Hydrochemical assessment of the Canray Chico catchment in the Cordillera Blanca

Abstract

Mountain ecosystems fulfill essential hydrological functions, as they act as important water resources and regulators (Molina et al., 2007; Buytaert et al., 2006). Glaciers are of great importance as they act as water reservoirs; 40% of the discharge during dry season in the Cordillera Blanca originates from glacial melt (Fortner et al., 2011). The glaciers in the Cordillera Blanca are retreating (Mark et al., 2010) and a long-term loss of the water storage is predicted (Mark et al., 2005). With this the quality of the water is of importance, especially since concern about the water quality has been raised. This paper conducts a hydrochemical assessment, including field work, chemical analysis and GIS processing, in the Canray Chico catchment. Values of pH, EC_{25} and concentrations of anions and cations were compared to drinking water quality standards in order to validate the water quality in the catchment. It should be stressed that no biological assessment was conducted, which is essential for a complete analysis of the water quality. The water quality in southern parts of the catchment was found to be good, whereas the water quality in the northern part in the Río Negro seems to be affected. The source of the Río Negro has high EC_{25} values (1529 µS/cm & 1030 µS/cm), a low pH of 3.8 and is highly polluted with sulfate (767.5 mg/L), aluminum (25.83 mg/L), iron (52.65 mg/L), manganese (5.93 mg/L), copper (0.47 mg/L), nickel (0.57 mg/L) and indium (0.15 mg/L). Downstream the contamination gets diluted, but stays present. The Río Santa is equally polluted as the Río Negro. An interesting spring was found in the western part of the area with a very high mineral content: chloride (>2729.88 mg/L)[1], potassium (647.87 mg/L), sodium (4446.88 mg/L), calcium (168.19 mg/L), strontium (9.02 mg/L), lithium (59.51 mg/L), arsenic (0.1 mg/L), boron (278.95 mg/L) and barium (0.96 mg/L). Since the ion composition is different than in the Río Negro, another origin is suspected, e.g. groundwater. The water was analyzed according to its recommended use for drinking, livestock, poultry and irrigation and it was found that the waters in the agricultural western part of the research area should not be used for irrigation. With exception of the peculiar spring and the source of the Río Negro, water is suited for livestock. Upper areas of the Río Negro are not recommended for poultry. The river is not drinkable, but its side streams can be used as drinking water. The origin of the pollution is believed to be at the source of the Río Negro. Furthermore, results have been compared to a modeled pollution map of the Cordillera Blanca by Aguierre Gutierrez et al. Discrepancies can be found especially for the source area in the higher part of the catchment. Lower parts with a medium contamination are modeled satisfactorily. The main outcome for local communities is the fact that the surface water pollution is purely natural and not of anthropogenic origin.

[1] Sample had to be diluted more than 20 times due to its high concentration; shown concentration could still be underestimated by 5-10 times, since concentrations were still too high for analysis.

Resumen

Las ecosistemas de montañas cumplen importantes funciones hidrológicas, actuando como recurso y regulador en el ciclo hidrológico (Molina et al., 2007; Buytaert et al., 2006). Los glaciares son de gran importancia ya que actúan como reserva de agua; de echo, el 40% de la descarga durante la estación seca en la Cordillera Blanca se origina a partir del derretimiento de los glaciares (Fortner et al., 2011). En la actualidad, los graciares de la Cordillera Blanca están disminuyendo (Mark et al., 2010) por lo que se ha pronosticado una perdida a largo plazo de los depósitos de agua (Mark et al., 2005). No solo la cantidad, también la calidad de estas aguas es de suma importancia para su uso, especialmente en la cuenca hidrográfica del Canray Chico, dónde dudas sobre la calidad de sus aguas han sido expuestas. Este articulo presenta un estudio hidroquímico. Para su realización ha sido necesaRío efectuar trabajo de campo, análisis químicos y procesado de data mediante SIG. La calidad del agua de la cuenca fue cualificada mediante análisis de pH, EC_{25} y concentraciones de aniones y cationes cuyos valores fueron validados con los estándares de calidad de agua disponibles. Cabe mencionar que no se llevó a cabo análisis biológico, el cuál es esencial para llevar va cabo un análisis de calidad de aguas completo. Las aguas en la vertiente sur de la cuenca parecen tener una buena calidad, mientras que las aguas localizadas en la vertiente norte, en el Río Negro, parecen estar contaminadas. Las aguas provenientes del Río Negro presentan elevados niveles de EC_{25} (1529 µS/cm & 1030 µS/cm), con un pH ácido de 3.8 y niveles elevados de contaminantes como sulfatos (767.5 mg/L), aluminio (25.83 mg/L), hierro (52.65 mg/L), manganeso (5.93 mg/L), cobre (0.47 mg/L), níquel (0.57 mg/L) e indio (0.15 mg/L). Aguas abajo los contaminantes parecen diluirse, aunque aun están presentes. El Río Santa presenta el mismo tipo de polución que el Río Negro. Adicionalmente, en el área occidental de la cuenca existe un manantial que presenta elevados niveles de: cloruro (> 2729,88 mg / L)[2], potasio (647,87 mg / L), sodio (4446.88 mg / L), calcio (168,19 mg / L), estroncio (9,02 mg / L), litio (59,51 mg / L), arsénico (0,1 mg / L), boro (278,95 mg / L) y baRío (0,96 mg / L). Aunque debido a una composición ionica diferente a la del Río Negro se sospecha otro origen, por ejemplo, a través de las aguas subterráneas. Las aguas fueron análizadas y validadas de acuerdo con las recomendaciones establecidas para consumo humano, uso en ganadería y uso en agricultura. Los resultados muestran que en la parte occidental del área de estudio las aguas no cumplen con los requiusitos para su uso en irrigación. En general, el agua se considera apta para su uso en ganadería, a excepción del peculiar manantial encontrado y del Río Negro. En las zonas altas del Río Negro no se recomienda la cría de aves. El Río se considera no apto para consumo humano, aunque las corrientes laterales si se consideran potables. Los resultados sugieren que el origen de la contaminación parece encontrarse en la fuente del Río Negro. Además nuestros resultados se han comparado con un mapa de contaminación modelado por Aguirre Gutiérrez et al. para la Cordillera Blanca. Se ha encontrado que la mayores discrepacias se encuentran en la parte alta de la cuenca, especialmente en el área del origen, mientras que las partes infeRíores, con una contaminación media, se modelan satisfactoriamente. El resultado de mayor relevancia para las comunidades locales es el hecho de que la contaminación de las agua superficiales es puramente natural y no de origen antropogénico.

[2] Muestra estuve diluido más de 20 veces por la concentración alta; sin embargo la concentración puede ser subvalorado 5-10 veces porque concentración todavía estuve demasiado alta.

Introduction

Mountain ecosystems fulfill essential hydrological functions, as they act as important water resources and regulators for agriculture, food production and hydro power generation (Molina et al., 2007; Buytaert et al., 2006). The Peruvian Andes are characterized by enhanced precipitation due to their orography (Kaser et al., 2003). Glaciers are also of great importance as they act as water reservoirs, 40% of the discharge during dry season in the Cordillera Blanca originates from glacial melt (Fortner et al., 2011). The hydrological response of mountain catchments is controlled by biotic and abiotic factors, such as chemical and physical characteristics, vegetation type and density, and local topographical features (Molina et al., 2007).

Water resources are stressed by human activities like mining and agriculture. Recent events show a mistrust of the general population towards mining activities, which results in the attitude of the public that every possible contamination of surface waters can be accredited to mining companies. In view of these socioeconomic problems it is important to examine waterbodies objectively. Additionally, global warming might bring further water related problems in the future. The competition for water in the Río Santa watershed is already increasing (Lynch, 2012). With this the quality of the water is of importance. Mayor cities at the coast of Peru, especially Lima, depend on the water supply from the Andean communities. Thus, it is essential that water resources and their quality can be maintained for the future. Impractically, concern about the water quality in the catchment has been raised since some rivers possess atypical coloring. It is of interest for the community to assess the water quality and with that the origin of this suspected pollution in the catchment. Geological, geomorphological and biotical factors are also of interest since water quality downstream of retreating glacier fronts relates not only to water management practices, but also to natural biogeochemical cycling (Fortner et al., 2011). This paper aims to assess the hydrochemistry of rivers in the Canray Chico catchment to get more insight into these dynamics.

Aim and research questions

The main aim is to determine if the potential pollution map by Aguierre Gutierrez et al. represents the actual pollution of the area (model validation). This will be done by answering the following research questions:

1. What is the chemical water quality (indicators: pH, EC, anions and cations)?
2. Can the origin of the polluted water be determined?
3. Which animal routes should farmers change in order to avoid that cattle drink from polluted water?

Expectations

The geology of the area is characterized by zones which show a high degree of mineralization. This influences the hydrochemical composition of ground and surface waters. Therefore a natural hydrochemical pollution of the waters is expected. Whether concentrations are exceeding water quality regulations, needs to be determined. Through the detailed assessment of the area, we expect to get an idea about the source of the pollution. However, since there are no mines in the area, the pollution will be natural.

Field work area

The field work was conducted in the Canray Chico catchment of the Cordillera Blanca, Peru. The mountain range contains more than 25% of the world's tropical glaciers (Mark et al., 2010), with an extent of 631 m² (Suarez et al., 2008 in Baraer et al., 2009).The area of the studied catchment has an extent of 115.2 km², ranging from 3400 to 5300 m a.s.l. with 10% of the area being glaciated (Mark et al., 2010). The Río Negro, as well as other rivers and streams that drain into the Río Santa can be found. The area contains three major rivers: the Río Negro in the north and another river in the south of the area. Both stream toward the Río Santa in the west (Figure 1). The Río Santa divides the Cordillera Blanca from the Cordillera Negra. It flows northwest, is 300 km long and drains a total watershed of 12.200 km² (Mark et al., 2005). It originates from a lake called Laguna Conococha at 4000 m a.s.l. (Baraer et al., 2009).

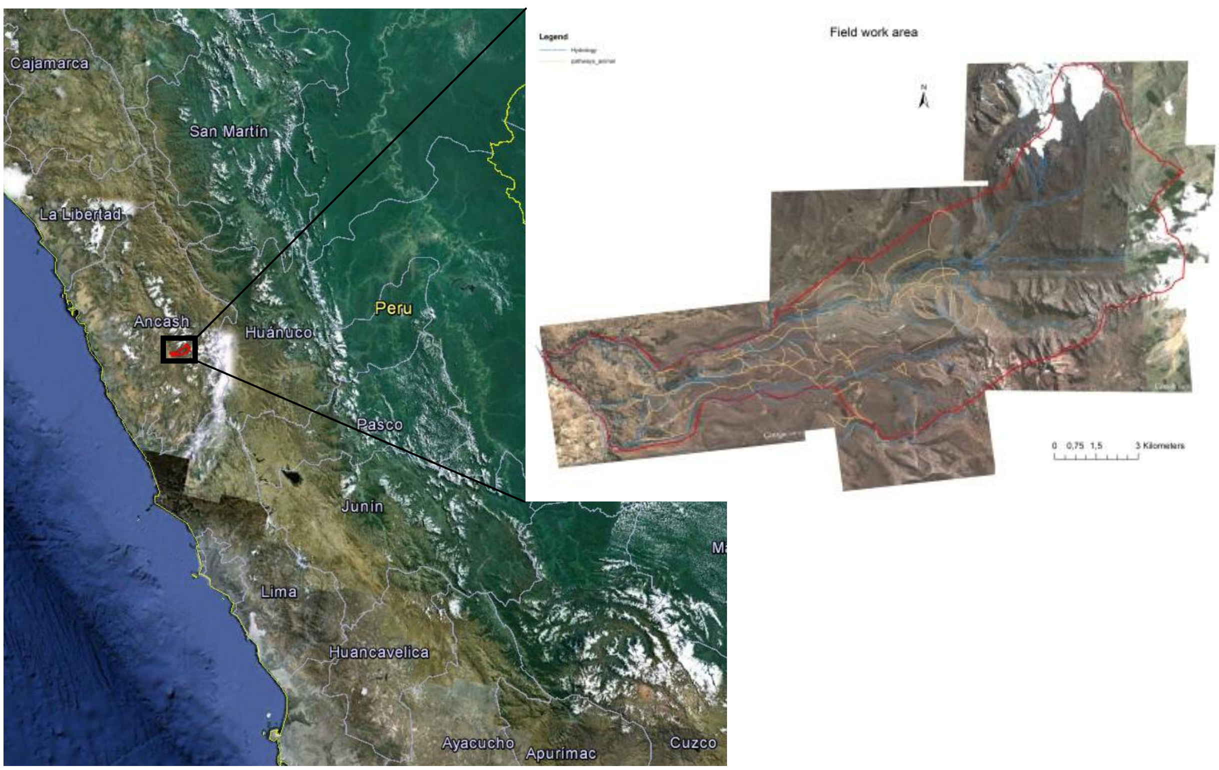

Figure 1: Location of the field work area in Peru.

