Climate change impact in Andean cities in Bolivia: the Tiquipaya case and a community led New Urban Agenda for resilient planning

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Abstract

According to several UN (FAO Aquastat) featured studies, Bolivia belongs to the twenty countries with the highest renewable internal freshwater resources per capita and total renewable freshwater supply. Paradoxically, the rapid glacier retreat in the Tropical Andes is compromising the fresh water provision in many important urban centres in the middle term, including the large cities of La Paz and Cochabamba. The beginning of the rainy season during the last austral summer was again marked by several natural events in some of the most fragile urban and rural areas in the mountainous as well as plain regions. One of these events was the flash floods in Tiquipaya, Cochabamba. In this paper these elements are described, analyzed and possible solutions are proposed.

Keywords: climate change, vulnerability, land use, new urban agenda

1. Introduction

The rapid glacier retreat in the Tropical Andes of Bolivia is compromising the fresh water provision in many important urban centres in the middle term, including the large cities of La Paz and Cochabamba. At the same time, changes in the rain patterns in practically the whole country are causing severe damage to agriculture, farming and urban infrastructure, compromising as well the production of food, an economic branch in which more than 60% of the population works. Climate experts of the Global Atmosphere Watch monitoring system coincide in that Bolivia and other Andean countries are in urgent need to implement effective measures to improve their resilience to climate change impacts (Hoffmann, 2012). The recently adopted Habitat III New Urban Agenda is an example of what these measures should imply schematically. But what can this imply in practical terms is such a poor and vulnerable country?

The Tiquipaya flash floods is considered by the author very symptomatic. It is the result of the mixing of several elements, most of them human made, into a chain of events that resulted in a foreseeable tragedy for locals and destructive for their infrastructure. These include insufficient management of a fragile system of watersheds, human led destruction of natural ecosystems, overuse of agricultural soil, reduction of soil permeability, and a permissive (perhaps corrupt) attitude of authorities to settlements in vulnerable areas.

This paper discusses the threats caused by uncontrolled changes of land use in these fragile ecosystems, which are specially exposed to climate change impact. It discusses how it may be possible to implement effective impulses of the New Urban Agenda, some of them corresponding to traditional communal collaboration uses in this region. As well it suggests how low tech landscape and urban design measures should be incorporated to improve resilience and commit authorities and the local population to cooperate to reach results.

2. Climate Change Effects in Bolivia

Bolivia can be divided into three topographical regions: Andean, Subandean and Plains regions. They feature different average precipitation rates: Andean 500mm, Sub Andean 950mm and Plains 1870mm. The endorheic basins of the Altiplano region around Titicaca lake have a higher ETP (potential evapotranspiration) than precipitation, indicating vulnerability to water scarcity in these regions. According to a government study from 2007 (Ministerio de Planificación del Desarrollo, 2007), climate change will also contribute to glacier melting in the endorheic basins area.The fresh water availability per capita and year is 160m³ (year 2000), comparable to the one in Norway, one of the highest in the world. Therefore Bolivia is considered a world fresh water reservoir.

A World Bank study from 2013 based on remote sensing data, primary data of 268 weather stations and modelled climate change impacts on water balance identifies regions with potentially critical water availability. It recommends a "countrywide integrated national plan" for improving watershed management (Escurra, 2013). The study confirms that the mountainous regions may experience draughts and the lowlands floods. The data indicates a temperature increase 0,11°C per decade in the Andean region of Bolivia, which is 0,05°C higher than the global average.

In general terms, the World Bank funded study concludes that climate change will have an impact in both dry and wet scenarios, a decrease of average renewable surface water in the Altiplano and an increase of floods in the northern plains of the country.

To understand the effects for the poorest population of the country it is worth to mention that forty percent of the main water collection surface and water sources are concentrated in rural areas in Bolivia. Around 60% of the population depend from these resources in agriculture and food production, and here also most of the poor population is concentrated.

2.1 Climate Change Effects on fresh water availability in the Cochabamba region

Cochabamba and its surrounding valleys are a visible example of how rural poverty and poor watershed management are correlated.

The geology of the valley of Cochabamba will be described in the next section, but climate change effects can be named here.

- Secondary rivers' waters rarely reach the Rocha River during the dry season. Rocha is the main river in the central valley of Cochabamba;

- Lakes in the lower sites of the central valley, together with lagoons on the Tunari Cordillera are today water reservoirs. Some of them dry out during the dry season.

- Calculations of the beginning of the 2000s predict an overall deficit from 2015 onwards, which should be covered by the extraction of underground reservoirs. The cities in the mountains in Bolivia have been consistently served by glacier melting water. Climate change puts this balance since many years under threat.

