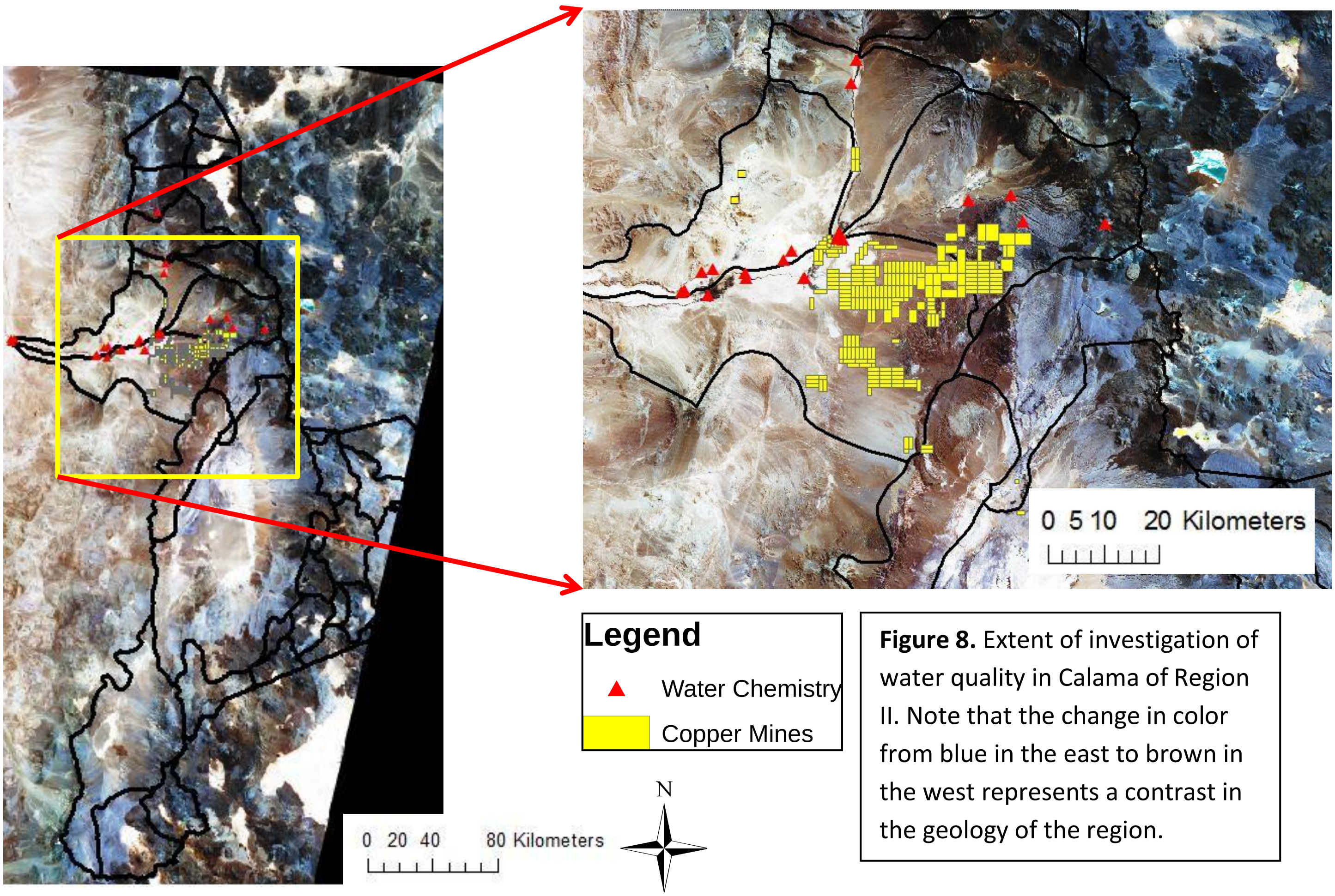