In lower parts of the area agriculture and smaller settlements are present (communal grounds), whereas the higher areas are part of the Huascaran National Park. In the middle of the research area the Puna ecosystem, which is characterized by high grasses and small shrubs, is present. Higher areas are characterized by scarcer vegetation – the superpuna. The area furthermore possesses numeral moraine ridges and is covered in glacial tills. Also river incisions and alluvial fans are found. Main geologic formations are the Chicama and the Calipuy formations (see Figure 2). The Chicama formation consists mainly of Mesozoic dark colored sandstones with many shale intercalations. It originates from deltaic environments and contains pyrite (Sevink, 2009). The Calipuy group is of Cenozoic age and contains volcanic strata, mostly coarse andesitic pyroclastic rocks

(Sevink, 2009). Furthermore fluvio-glacial, glacial and alluvial deposits are present. An intrusion of granodiorite can be found. Predominant soil types are umbrisols, histosols and regosols. Umbrisols and histosols are mostly present in the middle of the area, predominantly close to wetlands, the regosols are mainly found in the agricultural area in the west. There are no mines in or near the field work area.

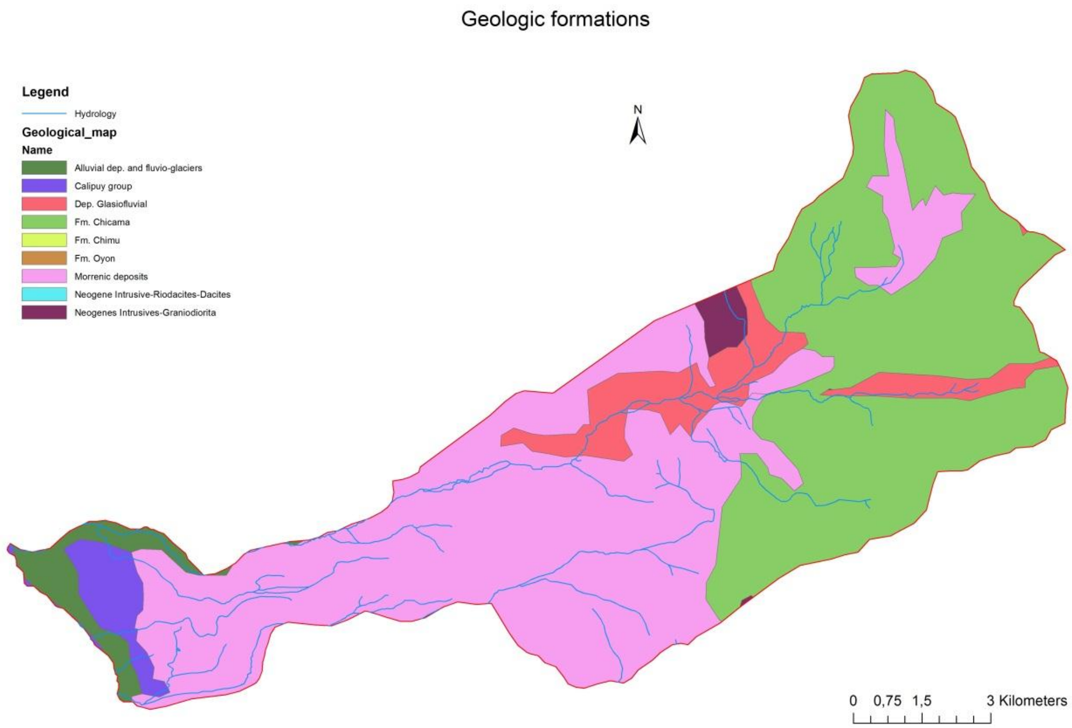

Figure 2: Geologic formations of the field work area, with rivers and irrigation channels.

A typical tropical climate is at hand, where the average annual air temperature is less variable than the daily temperature range (Baraer et al., 2009). Approximately 80% of precipitation falls in the wet season between October and May (Baraer et al., 2009). Glacial melt provides 10 to 20% of annual discharge, with a higher percentage during the dry season (Mark et al., 2005). This makes the watershed vulnerable for droughts, especially in the view of glacial retreat (Baraer et al., 2009).

Methods

Field methods

The field survey was done along transects to determine the general geologic, geomorphologic, hydrologic and soil characteristics of the research area. Field points were made at for each area representative points. Data was recorded by means of field forms, of which an example can be found in the annex (see Table I). Additionally, soil and water samples were taken. For all water samples EC_{25} and pH were measured directly, a part (40) was also analyzed in the laboratory for additional information. The sampling was done in the dry season with minimum river discharge.

Methods in the laboratory

The 40 Water samples were filtered by a 2 µm filter. pH was determined. Alkalinity was identified by means of titration. A pipet volume of 15 ml was used. Samples with a pH < 7 were titrated by means of 0,0111M hydrochloride acid, whereas samples with a higher pH were titrated by means of 0,1M hydrochloride acid. Furthermore sample JMJ_06 needed to be diluted (2 ml sample, 13 ml demi water) due to its high EC_{25}. The water samples have been further analyzed for cations and anions by staff of the UvA. Between different working processes samples have been stored in the freezer.

GIS methods

ArcGIS 10 was used in preparation to visualize the area, in terms of expected geology, geomorphology and land use. Google Earth images were used to get a general idea of the area. All sample locations (field points, water samples and soil samples), with their corresponding data, have been processed in GIS. Polygon maps of geomorphology and land use were produced. Animal paths and hydrology have also been drawn in GIS, based on field observations and Google Earth images. Some of the data from the field points have been converted into a surface covering map using a discrete model for spatial interpolation, Thiessen Polygons. After fieldwork, GIS was used again mostly to visualize the results.

Analysis methods

Before visualizing the results in GIS all concentrations of cations and anions were compared with drinking water quality standards from EU (Drinking Water Directive, 1998.), WHO (World Health Organization, 2011), Canada (Health Canada, 2012), EPA (Environmental Protection Agency, 2009), NamWater (Namibia Water Corporation Ltd.) and one ground water quality standard from the department of environmental protection in New Jersey for some of the missing boundaries (Ground Water Quality Standards, 2011). For each ion the contamination was classified in four classes, which can be seen in Table 1.

Table 1: Contamination classes for single cations and anions.

Class	Contamination	Concentration	Assigned value
1	No contamination	Below drinking water standards	0
2	Low contamination	Less than 25% above drinking water standards	1
3	Medium contamination	Between 25% and 100% above drinking water standards	3
4	High contamination	More than twice the drinking water standard	9

For each sample concentrations of ions have been determined in the lab. Each ion received an assigned value according to the classes in Table 1. Thus, every sample contained the values of several different ions. These assigned values have been added up together to result in a total cation-anion contamination value for each sample. This total contamination was again divided into five categories, which were visualized in GIS. The categories are listed with their contamination value in Table 2.

Table 2: Categories of summed anion and cation contamination of the samples.

Category	Contamination	Total contamination value
1	No contamination	0
2	Low contamination	1-10
3	Medium contamination	11-30
4	High contamination	31-50
5	Very high contamination	> 50

Based on the field EC_{25} a similar map was made. The EC_{25} values were divided into five categories (Table 3) based on usability for drinking (Environmental Protection Agency, 2012), irrigation (Bauder et al., 2012), livestock and poultry (Ayers and Westcot, 1994). This is just a first indication of water quality based solely on EC_{25}, not taking into account which minerals cause this.

Table 3: Categories of EC_{25} values according to their use as drinking water, for livestock, poultry and irrigation.

Category	EC_{25} (µS/cm)
Satisfactory	<150
Satisfactory for drinking, livestock & poultry, not recommended for irrigation	150-250
Satisfactory for livestock & poultry, not recommended for drinking & irrigation	250-500
Satisfactory for livestock, not recommended for drinking, irrigation & poultry	500-1100
Not recommended for any use	>1100

To analyze the pH only three classes were used: pH < 5.5, pH = 5.5-6.5 and pH = 6.5-8.5, the last being the best category, based on European (Drinking Water Directive, 1998) and Canadian (Health Canada, 2012) standards for drinking water. Higher pH values were not found.

Results of the hydrochemical assessment

The chemical water quality has been assessed by means of pH, EC_{25} and concentrations of cations and anions. 40 water samples were taken in the field and analyzed in the lab. Further 125 points have been measured directly for pH and EC_{25} during the fieldwork.

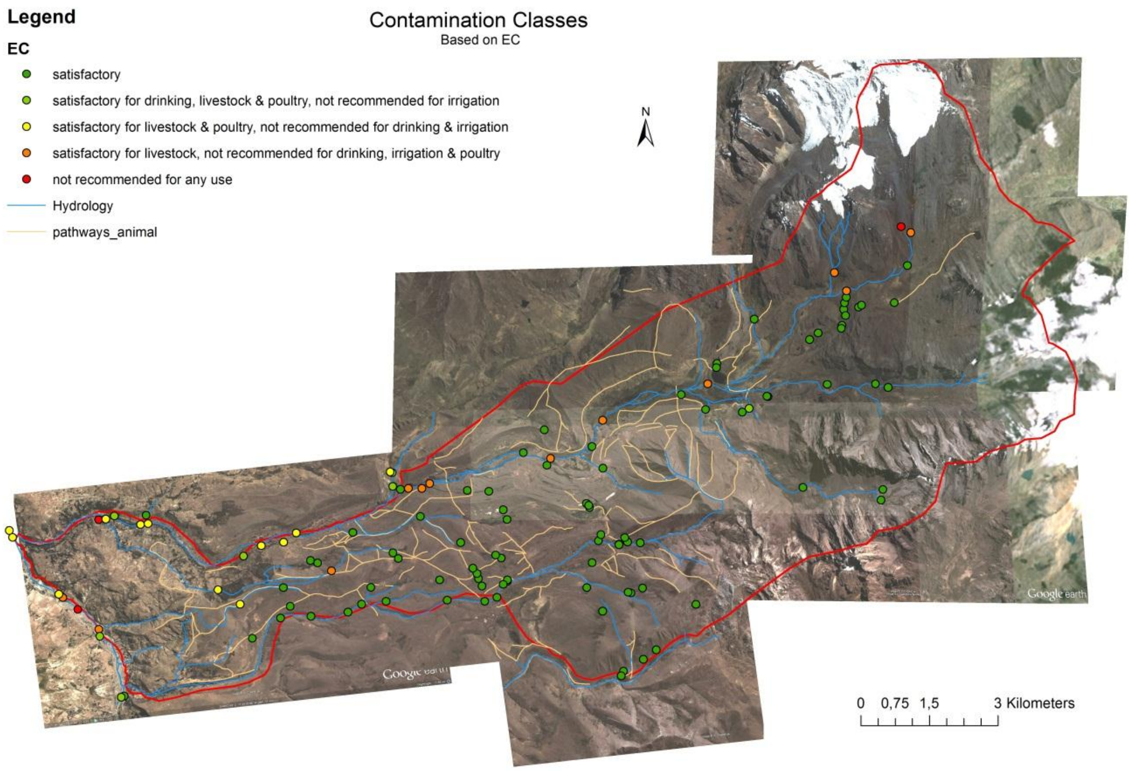

Figure 3: Contamination classes based on EC_{25}. Classes are based on standards from the Environmental Protection Agency (2012) for drinking water, Bauder et al. (2012) for irrigation water and Ayers and Westcot (1994) for water used for livestock and poultry. Sample IDs can be found in Figure I in the annex.