- The public company SEMAPA has no other option but to purchase water from community reservoirs during the driest months of the year. Yet some of the distribution ducts are in bad condition and water drains into the ground before reaching treatment plants.

3. The Cochabamba valley, its environment and water situation

This section describes briefly the background mix of elements, some of them natural, some of them human made, that summarize the current technical, geological and environmental framework of the water provision in the metropolitan area of Cochabamba. These elements include the geology, geomorphology, rural poverty and insufficient water management and infrastructure. The social aspects and the commitment of the local population in the water issue can be described through the Cochabamba Water War of the year 2000. Further on, the Misicuni dam has to be mentioned, which can be understood as light at the end of the tunnel, but not yet the final solution.

3.1 Geology and Geomorphology of the Valley of Cochabamba

The valley of Cochabamba is geologically a very interesting setting. For long periods of time, this tectonic basin was occupied by a lake. It contains distinctive sediments in the deepest sites. The deepest point is 2470m, the highest is mount Tunari at 5030m. The average central basin plain height is 2600m.

Regrettably, literature with detailed information about the geology of the Cochabamba valley is very limited. This section is based on a study financed by the German Bolivian Agreement on Groundwater published in 2000 (Renner & Velasco, 2000).

Regarding its geomorphology, the central valley can be divided in three zones: (1) a mountainous zone, with high peaks and deep slopes that are prone to originate landslides and rock material that is carried down to the valley; (2) a zone of slope and piedmont, with mostly coarse grained material with high hydraulic permeability, coarser in the higher areas at the mountain edge and finer in the lower areas down the valley; and (3) a plain zone with older sedimentation, fluvial lacustrine deposits, fine materials where most populated areas are located. These areas are swampy and contain salt efflorescences.

Consulted Landsat imagery shows some alluvial cones or fans that are produced by stormwater carrying sediments and flowing at high speed due to the deep slopes. Under these cones water deposits have evolved as important reservoirs. (See document graphs and charts (Annex): rivers in the valley; geological map; schematic geological section; sediments map).

The zones of slope and piedmont and some central parts in the basin are important groundwater host formations. They contain complex multilayered aquifers with confined and semi-confined characteristics. However, not all these reserves are favourable for exploitation of fresh water.

3.2 Water balance and management in the Tiquipaya basin

All water provision systems in the Tiquipaya basin are used for crops irrigation, except the water from deep wells, which is mainly used for consumption. Outside the urban areas there is an important community involvement in irrigation water management. One example is the community water distribution of the river Khora called Machu Mit'a. This is one of the only rivers with a permanent flow throughout the year. The Machu Mit'a isi used to manage also lagoons, dams, small reservoirs and distribution trenches. The locals distribute water as equally as possible but use superficial irrigation, which is considered less efficient. The availability of water has dropped according to records since 1986.

There is also a growing number of private wells in the valley area and overall water scarcity. A study from 2004 estimates a deficit of 2 to 4% in ground water recharging every year (Sáenz et. al., 2005). Therefore management and water storing capacities need to be improved.

The economy in the rural Tiquipaya region is based on agriculture (mainly potatoes, quinoa, barley, beans) and cattle growth (sheeps, camelides). Sewage, drink water and electricity service is practically absent. Only the rural neighbour cities of Titiri and Totora have primary schools.

Even though the Cordillera of Tiquipaya has available water resources, they don't cover the demand of intensive agriculture. Urban developments are more profitable, which contributes to urban sprawl. Studies and infrastructure development for agricultural water provision did not change this. With new urban developments poping up in the area, the demand for domestic water and the need for sewage infrastructure will increase considerably in the next decade, which represents a serious challenge for planning and environment.

3.3 Cochabamba's water war of 2000

Cochabamba, neighbour municipality and the capital city of the department to which Tiquipaya belongs, witnessed the well remembered Cochabamba Water War in February 2000.

Bolivia's hyperinflation crisis of 1985 led to the adoption of last instance economic measures taken to avoid economic meltdown, most of them forced by global financial institutions, the World Bank being the main player. Among these was the privatisation of pivotal state assets, such as railways, communications, and hydrocarbon and aviation corporations.

As single bidder, an international consortium of construction giants and a minority of Bolivian investors acquired a 40 year concession to provide drink water, electricity and irrigation for agriculture. They were guaranteed 15% annual return of investment, adjusted to the US consumer price index. The subsequent law that was necessary to regulate the concession and the first contract executions of the company caused substantial social rejection. The unwillingness of government and company executives to negotiate a settlement heated up the tension to an extreme. After weeks of strikes, clashes and a toll of at least six deaths, the concession was revoked.