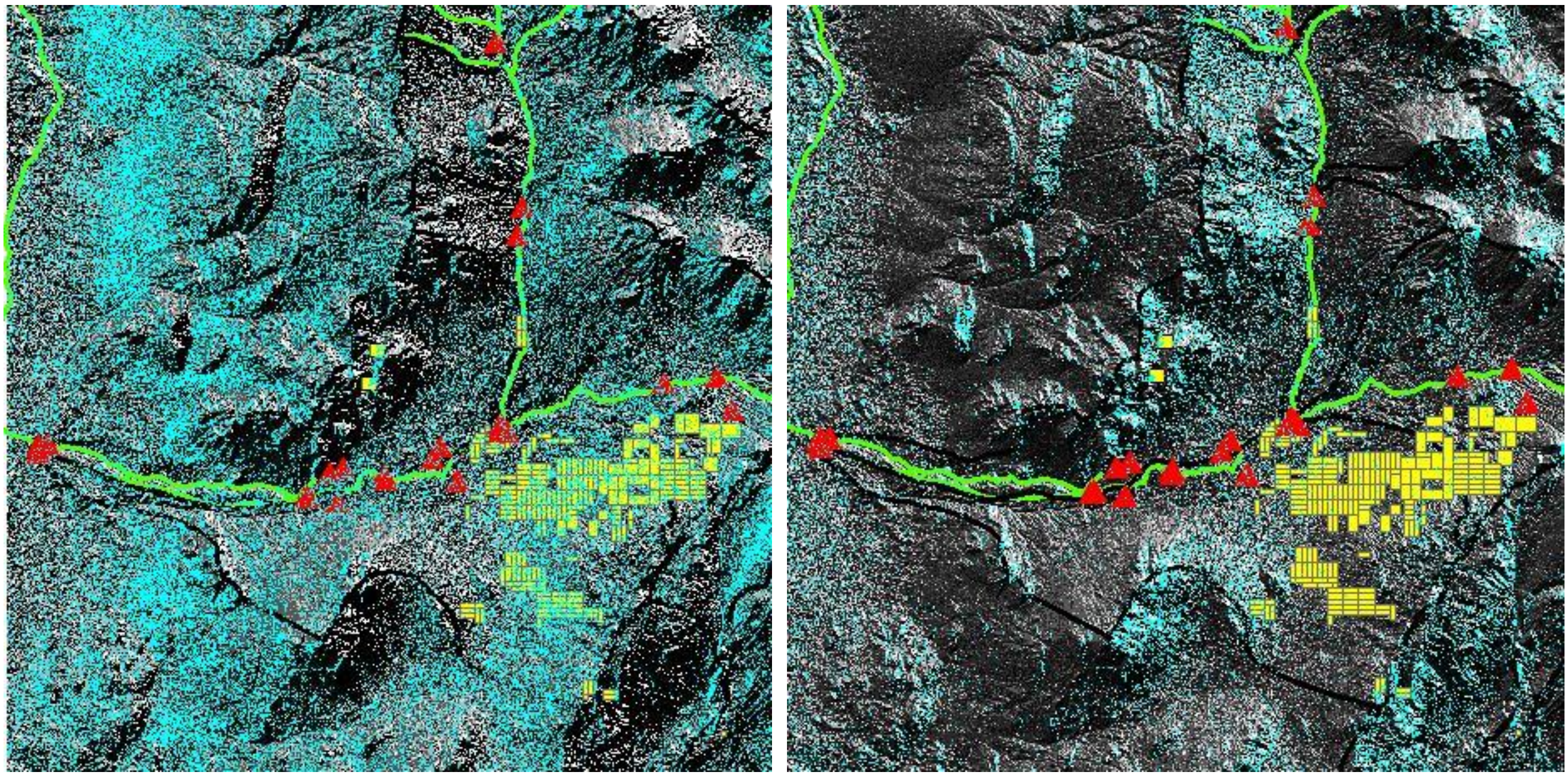