The electrical conductivity, EC_{25}, gives an overview of dissolved organic solids in water and serves as a first indicator of water quality in the field, but does not show which ions cause its enhanced values. In Figure 3 one can see different contamination classes based on the EC_{25} measured in the field. It is striking that most samples taken in the western area, which is characterized by agriculture and settlements, are neither recommendable as drinking water nor for irrigation. The water is still usable for livestock and poultry. The two red points are a sample in the Río Santa (2030 µS/cm) and a very peculiar small spring of bubbling water that comes out of the ground and builds up a cone like formation (JMJ_06). Its EC_{25} value is 21.500 µS/cm and it holds a high mineral content, which will be discussed in the following paragraphs (see Figure 4). Southern areas possess a satisfactory chemical water quality in accordance with EC_{25}. Only one value can be found (RTL_irrigation: 548.5 µS/cm) that is not recommended for drinking, irrigation and poultry. This sample was taken in an irrigation channel. The two yellow sample points west of it, Hua02 (410 µS/cm) and TM_2 (480 µS/cm),

Figure 4: Photo of the particular spring JMJ_06.

were also taken in irrigation channels. The samples along the Río Negro show very mixed values. Starting at the eastern part of the field work area, we find two sources with very high EC_{25} values (DRLR_26_W2: 1529 µS/cm, DRLR_26_W3: 1030 µS/cm). The water sample just south of it marks a cleaner stream that joins the main river. Side stream UP_5 shows a very high EC_{25} value of 683 µS/cm as well, but the next side stream (JRJ_02A) appears to be fine. Following the Río Negro EC_{25} values stay high, which indicates that it is not recommended for drinking, irrigation and poultry. The use of the water for livestock is fine. The next side river coming from the northern valley, JCJ_W_04, is only slightly polluted, but the water use is still appropriate for drinking, livestock and poultry. Right next to it in another irrigation channel sample JCJ_W_05 (271 µS/cm) should neither be used as drinking water nor for irrigation. Downstream of the Río Negro EC_{25} values get slightly better, but the water is still not recommendable as drinking water or for irrigation, as we have discussed above. Samples in wetlands appear mostly satisfactory, only one in the lower part is not recommended for irrigation use and drinking water. Rivers in the east-southern valleys possess low EC_{25} values and waters are satisfactory for any use.

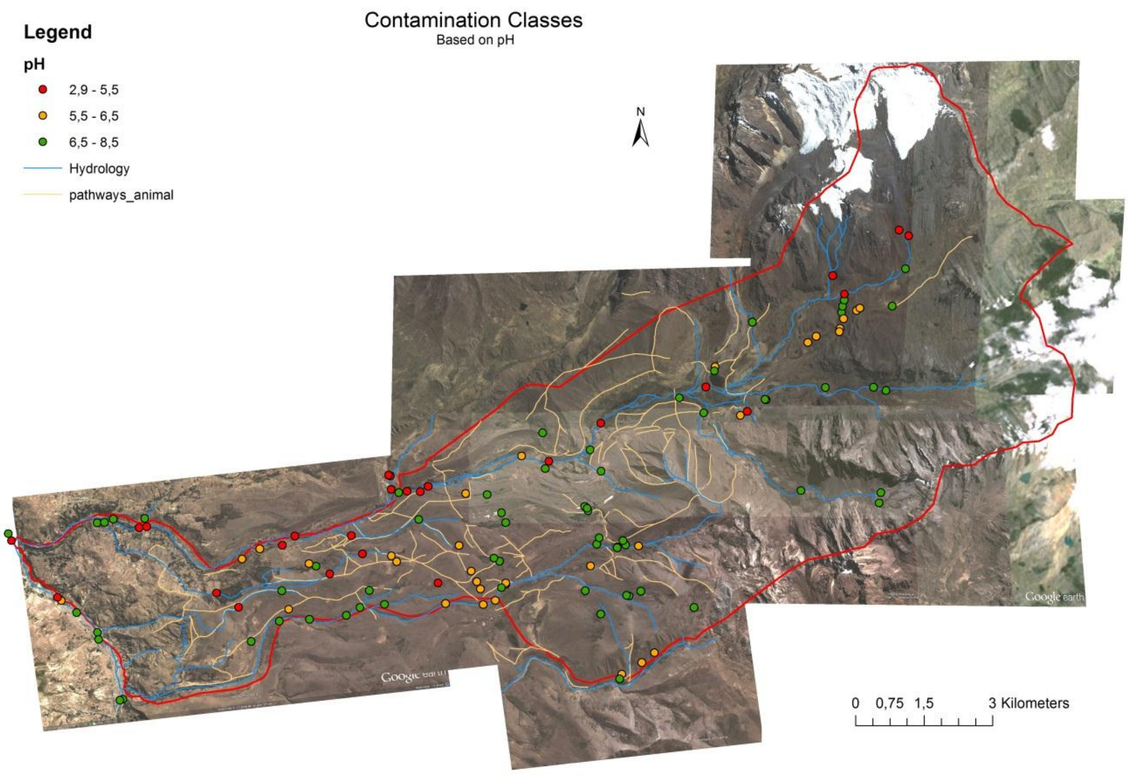

Figure 5: Contamination based on pH. Sample IDs can be found in Figure II Error! Reference source not found. **in the annex. Green values comply with Canadian and European limit values for drinking water, orange values comply with water regulations from WHO. Red samples should not be used as drinking water.**

When we consider the drinking water quality based on pH measured in the field we get a slightly more pessimistic picture. In Figure 5 one can see the abundance of water samples with a pH of less than 5.5 in red. Almost all samples of the Río Negro have a pH of less than 5.5. The most acidic Río Negro sample has a pH of 3 (DJJ_23). Additionally to the river samples, also most irrigation channels and two samples of the Río Santa, as well as the side river coming from the northern valley (JCJ_W_04) have a low pH. The most acidic sample of the research area with a pH of 2.9 is located in an irrigation channel (RTL_irrigation). Some samples of the higher area, which were taken in wetlands and smaller streams are less acidic, but still possess pH values between 5.5 and 6.5. Surprisingly, also the southern area, that did not appear to be contaminated based on the EC_{25} values, shows slightly acidic pH values of 5.9 – 6.5. pH values of the south eastern valleys are satisfactory for the use as drinking water.

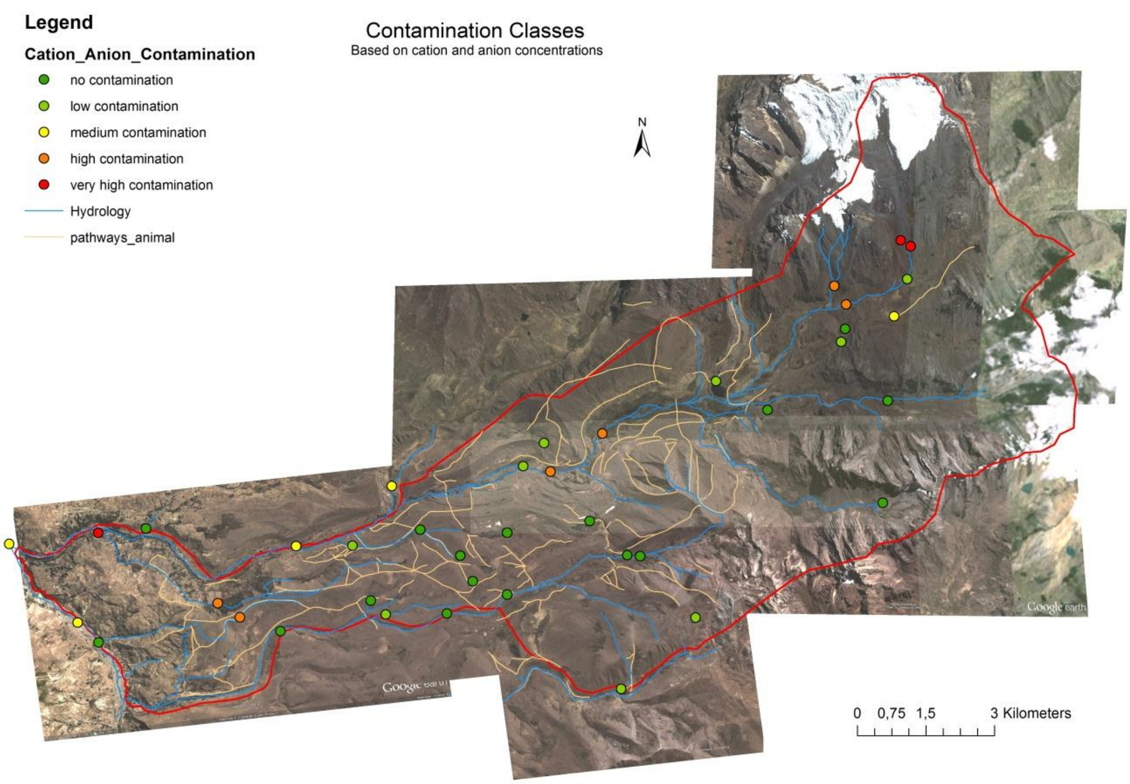

Figure 6: Contamination classes based on cation and anion concentrations. Categories are based on boundary values from EU, WHO, Canada, EPA, NamWater and ground water quality standards from New Jersey (2011). Sample IDs can be found in Figure III in the annex.

Finally, the contamination of the surface water samples based on the cation and anion concentration shall be described. This is based on the 40 samples that have been analyzed in the lab and holds therefore fewer samples. The map, which you can see in Figure 6 resembles the contamination map based on EC_{25}: samples at the source of the Río Negro are very highly contaminated with sulfate (767.5 mg/L), aluminum (25.83 mg/L), iron (52.65 mg/L), manganese (5.93 mg/L), copper (0.47 mg/L), nickel (0.57 mg/L), and indium (0.15 mg/L). The sample of the first side stream only shows low contamination with iron (0.25 mg/L), as could also be seen in EC_{25} values. The next side stream from the northern glacier is also highly contaminated with aluminum (5.28 mg/L), iron (1.29 mg/L), manganese (1.3 mg/L) and nickel (0.09 mg/L). When we follow the river the contamination goes down to a medium contamination in the lower parts of the fieldwork area. Wetlands along the Río Negro only possess low contamination, since only iron is above the limit value of 0.2 mg/L for drinking water with 0.29 mg/L and 0.45 mg/L respectively. Exact results for single anions and cations of all samples can be found in Table II in the annex.

Eastern and southern valleys show no or only low contamination, as well as the lower southern part. Irrigation channels Hua02 and TM_02 are highly contaminated with aluminum (2.1 mg/L), iron (0.56 mg/L), manganese (0.53 mg/L) and nickel (0.05 mg/L). Samples taken in the Río Santa show a medium contamination with manganese, boron, some sulfate, calcium and magnesium, which gets diluted after the Río Negro enters the Río Santa. The small side river that enters the Río Negro in the western part does not show a contamination.

As an example for the contamination of a specific compound, the sulfate concentration shall be described. Concentrations are not very critical in terms of the drinking water quality, but they illustrate a decrease of concentrations along the Río Negro from 767.5 mg/L at its source to 4.1 mg/L at the lowest measured point (Figure 7). Side streams possess comparatively low concentrations. For the southern river the opposite effect can be determined. Sulfate concentrations seem to increase from 0 mg/L in the east to 6.84 mg/L in the west. Some side streams have slightly higher concentrations, e.g. sample CT_13 with 31.11 mg/L.