Cochabamba's water war is today a symbol of Bolivia's government traditional anti globalisation rhetoric, supported by the majority of the population. It was at the same time a platform for several work union leaders who joined years later current president Evo Morales in power. However at the same time it represents the failure of political leaders to find solutions, because the fresh water provision is still insufficient and the management poor.

Since then, the public water company SEMAPA has severe difficulties to negotiate credits by financial institutions.

According to last census data, only 46% of the urban population has a connection to the drink water services, the rest being serviced by cisterns to a much higher end user price.

3.4 The Misicuni Dam, some light at the end of the tunnel?

The Misicuni dam and complimentary infrastructure is a reservoir with connected turbines for electricity generation and provision of fresh and irrigation water with a capacity of around 800M m^3 in its main dam.

The planning started in the early 1960s and could not be completed until 2017 for diverse financial and technical reasons. The installed generation capacity is 120MW and the projected fresh water provision for the region of Cochabamba is 1200l/s. Misicuni is meant to solve the water scarcity problems of the region for the next decades.

Misicuni was never considered financially viable, which made it nearly impossible to acquire credits for completion. Eventually, available cash from the revenue of natural gas exports and a redesign of the infrastructure to incorporate electricity generation improved the success perspectives and the project was concluded with national funds. Today the dam is serving for irrigation purposes and delivering energy to the national network. It does not provide fresh water for household consume because of a lacking proprietary pipe connection and missing capacities in existing treatment plants.

4. The Tiquipaya Flash Flood Disaster

The Tiquipaya flash flood of sixth of February 2018 occurred after a sequence of days of rainy weather that saturated the soil in the upper areas of the Tiquipaya Cordillera, which eventually collapsed as landslides. The accumulated sediments slid down to the valley covering streets and buildings very early in the morning, surprising most victims in their sleep.

But this is the short sight version of the story. A more detailed perspective reveals a series of elements, which combined generated an explosive cocktail. Because of the awareness about the fragile geology of the Tiquipaya Cordillera, as described in the previous section of this paper, and the ongoing deforestation, reduction of permeability and indolence of local authorities towards settlements in vulnerable areas, the Tiquipaya flash flooding and its outcome was a foreseeable event.

Nonetheless it is fair to mention that proprietary measures had been implemented long before the area became populated. Around 30 years ago, the watershed management was implemented by the PROMIC initiative. PROMIC was a watershed management project initiated by the Belgian development programme in Bolivia. It was established in Cochabamba in 1990 and discontinued its cooperation with Bolivian authorities in 2009. It was replaced by a local office called *Servicio Departamental de Cuencas*. It focused on five of the nine watersheds within the Tunari Cordillera.

According to PROMIC project descriptions, the Tiquipaya watershed area (27,23 km^2) has suffered soil degradation and erosion in its higher streambed, which increases the risks of floods in the valley flats. Even though floods occur every year, the situation becomes more critical with the growth of illegal settlements and uncontrolled change of soil cover (Méndez Torrico, 2004).

Erosion in productive soils in the Tiquipaya Khora watershed is caused by inadequate soil management (high pressure on natural resources) and poorly prepared crops on inclined grounds. The natural and irregular topography intensifies the erosion process because of steep slopes, since only 10% of the topography has a slope under 18% (10°=. A reform of land ownership regulations adopted in the 1990s and its consequent land use changes meant a loss of 10% natural vegetal coverage, and half of the naturally dense grass cover was also lost. Agricultural productivity has still dropped due to bad quality seeds, inefficient water management, uncontrolled firewood use, lack of adequate technology, insufficient road connections, pests/ parasites, etc.

4.1 Aftermath reactions and analysis following the Tiquipaya event

Experts coincide that since 2009, when the cooperation contract with the Belgian project PROMIC finished, the watershed monitoring was not continued by the local authorities, thus the risks were not detected.

The unstable topography of the 39 micro watersheds of the Tunari National Park is acknowledged and a constant monitoring is mandatory to prevent disasters. A logical task in zones like this is to manufacture a risks map. This was not undertaken by authorities (Mazaneda, 2018).

The Tiquipaya flash flood from 6th of February 2018 killed five and damaged or destroyed 122 houses, most of them built in buffer zones along the river, which were foreseen as washland in the urban plan of 1981. Despite of existing regulations, some buildings had received build permit, a fact that may be related to corruption and land trafficking (Callapa Cabezas, 2018). One of the experts of the local engineers association warned about corruption tainted watershed management and irresponsible decisions taken to serve political interests. Despite of identified urban developments within washland areas, permits were issued in favour of political support (Carrillo, 2018).