Figure 8. Extent of investigation of water quality in Calama of Region II. Note that the change in color from blue in the east to brown in the west represents a contrast in the geology of the region.

The natural neighbor interpolation method was used amongst the 31 data points that were collected to demonstrate the distribution of water chemistry. Preliminary prediction of the mines influence of water quality was determined by highlighting flow direction to the east and west of the mines (Figure 9). Water is shown to flow primarily to the west of the mines, suggesting that water is more likely to be contaminated in this direction. Maximum contaminant level (MCL) values and information from the environmental protection agency (EPA) were used to assess water quality within the study area (Table 2).



Flow Direction – West

Flow Direction –

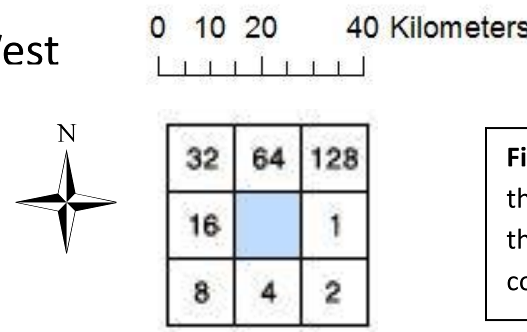


Figure 9. Predominant flow to the west of the mines indicates that water is more likely to be contaminated to west.

EPA Safe Drinking Water MCL Limits (µg/L)

pH	TDS	Nitrate	Fluoride	Al	Iron	Mn	Cu	Zn	Sulfate
6.5-8.5	500000	10000	4000	200	300	50	1300	5000	250000

Cd	Pb	As	Sb (Antimony)	Hg	Uranium
5	15	10	6	2	30

Table 2. Maximum contaminant levels (MCL) for various contaminants. Those boxed in red were analyzed in this study.

V. Results

Results from analysis of the water chemistry throughout west Calama of Region II indicates that water chemistry is likely affected by a shift in the natural and anthropogenic conditions of the region. The differences in the geology of the region as seen in the Landsat image as well as the mines likely affect water chemistry. High MCL values for contaminants may result from erosion of natural deposits. However, the corrosion of plumbing systems that may be associated with mines may cause an increase in the concentration of various contaminants as well. Furthermore, mines may influence water quality since the mining and extraction of copper can concentrate and expose radionuclides, resulting in the transport of contaminants in surface water (EPA, 2011).

The concentration of copper throughout the entire region exceeds the MCL value as suggested by the EPA (Figure 10). However, higher concentrations of copper are observed to the west of the mines, associated with the shift in geology. High concentrations of copper result from the erosion of natural deposits as well as the corrosion of plumbing systems (EPA, 2011). This indicates that the shift in contaminant levels is likely a result of the combined effects of the natural as well as anthropogenic conditions within the study area.

EPA MCL
1,300 µg/L

Legend

▲ ChemData

Copper Mines

Cu

1,926.806763 - 7,066.827321
7,066.827322 - 13,577.52003
13,577.52004 - 22,829.55703
22,829.55704 - 35,508.27441
35,508.27442 - 52,641.67627
52,641.67628 - 89,307.15625