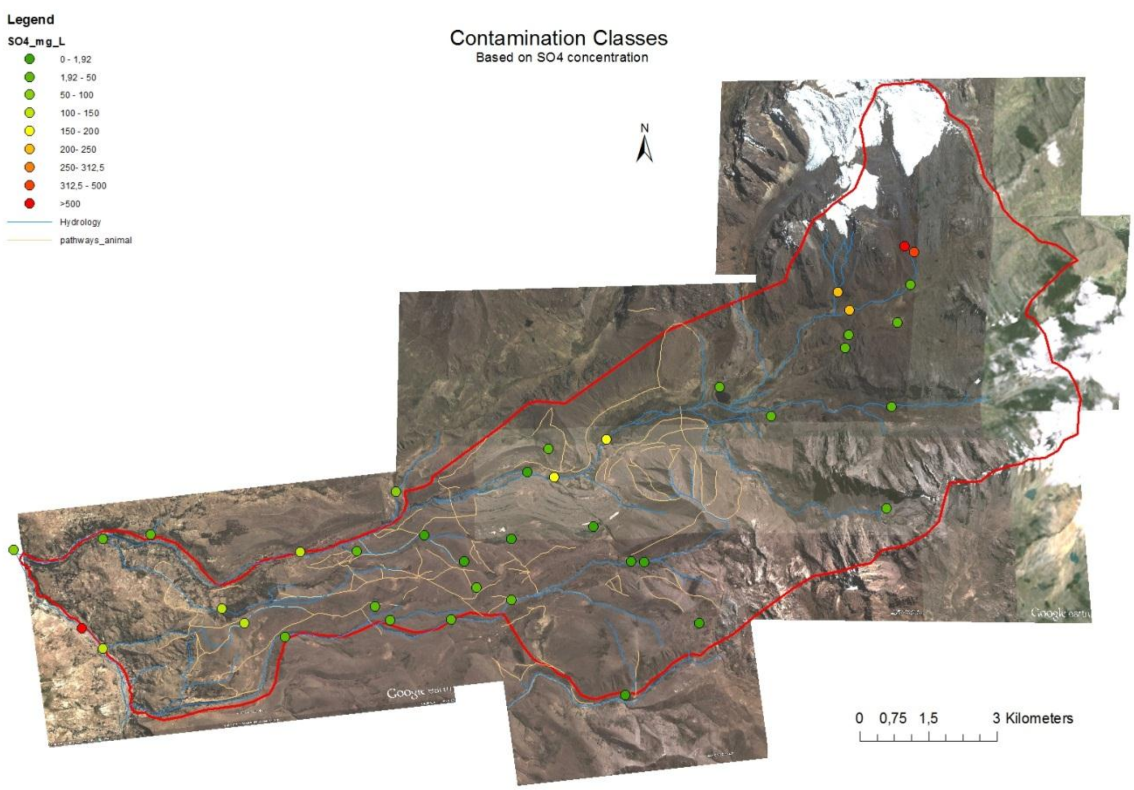

Figure 7: Sulfate concentration in water samples. Values > 250 mg/L are above the boundary value for drinking water. Each sample shows its name above and its concentration below. Sample IDs can be found in Figure IV in the annex.

Quite interesting to note is that boron can be found in only five samples: two in the Río Santa (0.66 and 3 mg/L), one in each of the two lakes of the higher area, Laguna_Alta (0.44 mg/L) and JRJ_W_05 (7.96 mg/L), and in the peculiar spring in the agricultural western part (278.95 mg/L). This spring has an atypical high concentration of chloride (>2729.88 mg/L)[3], potassium (647.87 mg/L), sodium (4446.88 mg/L), calcium (168.19 mg/L), strontium (9.02 mg/L), lithium (59.51 mg/L), arsenic (0.1 mg/L), boron (278.95 mg/L) and barium (0.96 mg/L).

Discussion

What is the water quality?

The glaciers in the Cordillera Blanca are retreating (Mark et al., 2010) and a long-term loss of the water storage is predicted (Mark et al., 2005). Water supply will be more dependent on precipitation and groundwater will play a greater role (Baraer et al., 2009). Droughts will severely affect the hydrology of the Cordillera Blanca (Baraer et al., 2009). In view of this, the quality of the water is of great interest; this will be analyzed and discussed in the following. It should be stressed that this paper only assessed and analyzed the chemical properties and no biological assessment has been made. For a complete picture of the water quality it is essential to additionally assess biological water functions and incorporate them in the analysis.

The three presented maps of the contamination based on EC_{25}, pH and concentrations of cations and anions show a similar picture: Río Negro, Río Santa and irrigation channels possess a high contamination. Main contaminants are sulfate, iron, aluminum and manganese. Central southern and south-eastern areas, which are fed by the second river, seem to have a satisfactory water quality. Nevertheless, the results should be interpreted with care. Sampling took place in the dry season in June, where river discharges are minimal. This influences the measured ion concentrations, which get diluted at other times during the year. Also the EC_{25} map should be interpreted carefully; one needs to remember that it only serves as a first indicator. High EC_{25} values are not always sign of a bad water quality since also unharmful ions like magnesium or calcium can have a high electrical conductivity. Therefore it is essential to inspect which ions caused the high EC_{25} values. The pH map distinguishes itself a bit from the other two maps. Central southern areas show slight acidic pHs between 5.9 and 6.5, which indicates that the water quality is confined. One has to mention that we found quite some differences between the pH that was measured in the field and the pH that was measured afterwards in the lab. This indicates that the pH-meter, which was used in the field, probably worked less accurate. During the analysis of the data it was decided to use the field pH regardless, since it delivers much more sample points than the lab pH. But therefore we need to consider this data with care. Field and lab pH of samples where both were present were compared. Most field pH values were lower than their lab values (e.g. DJJ_W_3: 6.84 & 6.4; DMR_W_2: 6.72 & 6; CT_Coca_bottle: 5.1 & 4.6). Only one sample has a higher pH in the field (RTNJ_W_9: 6.59 & 7.1). Half of the compared samples have a measured pH

[3] Sample had to be diluted more than 20 times due to its high concentration; shown concentration could still be underestimated by 5-10 times, since concentrations were still too high for analysis.

of > 6.5 in the lab, which influence the appearance of the map. It is still noticeable that no water sample has a high pH and thus one can interpret the pH as an indicator that water quality is not perfect and that there might be problems in the future. Furthermore some of these samples close to the boundary value between the pH-classes have a low cation-anion contamination, which exceeds only one limit value.

In literature some research has been done in another valley of the Cordillera Blanca, the Querococha basin: Baraer et al. (2009) found high sulfate concentrations of >50 mg/L. Also Mark et al. (2005) report a value of 165.4 mg/L for Olleros, a city in our research area. Baraer et al. (2009) conclude that the high sulfate concentrations are originating from melt water, which can also be seen in this study (see Figure 7). Minerals like pyrite (FeS_2) present in the Jurassic Chicama formation weather and sulfate and iron are being dissolved (Mark et al., 2005).

$$(eq. 1)\ FeS_2 + \frac{15}{4}\,O_2 + \frac{1}{2}\,H_2O \rightleftarrows Fe^{3+} + 2SO_4{}^{2-} + H^+$$

$$(eq. 2)\ FeS_2 + 14\,Fe^{3+} + 8H_2O \rightleftarrows 15\,Fe^{2+} + 2SO_4{}^{2-} + 16H^+$$

Through chemical and microbial oxidation of pyrite, iron and sulfur are released (eq. 1 and 2), thereby producing a large amount of acid, which enters aquifers and causes further rock weathering (Zhu, 2012). Since glaciers are melting, a high amount of water runs through the rock formations, enhancing this process. Figure 7 indicates that sulfate concentrations are high for the Río Negro, especially close to its source. The southern valleys are longer deglaciated and possess therefore lower sulfate concentrations. In the southern part concentrations increase downstream, which might be due to influences of groundwater, seepage or leaking of irrigation channels.

Origin of polluted water

Based on cation and anion concentrations, the hydrochemically most contaminated samples were found at the main source of the Río Negro. Several side streams, especially coming from the south and east show no or little signs of contamination. These streams dilute the water from the Río Negro and pollution declines in the lower part of the watershed, however even here a medium pollution is present. The side streams coming from the north into the Río Negro are also polluted, though the level of pollution is lower than that of the Río Negro. The larger rivers in the south of the area are barely polluted. Wetlands around the Río Negro also show low contamination, less pollution than the Río Negro itself. This all indicates that the pollution of the Río Negro originates from the source of the river.

The water from the western spring is highly polluted. This water might originate from the higher areas, reaching this spring as groundwater. If this would be the case, the groundwater of the entire area could be badly polluted. However, the ions found in this spring are completely different from the ions found at the river source, indicating that the pollution is picked up somewhere else. Groundwater might also run through the central area that has another geology, which might explain the different mineral composition. Two irrigation channels were also sampled in the western part, which show

contamination, though lower than the peculiar source. These channels possess the same ions as the Río Negro, indicating that the water is tapped from there.
The pollution of the Río Santa is comparable to the pollution of the Río Negro; the Río Negro flowing into the Río Santa does not have an effect on the pollution of the Río Santa.

Based on EC_{25} the same can be concluded: the most polluted areas are high near the source of the Río Negro. The Río Negro stays polluted till the end, where it joins the comparably polluted Río Santa. It should be mentioned that the pollution of the Río Negro represents a natural pollution by solute minerals, whereas the Río Santa might also be contaminated through mining activities upstream. The south of the research area has barely any pollution and rivers originating from there dilute the Río Negro water. The source of the pollution therefore appears to be near the river source in the north east. Again the western spring as well as the irrigation channels have a high pollution.

Animal tracks and other recommendations for the local population

Based on EC_{25} only a few spots should be avoided as drinking water for livestock (Figure 3). One is at the source of the Río Negro. The others are in the lower part of the area; one near the Río Santa, the last is the western spring, especially this one is important to notice, since it is located in a residential area, where people and animals are common. These are indicated as "not recommended for any use" in Figure 3 and also show a high ion contamination, see Figure 6. The Río Negro itself can be used for livestock along most of its course, however for poultry it should not be used in the upper area. Near the village this no longer states a problem. There is no real need to change any of the animal routes or avoid certain areas with cattle, except for the peculiar western spring. One should mention that this was not the only spring like that found in that area. However, they can be clearly recognized in the field, since they built up a cone like formation clearly different from the surroundings (Figure 4). It might also be better to avoid the Río Negro itself and mostly use the side rivers, since these are cleaner.

The main concern is for irrigation water. The water from the irrigation channels is based on the EC_{25} not suited for irrigation, since they possess medium-high ion concentrations (Figure 6). This counts for almost all waterbodies in the lower area. If irrigation is needed in these areas, it is not advisable to tab the water from the Río Negro, since this is too polluted, but to use water from the southern area or from the side streams, as this water is satisfactory for irrigation.
Also for drinking the Río Negro is not suited, however all the side streams can be used as drinking water. But it should be kept in mind that again only hydrochemical properties have been measured and that a biological assessment should also be considered.

Comparison with the pollution map

The pollution map by Aguierre Gutierrez et al. shows the same low pollution in the south of the area. The western part of the area also seems to be predicted quite good, medium pollution. However, looking at the top of the area, there are a lot of discrepancies. The source of the Río Negro is much more polluted than predicted, while the other side streams are much cleaner than predicted. What, based on our measurements, seems to be the source of the pollution, is here predicted to be the cleanest of the streams. Furthermore, the pollution of the Río Negro itself cannot be found back in the map. Although some features clearly match the actual found pollution, overall the map does not give an accurate view of the pollution, especially not of the source area.