5. Analysis and suggested interdisciplinary solutions in different domains

Water is no doubt a complex matter of multiple dimensions in Cochabamba, and not only there. As mentioned before, the recommendations for an improvement of conditions for water provision, environmental protection and soil consolidation need to be based on a common vision and combined measures. This means that authorities, citizens, farmers and other stakeholders need to hold an interdisciplinary collaboration that aims to create integral plans of operation.

The interdisciplinary discussion should contribute to elaborate integral strategies for improvement in at least three different levels: Agricultural areas, Tunari Natural Park and Urban setting.

The World Bank study mentioned before summarizes the importance of solving water issues in Bolivia because of four reasons: self reliance, increasing population regionally oriented economic development and preservation of local identities (Escurra, 2013).

The same study also warns that the increase on CO2 concentration in the atmosphere will affect the canopy conductance negatively, leading eventually to an increasing annual river discharge by 3 to 16,5%. This confirms that green coverage reduction contributes to reducing evapotranspiration and floods.

5.1 Rural areas, Agriculture and Farming

The above mentioned PROMIC programme suggested a series of measures that should be implemented and would have a large impact on different issues (see annex table/ matrix).

Additionally, a constant erosion control would create long term jobs for local population in activities such as construction of chipas (gavions) for terrain strengthening, retention dams and water distribution trenches and general maintenance work.

Past examples in the area have shown that a proper watershed management has to start at the source of the basin up the mountain, instead of trying to mitigate effects in the lower valley. As well it is important to improve the framework conditions for a smooth implementation of activities. Because of bureaucracy and slow implementation, not all the objectives of past projects were met.

Previous changes in water and soil management techniques did improve productivity and soil quality. This was corroborated by local farmers, who obtained higher yields (2x - 4x) and benefited by more affluent water springs. This pays back any efforts.

Proposed Improvement measures on rural areas of the Khora Tiquipaya watershed would benefit as well from measures undertaken in the Tunari National Park (see below).

A proper Management/ recovery of degraded soil will:

- reduce superficial soil loss (humus),
- control water flooding energy/ flows of stormwater using cross-cutting dams built with rubble and timber,
- strengthen slopes and banks mechanically and with vegetation,
- speed up natural regeneration with the use of native species.

5.2 Soil consolidation and forest regeneration in National Park Tunari

The National Park Tunari has to establish its necessary institutional structure, as well as design a management plan and work on inventories of flora and fauna and protection guides. The park's role goes beyond the natural heritage protection. The impact of the Park in issues such as awareness building and participation can be crucial for the general soil and air quality preservation in the region of Cochabamba. Proper protection measures are necessary to control the urban sprawl of neighbour municipalities, especially Cochabamba, and also to use the chance to bring environmental education to a broader population.

More than that, the Park is an asset with opportunities for economic activity in areas such as eco-tourism, adventure tourism, science, sport and leisure activities, etc.

The University of San Simon in Cochabamba used freely available remote sensing data to count bush and forest fires of the last 10 years. The number of fires doubled in the last five years to about two hundred per year in average. Among the reasons are lack of control, slash and burn clearing techniques and negligence (Challapa 2, 2018). Forest fires at the edge to urban areas have as an effect an increased number of informal settlements that can barely be controlled with reduced budget of local authorities. An improved landscape design at the urban edge shall provide clearer boundaries. It could as well motivate more involvement of the population in reporting fire events. Vegetation loss also contributes to erosion and landslides.

Even though these observations relate to the region around Cochabamba, this phenomenon occurs country-wide.

In a newspaper interview, Prof. Ramiro Uriarte Ardaya, agronomist at the University of San Simon, recommends a stepwise reforestation, according to the adaptability of native species to increased altitude. This means more bushes in the summits, endemic trees in the mountain slopes as fauna habitat and decorative native species in the forest borders.