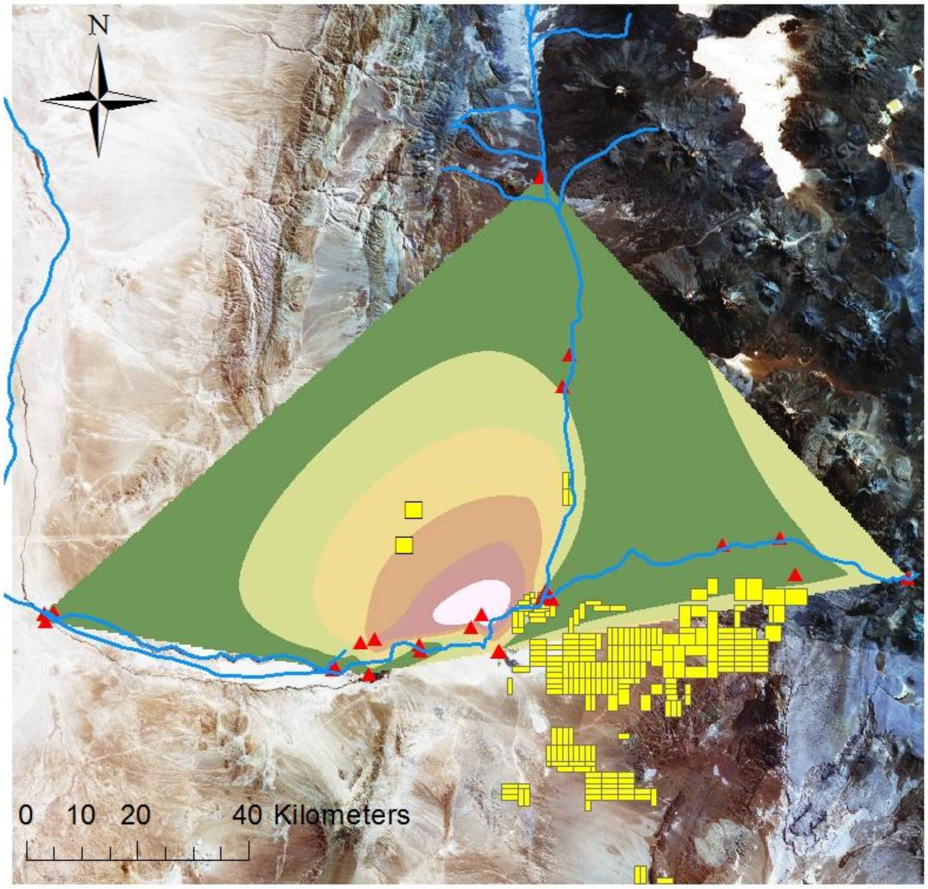


Figure 10. Copper concentration throughout the study area.

Variations in the extent of the distribution of the concentration for sulfate, iron, and aluminum vary; nonetheless, all of the contaminants exceed their respective MCL values with the shift in geology and to the west of the mines (Figure 11, 12, 13). All of these contaminants may be sourced from natural deposits as well as corrosion of plumbing systems, suggesting their high concentrations are a result of natural and anthropogenic influences. However, it’s worth noting that sulfat,iron, and aluminum fall under secondary drinking water regulations, since concerns regarding the concentration of these contaminants are not severe, as they can only cause water to smell bad, have an odd color, and/or taste odd (EPA, 2011).

EPA MCL
250,000 µg/L

Legend

- ChemData
- Copper Mines

S04

- 48,168.23 - 250,560.2
- 250,560.3 - 958,952.2
- 958,952.3 - 1,414,344
- 1,414,345 - 1,869,736
- 1,869,737 - 2,325,128
- 2,325,129 - 2,780,520