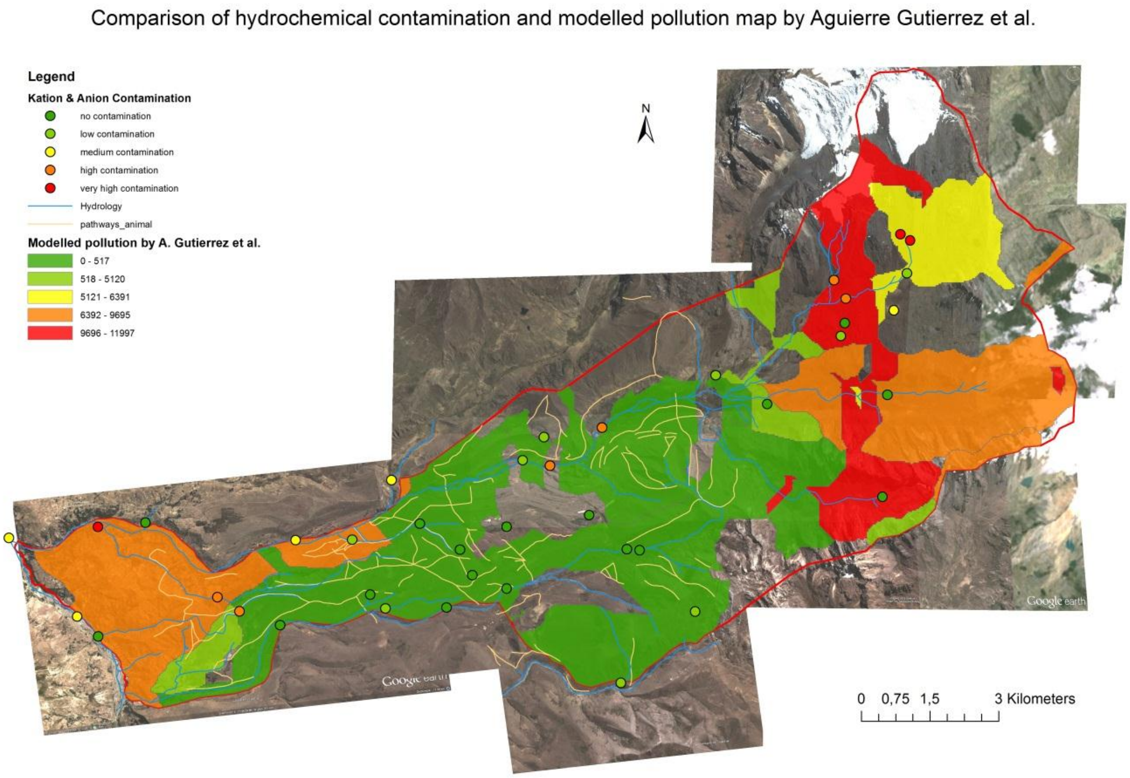

Figure 8: Comparison of the modeled pollution map by Aguierre Gutierrez et al. and the hydrochemical contamination of the field work area. A bigger map with corresponding sample IDs can be found in Figure V in the annex.

Conclusion

The hydrochemical water quality of especially the southern part is really good. However, for the other areas there are zones with less satisfactory quality. First of all, the source of the Río Negro is polluted, which affects the water quality of the entire river. The water is diluted by cleaner side rivers, indicating that the origin of the pollution is at the source of the Río Negro. When the Río Negro reaches the Río Santa it still has a medium pollution. At this point the Río Santa is equally polluted as the Río Negro, although the pollution of the Río Negro is of natural origin, whereas also anthropogenic activities like mining possibly pollute the Río Santa. The spring in the western part of the area is highly polluted, with different ions than the source of the Río Negro. This water is likely originating from groundwater that picked up its pollution somewhere else. The rest of the western area has a better water quality than the spring, but it is not suited for irrigation, where it is used for. Except for the spring and the source of the Río Negro, all water is suited for livestock; poultry can only be kept in the lower part of the area. The Río Negro is not suited as drinking water; however a lot of the side streams can be used for drinking

according to its hydrochemistry. The pollution map by Aguierre Gutierrez et al. offers some correct elements; however there are also a lot of important discrepancies, especially in the source area.
The main outcome for the local community is that the pollution found in this area is of purely natural origin, and that there are also environmental issues, which are not caused by anthropogenic activities. The origin of the pollution lies in mineral weathering, which is enhanced through the melting glaciers.

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Annex

Table I: Observation field form.

- Earth Sciences - IBED -
UvA - The Netherlands

Observation Form Peru 2012

General

site ID [initials _plotnumber]		X [..°..'.." S]	
date [year _ month _ day]		Y [..°..'.." W]	
slope angle [°]		Z [m]	
aspect		Position Valley [VAL/SLO/TOP]	
picture			

Vegetation

Distribution		Number of different species	
1 even | 2 patch s | 3 patch l | 4 isolated		Number of endemic species	
		Drought Stress	

Indicator species:	Cover [%]:

Total vegetation cover [%]

	Amount	Cover [%]:
trees		
shrubs		
herbs (flowers)		
grasses		
lichens		
succulents		
bare		
bedrock		
rocks		
moss		

Geomorphological Processes

0 = none | 1 = low | 2 = medium | 3 = high

Rockfall	
Slump	
Gully erosion	
Solifluction	
Rill erosion	

Lithology

Lithology type:

1. Subglacial Till	6. Granite
2. Ablation Till	7. Sandstone
3. Uncon. Gravel	8. Shales
4. Ignimbrite	9. Pyritic
5. Quartzite	10. Lacustrine

Frost Heaving/Sorting	
Peculiar Weathering	
Degradation state	

Rocks

Rock Type(s)

1. Intrusive
2. Extrusive
3. Sedimentary
4. Sedimentary CR

Human influences

None = 0 | Low = 1 | Medium = 2 | High = 3

Grazing intensity	
Fire damage	
Plough erosion	
Preventive measures?	
Agricultural product	
Eutrophication signs [0/1]	

Landform

Landform type:

1. Outwash fan
2. Boulders > 2m2
3. Lateral Moraine
4. Ground Moraine Plain
5. Terminal Moraine
6. Recessional Moraine
7. Medial Moraine
8. Alluvial fan
9. Debris cone
10. Ancient lake

Soil

Horizons:	Depth [cm]:	Colour:	Structure:	Texture:

1 = low / 2 = medium / 3 = high

Water availability		Prefix	
Aggregate stability		Type	
Internal drainage		Suffix	
Crust [0/1]		Soil sample(s)	
Root depth [cm]			

Land use

Land use type:	
Terracewall intact [0/1]	

1. Settlements
2. Agriculture
3. Abandoned Agriculture
4. Forest
5. Grassland
6. Fallow
7. Bare Rock

Water quality

EC [μS/cm]	
Water pH	
Water sample [0/1]	

Hydrology

Stream order	
Source	
Swamp / Wetland	
Temporary Swamp	
Overland flow	

Notes

Table II: Water samples with their concentrations of tested anions and cations, pH and EC_{25}, as well as their water quality boundaries from different standards. Orange cells indicate which values exceed these boundaries. Red stars indicate when sample amount was too small to undergo analysis.

sample nr.	name	pH lab	EC lab	pH field	EC field	Alkalinity	NH4	D.O.C.	NO3+NO2	PO4	Cl	SO4	DON
			[µS/cm]		[µS/cm]	[µmol/l]	[mg/L]	[µmol/l]	[mg N /L]	[mg/L]	[mg/L]	[mg/L]	[µmol/l]
detection limit							0.180	160	0.042	0.009	0.709	1.921	10
determination limit													
		>		<									
Parametric value (mg/L)		6.5	250	8.5	250	-	0.5	-	50	-	250	250	-
	EU	6.5	250	9.5	250	-	0.5	-	50	-	250	250	-
	WHO	-	250	-	250	-	-	-	-	-	250	500	-
	Canada	6.5	250	8.5	250	-	None	-	-	-	250	500	-
	EPA	-	-	-	-	-	-	-	-	-	250	250	-
	NamWater	-	-	-	-	-	1	-	-	-	250	-	-
Peru/1	CDTT_W2	3.17	436	4.1	433	0	<0.18	<160	0.09	<0.01	0.93	117.08	<10
Peru/2	CMT_03	2.94	675	4	582	0	<0.18	<160	0.04	<0.01	1.30	166.19	<10
Peru/3	CT_13	4.79	76	6.7	16.2	40	<0.18	<160	<0.04	<0.01	<0.71	31.11	<10
Peru/4	CT_coca bottle	5.10	67.5	4.6	75.2	35	<0.18	<160	<0.04	<0.01	<0.71	25.24	<10
Peru/5	CT_W_01	6.19	31.4	6.9	27.1	113	<0.18	<160	0.11	<0.01	<0.71	6.84	<10
Peru/6	DJJ_23	3.09	537	3	592	0	<0.18	<160	<0.04	<0.01	1.15	166.38	<10
Peru/7	DJJ_25	7.23	116.8	7.1	131.5	1264	<0.18	<160	0.11	<0.01	1.11	3.59	<10
Peru/8	DJJ_27	7.08	58.3	5.9	62.9	515	<0.18	1109	0.27	<0.01	1.41	<1.92	<10
Peru/9	DJJ_W_01	7.05	69	6.6	11.4	425	<0.18	605	<0.04	<0.01	<0.71	12.60	36.7
Peru/10	DJJ_W_03	6.84	31.3	6.4	30.5	141	<0.18	442	<0.04	<0.01	<0.71	6.07	12.4
Peru/11	DJJ_W_04	6.68	15.4	6.7	14.5	125	<0.18	291	<0.04	<0.01	<0.71	<1.92	<10
Peru/12	DMR_01	7.04	48.6	7.5	43.9	394	<0.18	300	<0.04	<0.01	<0.71	<1.92	<10
Peru/13	DMR_W_2	6.72	13.4	6	12.6	117	<0.18	397	<0.04	<0.01	<0.71	<1.92	<10

Peru/14	DRLR_26_W1	6.89	47.8	7.5	48	340		<0.18	209	<0.04	<0.01	<0.71	5.30	15.4
Peru/15	DRLR_26_W2	2.57	2010	3.9	1529	0		<0.18	<160	<0.04	0.01	<0.71	767.50	<10
Peru/16	DRLR_26_W3	2.70	1362	3.8	1030	0		<0.18	<160	<0.04	0.06	<0.71	392.85	<10
Peru/17	DRLR_26_W4	6.75	45.7	6.7	43	292		<0.18	<160	<0.04	<0.01	<0.71	8.07	<10
Peru/18	DRT_W5	6.04	67.1	6.5	68	51		<0.18	<160	<0.04	<0.01	<0.71	24.11	<10
Peru/19	DTT_W2	6.00	35.1	7	33	38		<0.18	<160	0.19	<0.01	<0.71	10.83	<10
Peru/20	Hua_2	3.22	385	3.2	410	0		<0.18	<160	0.07	<0.01	0.85	106.07	<10
Peru/21	JCJ_W_04	3.71	238	4.5	250	0		<0.18	<160	0.11	<0.01	0.72	84.17	16.3
Peru/22	JMJ_03	7.48	70.5	8.2	82	***		<0.18	<160	<0.04	<0.01	1.93	10.89	<10
Peru/23	JMJ_06	7.25	21500	6.6	24200	3427		<0.18	206	9.06	0.22	>2729.88	4.10	21.4
Peru/24	JRJ_W_05	7.10	91.6	6.9	70	590		<0.18	664	0.18	0.01	12.96	4.04	157
Peru/25	Laguna_alta	6.50	18.98	6.9	10.1	116		<0.18	193	<0.04	<0.01	1.25	<1.92	34.9
Peru/26	RLR_25_W1	7.46	217	6.9	251	488		<0.18	<160	0.11	<0.01	18.07	59.66	20.7
Peru/27	RLR_25_W5	7.74	1697	7.4	2030	2647		<0.18	<160	0.06	0.03	4.56	1126.10	<10
Peru/28	RLR_25_W6	7.68	538	8.1	639	4100		<0.18	<160	<0.04	<0.01	0.85	127.04	<10
Peru/29	RTL_17	6.59	16.5	6	40.3	***		<0.18	329	<0.04	<0.01	0.97	2.72	<10
Peru/30	RTL_19	6.24	23.9	5.9	23.7	158		0.36	230	0.08	<0.01	1.56	<1.92	27.9
Peru/31	RTL_22	6.28	23.3	6.6	21.7	187		<0.18	340	<0.04	<0.01	<0.71	<1.92	25.7
Peru/32	RTNJ_OW_2	6.34	22.2	7.2	20	140		<0.18	209	0.26	<0.01	<0.71	<1.92	22.9
Peru/33	RTNJ_W_9A	6.59	30.2	7.1	28.4	***		<0.18	<160	0.16	<0.01	<0.71	2.93	17.0
Peru/34	TLC_02	6.92	47.4	7.3	53.6	440		<0.18	<160	<0.04	<0.01	<0.71	<1.92	11.3
Peru/35	TM_02	3.13	423	3.4	480	0		<0.18	<160	0.07	<0.01	<0.71	118.42	<10
Peru/36	UP_04	2.91	824	3.9	747	0		<0.18	<160	<0.04	<0.01	<0.71	240.44	<10
Peru/37	UP_08	5.32	43.8	6.5	46	3981		<0.18	<160	<0.04	<0.01	<0.71	20.98	<10
Peru/38	UP_05	2.95	731	3.9	683	0		<0.18	<160	0.05	<0.01	<0.71	209.84	<10
Peru/39	DRT_22W_02	6.41	38	6.8	38	***		<0.18	<160	0.13	<0.01	<0.71	13.87	<10
Peru/40	UP_06	6.36	21.7	6.2	22	100		<0.18	<160	<0.04	<0.01	<0.71	6.09	<10

sample nr.	**name**	**K**	**Na**	**Ca**	**Mg**	**Al**	**Fe**	**Mn**	**Zn**	**Cu**	**Co**	**Cd**	**Sr**	**Ti**	**Li**
		[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]
detection limit		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
determination limit		0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parametric value (mg/L)		200	200	150	70	0.2	0.2	0.05	3	1	0.1	0.003	5	0.1	2.5
	EU	-	200	-	-	0.2	0.2	0.05	-	2	-	0.005	-	-	-
	WHO	-	200	-	-	0.2	-	0.5	3	2	-	0.003	-	-	-
	Canada	-	200	None	None	0.2	3	0.05	5	1	-	0.005	5	-	-
	EPA	-	-	-	-	0.05-0.2	0.3	0.05	5	1.3	-	0.005	-	-	-
	NamWater	200	100-400	150-200	70-100	0.15-0.5	0.1-1	0.05-1	1-5	0.5-1	0.25-0.5	0.01-0.02	-	0.1-0.2	2.5-5
	Ground Water	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-
Peru/1	**CDTT_W2**	1.05	3.24	15.81	8.90	2.42	0.19	0.56	0.13	0.00	0.03	<0.00	0.06	<0.00	0.02
Peru/2	**CMT_03**	0.93	3.10	15.36	11.58	3.49	0.84	0.76	0.18	0.00	0.05	<0.00	0.06	<0.00	0.02
Peru/3	**CT_13**	0.61	2.21	5.05	2.39	0.16	0.03	0.08	0.02	0.00	0.00	<0.00	0.05	<0.00	0.00
Peru/4	**CT_coca bottle**	0.45	2.08	4.71	2.11	0.01	0.01	0.06	0.01	<0.00	0.00	<0.00	0.05	<0.00	0.00
Peru/5	**CT_W_01**	0.35	0.97	2.87	0.56	<0.00	0.00	0.00	0.00	<0.00	<0.00	<0.00	0.01	<0.00	0.00
Peru/6	**DJJ_23**	0.79	2.93	15.70	11.82	3.51	10.84	0.76	0.18	0.00	0.05	0.00	0.06	<0.00	0.02
Peru/7	**DJJ_25**	1.01	4.31	18.20	2.19	<0.00	0.29	0.02	0.01	<0.00	0.00	<0.00	0.04	<0.00	0.00
Peru/8	**DJJ_27**	0.62	2.67	7.94	1.36	<0.00	0.45	0.00	0.01	<0.00	<0.00	<0.00	0.03	<0.00	0.00
Peru/9	**DJJ_W_01**	0.13	2.02	7.20	2.69	<0.00	0.03	0.00	<0.00	<0.00	<0.00	<0.00	0.07	<0.00	0.00
Peru/10	**DJJ_W_03**	0.36	1.12	3.38	0.55	<0.00	0.01	0.00	0.00	<0.00	<0.00	<0.00	0.02	<0.00	0.00
Peru/11	**DJJ_W_04**	0.52	1.07	0.91	0.30	<0.00	0.00	0.00	0.00	<0.00	<0.00	<0.00	0.01	<0.00	0.00
Peru/12	**DMR_01**	0.18	0.73	6.79	0.69	<0.00	0.03	0.00	0.00	<0.00	<0.00	<0.00	0.03	<0.00	0.00
Peru/13	**DMR_W_2**	0.17	0.33	1.21	0.54	<0.00	0.16	0.00	0.00	<0.00	<0.00	<0.00	0.01	<0.00	0.00

Peru/14	**DRLR_26_W1**	0.14	1.25	6.35	0.67	<0.00	0.25	0.00	0.00	<0.00	<0.00	<0.00	0.02	<0.00	0.00
Peru/15	**DRLR_26_W2**	0.59	0.80	33.75	64.47	25.83	52.65	5.93	0.64	<0.00	0.47	0.00	0.06	<0.00	0.04
Peru/16	**DRLR_26_W3**	1.01	1.27	28.59	29.56	11.86	9.09	3.16	0.64	<0.00	0.25	0.00	0.08	<0.00	0.04
Peru/17	**DRLR_26_W4**	0.17	0.79	6.81	1.55	0.29	0.48	0.09	0.02	<0.00	0.01	<0.00	0.02	<0.00	0.00
Peru/18	**DRT_W5**	0.94	2.15	4.71	2.19	<0.00	0.02	0.01	0.01	<0.00	<0.00	<0.00	0.04	<0.00	0.01
Peru/19	**DTT_W2**	0.39	1.06	3.02	0.70	<0.00	0.01	0.02	0.01	<0.00	0.00	<0.00	0.02	<0.00	0.00
Peru/20	**Hua_2**	0.95	3.02	14.92	8.32	2.10	0.56	0.53	0.11	<0.00	0.03	<0.00	0.06	<0.00	0.02
Peru/21	**JCJ_W_04**	0.85	2.74	15.96	6.33	1.39	0.03	0.44	0.08	<0.00	0.02	<0.00	0.05	<0.00	0.02
Peru/22	**JMJ_03**	0.57	5.03	9.18	1.35	0.03	0.00	0.01	0.00	<0.00	<0.00	<0.00	0.05	<0.00	0.01
Peru/23	**JMJ_06**	647.87	4446.88	168.19	49.02	<0.00	0.01	0.02	<0.00	<0.00	<0.00	<0.00	9.02	<0.00	59.51
Peru/24	**JRJ_W_05**	18.88	153.53	14.34	2.68	<0.00	0.10	0.00	<0.00	<0.00	<0.00	<0.00	0.31	<0.00	1.77
Peru/25	**Laguna_alta**	1.01	5.53	1.55	0.40	0.03	0.01	0.00	0.00	<0.00	<0.00	<0.00	0.02	<0.00	0.07
Peru/26	**RLR_25_W1**	2.64	16.28	20.93	5.08	<0.00	<0.00	0.25	0.11	<0.00	0.01	<0.00	0.14	<0.00	0.16
Peru/27	**RLR_25_W5**	19.13	59.16	266.38	116.58	<0.00	<0.00	0.01	<0.00	<0.00	<0.00	<0.00	1.33	<0.00	0.30
Peru/28	**RLR_25_W6**	3.93	19.27	62.30	33.73	<0.00	<0.00	0.00	<0.00	<0.00	<0.00	<0.00	0.71	<0.00	0.10
Peru/29	**RTL_17**	0.99	1.67	2.77	1.34	0.03	0.02	0.00	0.00	0.00	<0.00	<0.00	0.03	<0.00	0.00
Peru/30	**RTL_19**	1.68	1.79	0.70	0.31	<0.00	0.05	0.00	0.00	<0.00	<0.00	<0.00	0.01	<0.00	0.00
Peru/31	**RTL_22**	1.10	1.81	1.33	0.56	0.02	0.04	0.00	0.00	<0.00	<0.00	<0.00	0.01	<0.00	0.00
Peru/32	**RTNJ_OW_2**	0.59	2.12	1.29	0.40	0.02	0.01	0.00	0.00	0.00	<0.00	<0.00	0.01	<0.00	0.00
Peru/33	**RTNJ_W_9A**	0.35	1.23	3.66	0.46	<0.00	<0.00	0.00	0.01	0.00	<0.00	0.00	0.02	<0.00	0.00
Peru/34	**TLC_02**	0.25	0.75	7.58	1.13	<0.00	0.01	0.00	0.00	<0.00	<0.00	<0.00	0.04	<0.00	0.00
Peru/35	**TM_02**	0.75	2.87	12.69	9.50	2.65	0.99	0.60	0.14	0.00	0.04	<0.00	0.05	<0.00	0.02
Peru/36	**UP_04**	0.53	1.20	17.71	19.80	7.64	2.09	1.89	0.31	0.00	0.15	<0.00	0.05	<0.00	0.02
Peru/37	**UP_08**	0.17	0.94	4.63	1.59	0.16	0.08	0.18	0.01	<0.00	0.00	<0.00	0.02	<0.00	0.01
Peru/38	**UP_05**	0.84	0.82	17.61	18.29	5.28	1.29	1.30	0.30	0.01	0.07	0.00	0.07	0.00	0.02
Peru/39	**DRT_22W_02**	0.30	0.91	4.70	0.86	0.02	0.02	0.02	0.00	<0.00	0.00	<0.00	0.02	<0.00	0.00
Peru/40	**UP_06**	0.08	0.67	2.36	0.60	<0.00	0.09	0.00	<0.00	<0.00	<0.00	<0.00	0.02	<0.00	0.01

sample nr.	name	Be	Cr	Mo	Ni	Sb	As	B	Ba	Ga	In	P	S	Si		total
		[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]		[mg/L]
detection limit		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.02	0.01		
determination limit		0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.01	0.04	0.04	0.08	0.02		
Parametric value (mg/L)		0.004	0.05	0.04	0.02	0.005	0.01	0.3	0.3		0.05	1				500
	EU	-	0.05	-	0.02	0.005	0.01	1	-	-	-	-	-	-		500
	WHO	-	0.05	-	0.02	0.005	0.01	0.3	0.3	-	-	-	-	-		500
	Canada	-	0.05	-	-	0.006	0.01	5	1	-	-	-	-	-		500
	EPA	0.004	-	-	-	-	-	-	2	-	-	-	-	-		500
	NamWater	0.002-0.005	0.1-0.2	0.05-0.1	0.25-0.5	0.05-0.1	0.1-0.3	0.5-2	0.5-1	-	-	-	-	-		-
	Ground Water	-	-	0.04	-	-	-	-	-	-	0.05	1	-	-		-
Peru/1	**CDTT_W2**	0.00	0.00	<0.00	0.05	<0.00	<0.01	0.01	0.00	0.01	0.02	<0.01	40.41	3.17		194.18
Peru/2	**CMT_03**	0.00	0.00	<0.00	0.08	<0.00	<0.01	0.02	0.00	0.04	0.02	<0.01	56.74	3.04		263.84
Peru/3	**CT_13**	0.00	<0.00	0.00	0.01	<0.00	<0.01	<0.00	0.01	<0.00	<0.01	<0.01	9.49	2.26		53.50
Peru/4	**CT_coca bottle**	0.00	<0.00	<0.00	0.00	<0.00	<0.01	<0.00	0.01	<0.00	<0.01	<0.01	8.08	2.22		45.05
Peru/5	**CT_W_01**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.00	0.00	<0.00	<0.01	<0.01	2.28	1.24		15.24
Peru/6	**DJJ_23**	0.00	<0.00	<0.00	0.08	<0.00	<0.01	<0.00	0.00	<0.00	0.02	<0.01	58.74	3.08		276.12
Peru/7	**DJJ_25**	<0.00	<0.00	<0.00	0.00	<0.00	<0.01	<0.00	0.00	0.03	<0.01	<0.01	2.41	4.54		37.86
Peru/8	**DJJ_27**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.00	0.00	<0.00	<0.01	<0.01	0.26	5.41		20.42
Peru/9	**DJJ_W_01**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.00	0.01	0.01	<0.01	<0.01	4.08	3.13		31.96
Peru/10	**DJJ_W_03**	<0.00	<0.00	0.00	<0.00	<0.00	<0.01	<0.00	0.00	<0.00	<0.01	<0.01	2.04	1.15		14.69
Peru/11	**DJJ_W_04**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.00	0.00	<0.00	<0.01	<0.01	0.27	1.51		4.59
Peru/12	**DMR_01**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.00	0.00	<0.00	<0.01	<0.01	0.78	1.35		10.57
Peru/13	**DMR_W_2**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.00	0.00	<0.00	<0.01	<0.01	0.16	1.16		3.75