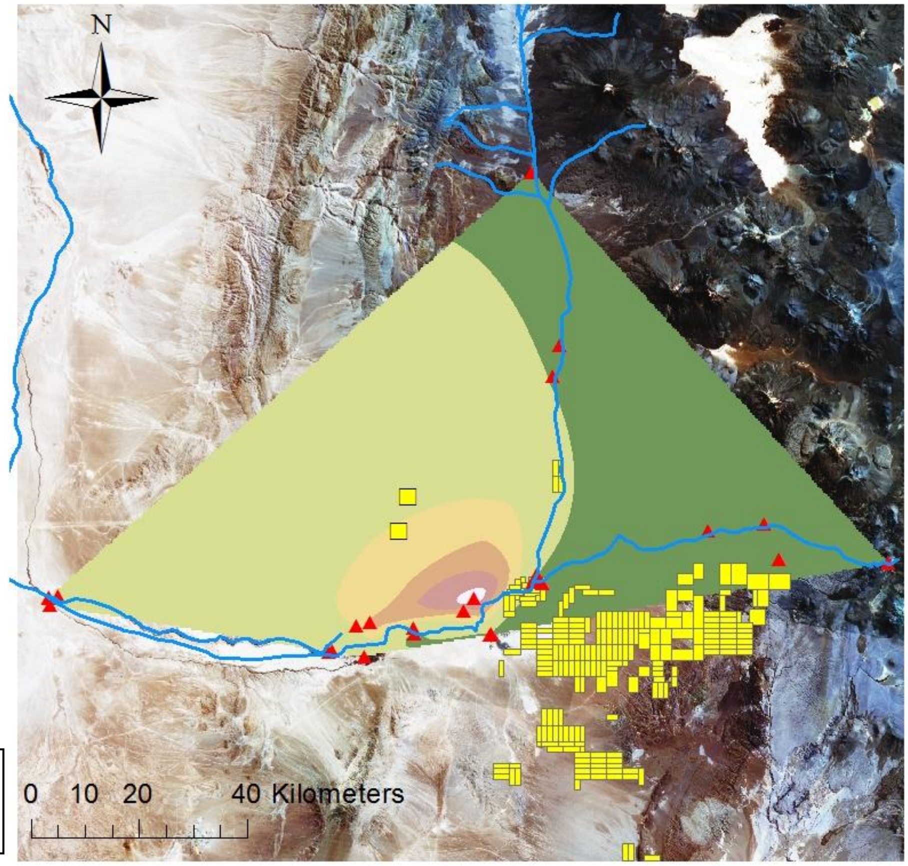


Figure 11. Sulfate concentration throughout the study area.

EPA MCL
300 µg/L

Legend

- ChemData
- Copper Mines

Fe

- 44.14 - 107.7
- 107.8 - 131.3
- 131.4 - 169
- 169.1 - 225.5
- 225.6 - 296.2
- 296.3 - 378.7
- 378.8 - 477.6
- 477.7 - 644.9

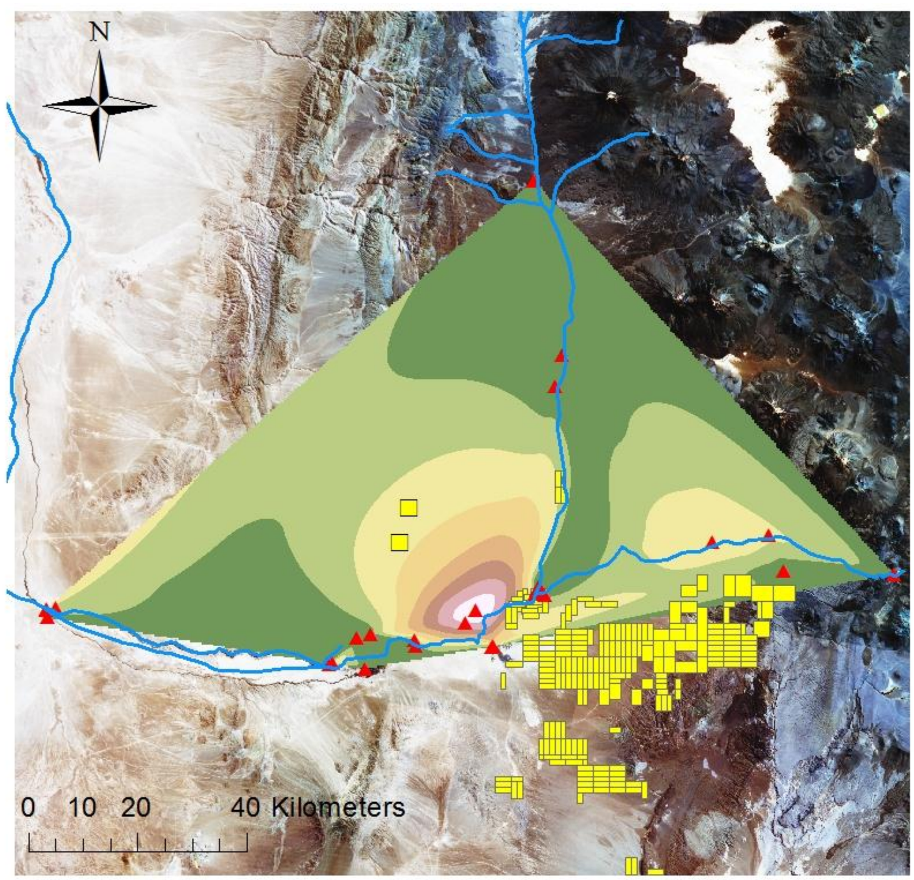


Figure 12. Iron concentration throughout the study area.

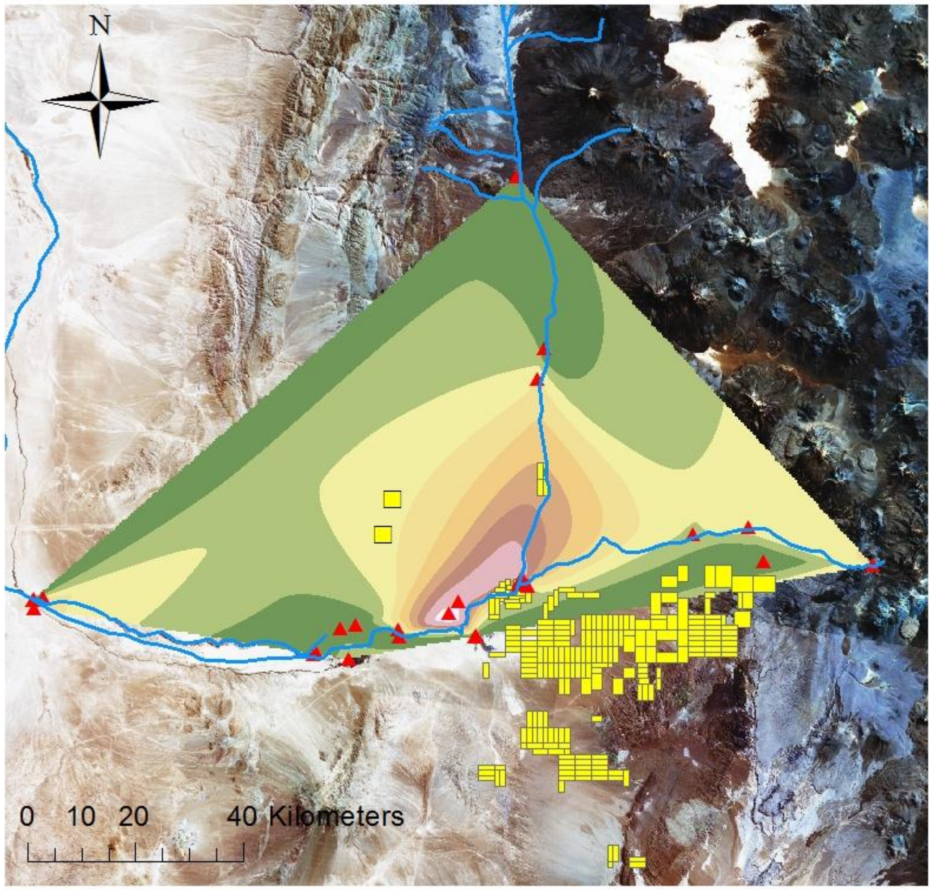


Figure 13. Aluminum concentration throughout the study area.

The concentration of antimony and arsenic, which may result from the discharge of waste from copper mines, both exceed their respective MCL values with the shift in geology and to the west of the mines (Figure 14 and 15). Antimony is typically sourced via discharge from mines, whereas arsenic may be sourced from natural deposits as well as waste discharge from electronics production wastes (EPA, 2011). The distribution of the high concentration of these two contaminants to the west of the mines indicates that mines influence the water quality in the region.