Peru/14	**DRLR_26_W1**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.00	<0.00	0.02	<0.01	<0.01	2.05	1.40		17.44
Peru/15	**DRLR_26_W2**	0.00	0.00	<0.00	0.57	<0.00	<0.01	0.23	0.01	<0.00	0.15	0.05	261.25	4.72		1219.74
Peru/16	**DRLR_26_W3**	0.00	0.00	<0.00	0.35	<0.00	<0.01	0.03	0.01	0.11	0.09	<0.01	134.19	3.37		616.58
Peru/17	**DRLR_26_W4**	<0.00	<0.00	<0.00	0.01	<0.00	<0.01	<0.00	0.00	<0.00	<0.01	<0.01	6.14	1.21		25.67
Peru/18	**DRT_W5**	<0.00	<0.00	<0.00	0.00	<0.00	<0.01	<0.00	0.00	<0.00	<0.01	<0.01	7.98	2.98		45.14
Peru/19	**DTT_W2**	<0.00	<0.00	<0.00	0.00	<0.00	<0.01	<0.00	0.00	<0.00	<0.01	<0.01	3.74	2.25		22.26
Peru/20	**Hua_2**	0.00	<0.00	<0.00	0.05	<0.00	<0.01	0.00	0.01	0.03	0.02	<0.01	37.44	3.17		178.31
Peru/21	**JCJ_W_04**	0.00	<0.00	<0.00	0.03	<0.00	<0.01	0.03	0.00	0.12	0.01	<0.01	27.40	2.88		143.40
Peru/22	**JMJ_03**	<0.00	<0.00	<0.00	0.00	<0.00	<0.01	0.04	0.00	0.10	<0.01	<0.01	2.10	3.00		34.31
Peru/23	**JMJ_06**	<0.00	0.00	<0.00	<0.00	<0.00	0.10	278.95	0.96	0.20	<0.01	0.11	3.68	7.24		5685.15
Peru/24	**JRJ_W_05**	<0.00	<0.00	0.00	<0.00	<0.00	<0.01	7.96	0.03	0.07	<0.01	0.02	1.45	1.43		219.76
Peru/25	**Laguna_alta**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	0.44	0.00	0.01	<0.01	<0.01	0.31	0.70		11.35
Peru/26	**RLR_25_W1**	<0.00	<0.00	<0.00	0.01	<0.00	<0.01	0.66	0.01	0.12	<0.01	<0.01	19.25	2.70		146.19
Peru/27	**RLR_25_W5**	<0.00	<0.00	<0.00	0.00	<0.00	<0.01	3.00	0.03	0.47	0.01	<0.01	352.88	2.04		1952.08
Peru/28	**RLR_25_W6**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	0.21	0.06	0.29	<0.01	<0.01	38.05	3.92		290.46
Peru/29	**RTL_17**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	0.03	0.00	0.03	<0.01	0.01	1.74	1.00		13.38
Peru/30	**RTL_19**	<0.00	0.00	<0.00	<0.00	<0.00	<0.01	0.02	0.00	0.05	<0.01	<0.01	0.52	1.27		8.40
Peru/31	**RTL_22**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	0.02	0.00	0.01	<0.01	<0.01	0.65	1.24		6.81
Peru/32	**RTNJ_OW_2**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	0.02	<0.00	<0.00	<0.01	<0.01	0.50	1.33		6.56
Peru/33	**RTNJ_W_9A**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	0.01	0.00	0.04	<0.01	<0.01	1.30	1.09		11.25
Peru/34	**TLC_02**	<0.00	<0.00	<0.00	<0.00	0.01	0.01	0.01	0.00	0.05	<0.01	<0.01	0.75	0.91		11.52
Peru/35	**TM_02**	0.00	<0.00	<0.00	0.07	<0.00	<0.01	0.04	0.00	0.08	0.02	<0.01	82.02	3.33		234.35
Peru/36	**UP_04**	0.00	0.00	<0.00	0.20	<0.00	<0.01	0.02	0.01	0.10	0.05	<0.01	70.76	2.77		365.73
Peru/37	**UP_08**	<0.00	<0.00	<0.00	0.01	<0.00	<0.01	0.01	0.00	0.01	<0.01	<0.01	7.33	2.26		38.41
Peru/38	**UP_05**	0.00	0.00	<0.00	0.09	<0.00	<0.01	0.01	0.01	0.12	0.04	<0.01	69.67	2.91		328.63
Peru/39	**DRT_22W_02**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	0.01	0.00	0.04	<0.01	<0.01	3.39	1.54		25.83
Peru/40	**UP_06**	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	0.01	0.00	0.02	<0.01	<0.01	1.70	1.07		12.71

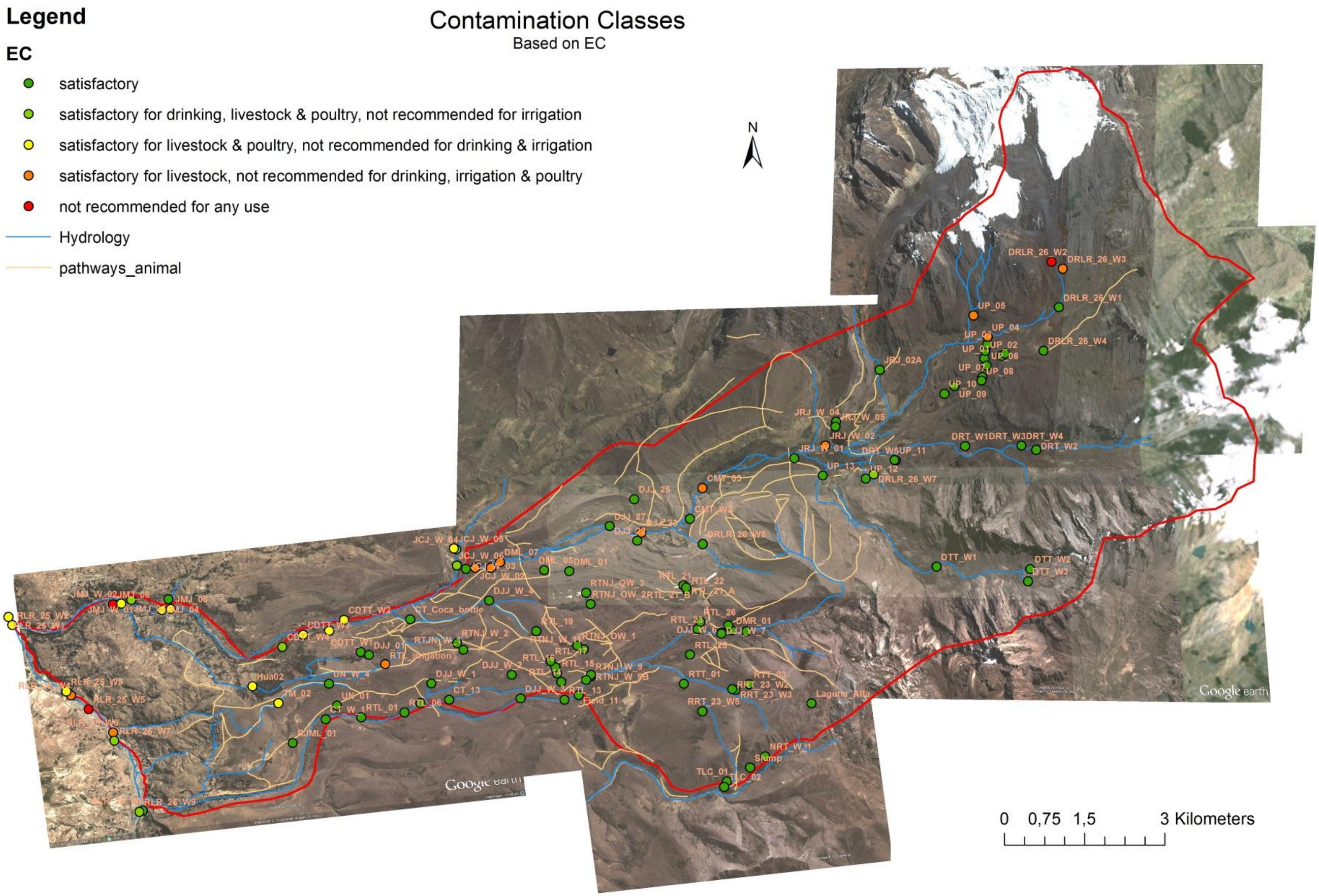

Figure I: Contamination classes based on EC_{25}. Classes are based on Environmental Protection Agency (2012) for drinking water, Bauder et al. (2012) for irrigation and Ayers and Westcot (1994) for livestock and poultry.

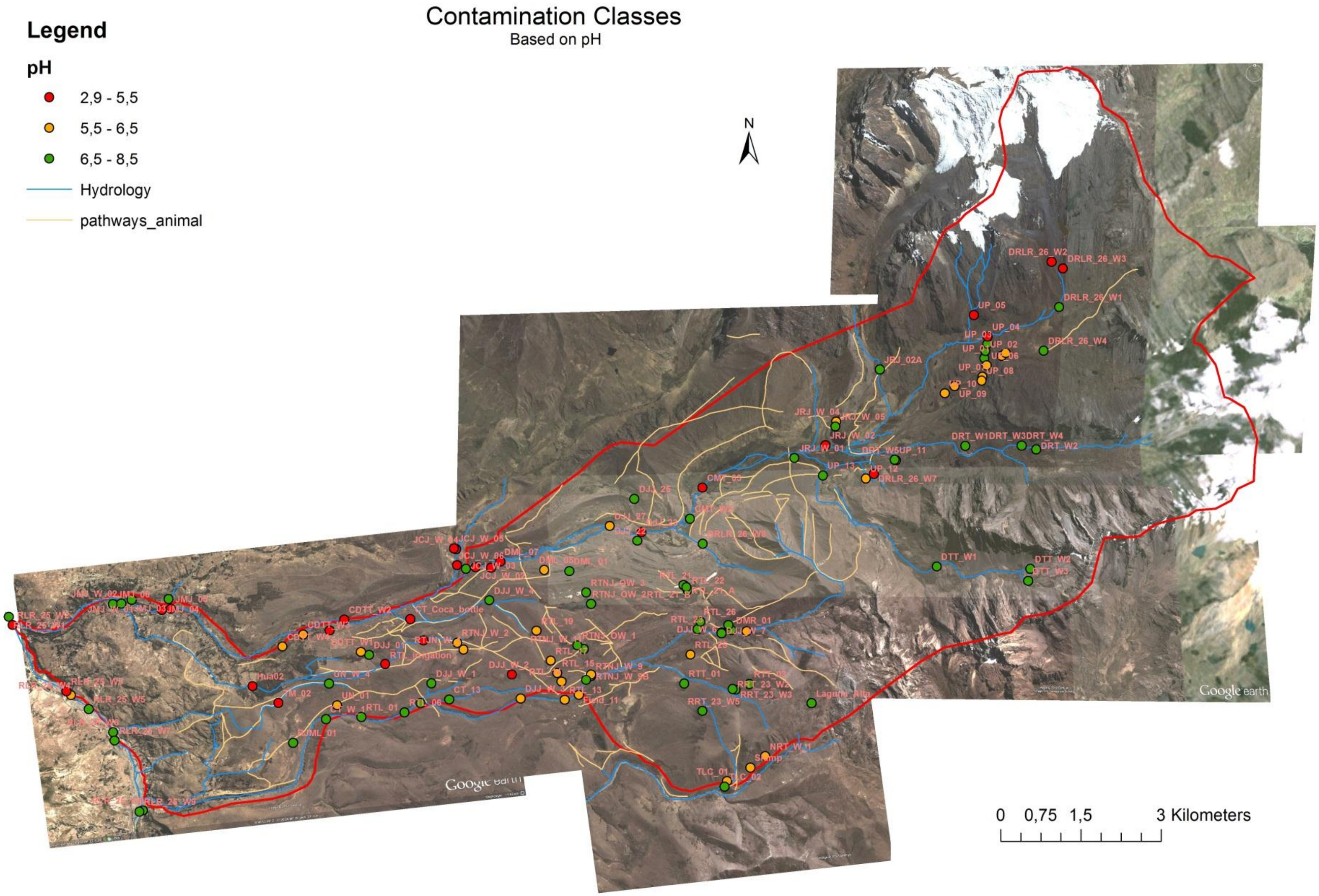

Figure II: Contamination classes based on pH. Green values are in accordance with Canadian and European drinking water standard, orange values are in accordance with the WHO drinking water standard and red values are not recommended as drinking water by any of those standards.