EPA MCL
6 µg/L

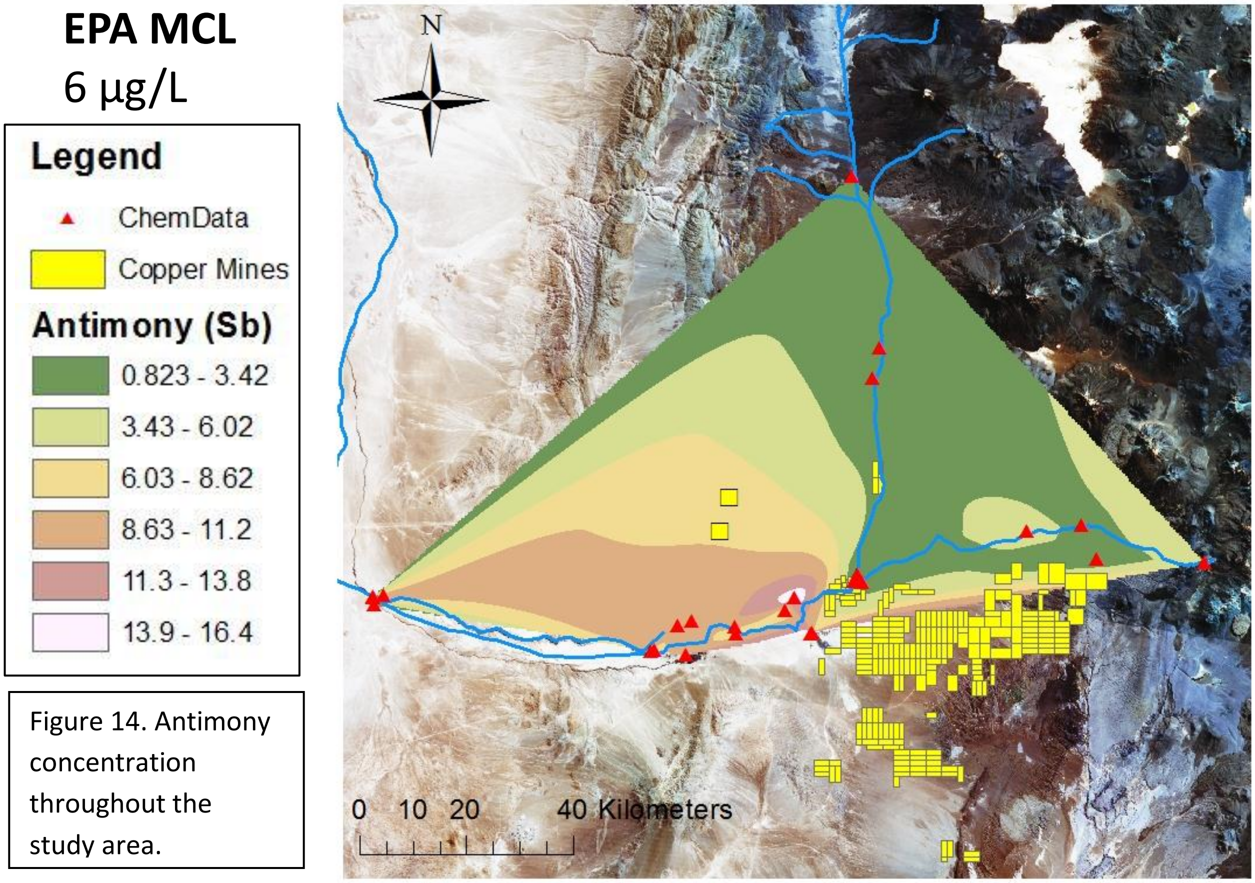


Figure 14. Antimony concentration throughout the study area.