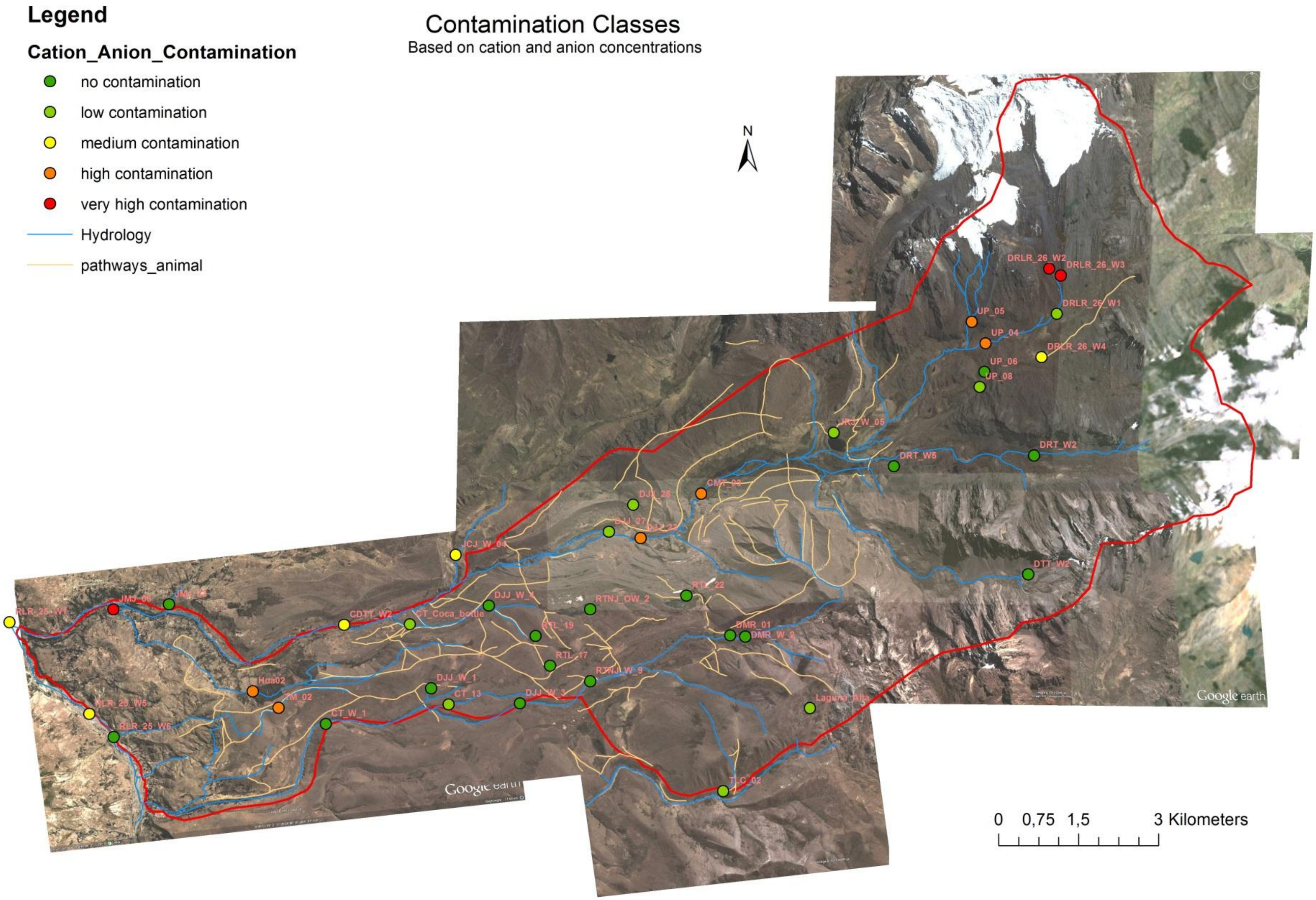

Figure III: Contamination classes based on cation and anion concentrations. Categories are based on boundary values from EU, WHO, Canada, EPA, NamWater and ground water quality standards from New Jersey (2011).

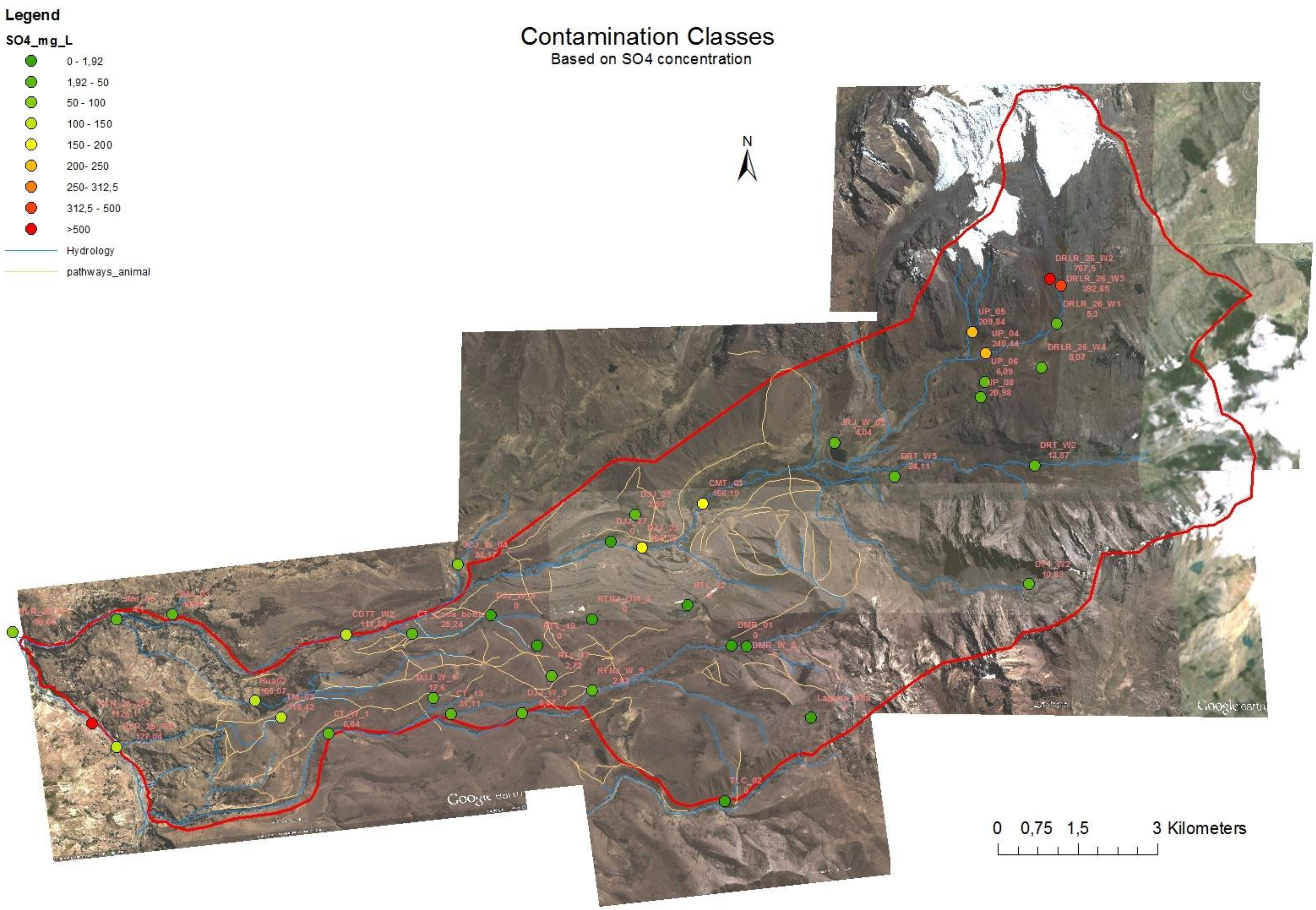

Figure IV: Sulfate concentration in water samples. Values > 250 mg/L are above boundary value for drinking water. Each sample shows its name and its concentration below.

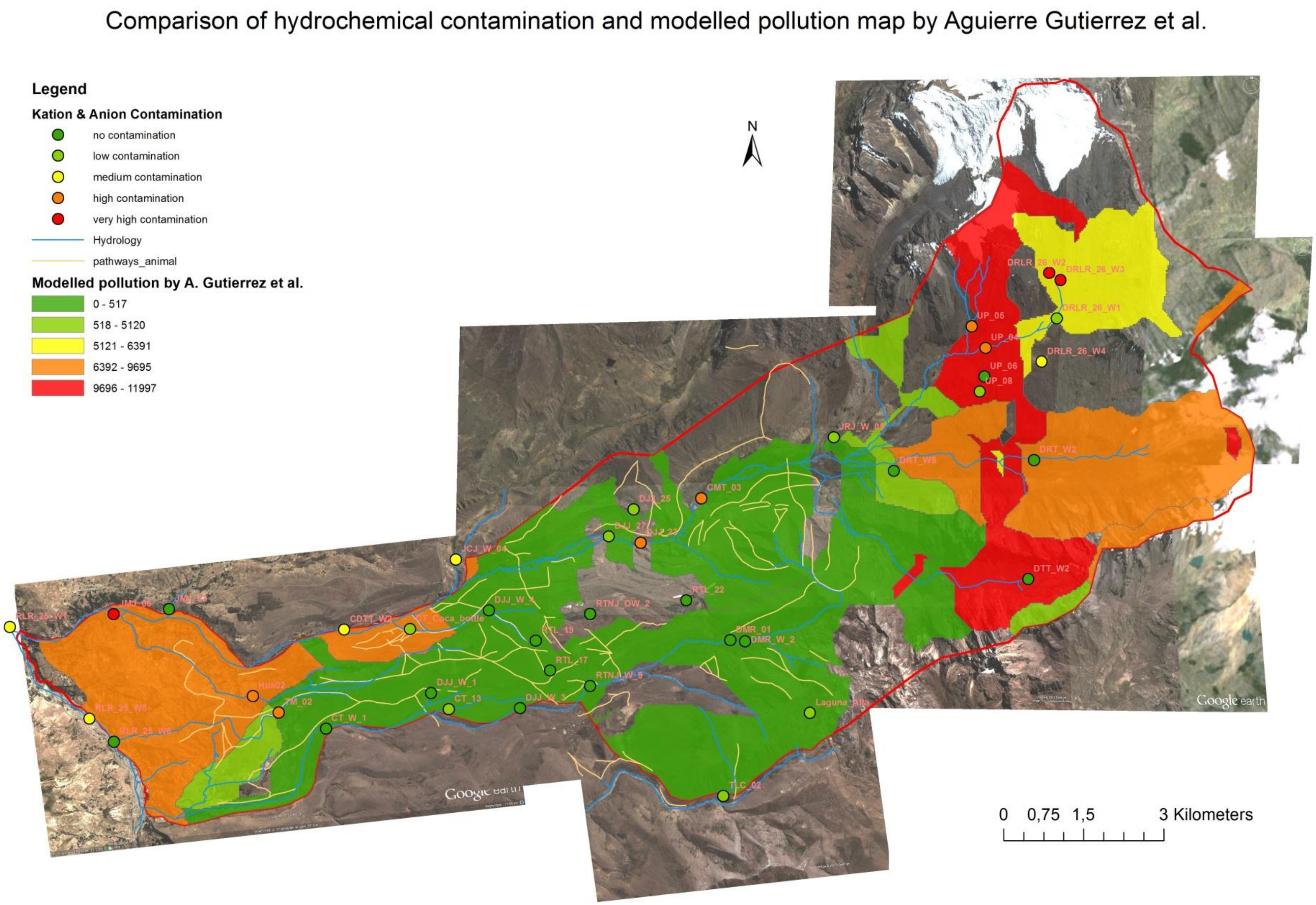

Figure V: Comparison of the modeled pollution map by Aguierre Gutierrez et al. and the hydrochemical contamination of the field work area.