EPA MCL
10 µg/L

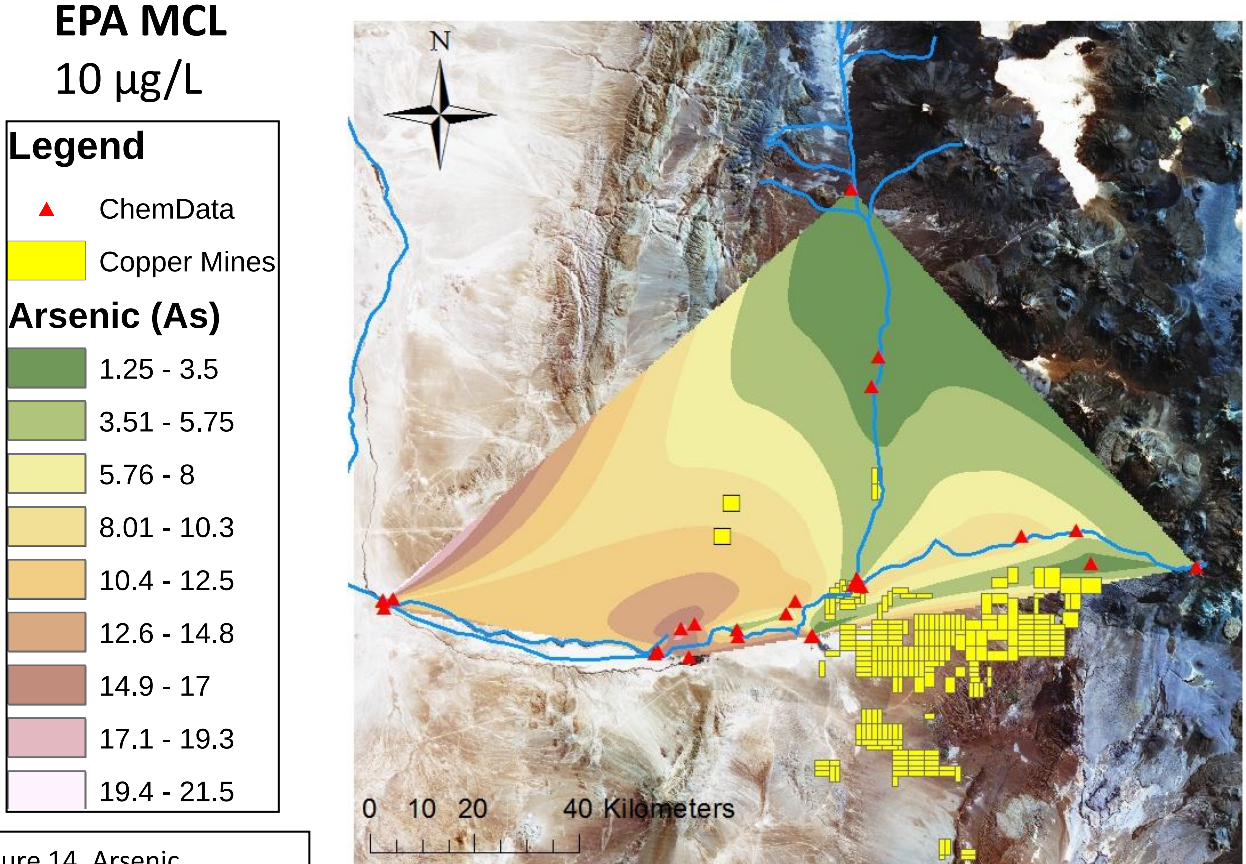


Figure 14. Arsenic concentration throughout the study area.

VI. Conclusions

For the given data set (31 water samples from 1999 to 2000) results indicate that water quality is affected by a combination of the shift in geology of the region as well as waste discharge from mines and possible corrosion of their plumbing systems. This has important implications for water management within the area. Moreover, the results indicate that the water within the western portion of the study area should not be consumed unless otherwise treated.

While analysis was successfully performed for this part of the study, analysis of the current state of water quality in Calama of Region II could not be performed because up-to-date data is not available to the public. Overall results, from this study, including part 1 and part 2, suggest that we must work towards developing a broader, open exchange database that allows for GIS analysis in order to assess our natural resources.

VII. Data Sources

http://sitha.ciren.cl/

http://www.dga.cl/

http://www.mma.gob.cl/

VIII. References

Contreras, Ernesto, 2008. Las comunidades Indigenas y su participacion en la politica nacional de energias renovables no convenciales. Ministerio del Medio Ambiente, Gobierno de Chile.

Environmental Protection Agency (EPA). Drinking Water Contaminants. November 24, 2011. http://water.epa.gov/drink/contaminants/index.cfm