Native species that can be re-introduced, proposed location

- K'apa K'apa (*Lippia boliviana*): aromatic shrub. All heights, especially mountain summits
- Thola (*Baccharis dracunculifolia*). All heights, especially mountain summits
- Moto Moto (*Senna aymara*): flowering shrub. All heights, especially mountain summits.
- Retama (*Spartium junceum*): medicinal plant, deciduous shrub with yellow flower
- Kishwara (*Buddleja hypoleuca*): shrub/ tree with 4m max height. Middle heights, Lower slopes and riverisdes up to 3200 m above sea level:
- Aliso (*Alnus acuminate*): tree up to 20 height, good for city borders and forests at middle altitudes.
- Sauce (*Salix humboldtiana*): along water courses, up to 25m height, landscaping at city borders
- Alamo (*Populus nigra*): it is not a native tree, probably Asian, but it is well adapted and was introduced centuries ago. It grows up to 3500 m above sea level and can be used to cut winds at city borders.
- Molle (*Schinus molle*): evergreen tree, up to 15m height, ideal as ornamental tree at city boundaries with the park.
- Kehuiña (family *Polylepis*): robust shrub that can grow at all heights within the park, it used to cover ancient Andean forests, before extensively being sacrificed as firewood.

Other species already available in the national park to be considered: Chirimolle (*Fagara coco*), Algarrobo (*Prosopis juliflora*), Lloke (*Kageneckia lanceolata*), Chacotea (*Dodonaea viscosa*) K'inhi (*Acacia macracantha*).

A detailed study of existing species and extensive inventories, also for living fauna in the National Park Tunari are necessary to evaluate biodiversity issues and make proper decisions.

5.3 Applying the New Urban Agenda principles to improve Urban design, adaptation and reduction of vulnerability

On the urban scale the strategies to reduce vulnerability have to be integral as well. This relates to the first of five focus areas of the New Urban Agenda (NUA), namely *improving existing urban policies*. In developing countries the boundary between urban and rural zones on the plan is seldom clearly visible on site. In Tiquipaya authorities set in 1991 the elevation contour 2750 as the south boundary between the Tunary National Park and the urban zone. Along the rivers, also the washland boundaries have not been successfully implemented, as mentioned before.

The author of this paper considers that the solution should incorporate strong community participation and start with a horizontal discussion. Neighbours need to understand that they have the right to have a place to settle down as much as authorities have the obligation to make sure it is safe, but this can only happen when both sides cooperate.

Because of slow recharge and the few aquifer recharge sites, diverse studies estimate a deficit in seasonal recharge of 8,5M m³/year in the Tiquipaya watershed area (Saenz, 2005). For this reason, land use in the northern edge of the valley should not interfere water recharge neither threaten water extraction sites. Industrial use with potential soil contamination must not operate here. Agricultural activity must keep the amount of pesticides and fertilizers under strict limits. Contaminated waters must not pass through protected areas and industrial land use must be limited to the south of the valley, where water treatment plants should be located. This is addressed by the second NUA focus area: *designing and applying a solid urban legislation with rules and regulations*.

The buffer distance for the washland areas along the river within the urban limits of Tiquipaya is 60m (at the city outer line), 40m and 25m at its narrowest site, between the center line of the river and the outer border of the washland area. After last February floods however experts recommended increasing the buffer to 90, 60 and 30m (Pimienta, 2018).

Local planners urge to persuade settlers to move away from vulnerable sites or give up areas of their parcels that intersect the buffer zones. Authorities announced instead that settlers shall state to assume responsibility for any personal or material damage in their private property in case of being affected by floods. Proper landscape design and community collaboration can help to persuade more social responsibility in this issue. This point is addressed by the third focus area of the NUA: *Urban Planning and Design* with which locals can identify. Here especially guaranteeing a sustainable use of public space is crucial. The ancient community water distribution management Machu Mit'a is a perfect example.

The absence of reliable information, inventories, digital cadastres, etc. shows also the lack of proper data acquisition and management. Increasing the efficiency of the city implies better information about the existing resources. This relates to the NUA focus area four: *Urban Economy and Municipal Finance*. Also Weather and climate models cannot rely on interpolated data generated with a low density of monitoring stations. It is imperative to increase the number of weather stations extensively in the country to make sure reliable data is available, a better accuracy is possible and climate change effects can be more closely monitored. Only a reliable observation of climate change effects will improve decision making on vulnerability and adaptation.

The fifth focus area of the NUA addresses *local physical implementation*, which groups all the issues mentioned before into a proper preventive and smart planning, which is an investment towards a resilient and inclusive city.

6. Concluding Remarks

In the sense of the NUA, urbanization of the Tiquipaya valley is a logical development that may not be stopped any more. Planners should see it as an opportunity, a *tool for sustainable development* (New Urban Agenda, 2017), which improves social integration and equity.

The Economy in Bolivia has substantially improved in the last decade. Yet there is still a lot to do in terms of basic services, sanitation and transparency. It is urgent to educate, build and invest. And now that the dependency on foreign cash has changed, it is an opportunity to educate, build and invest.

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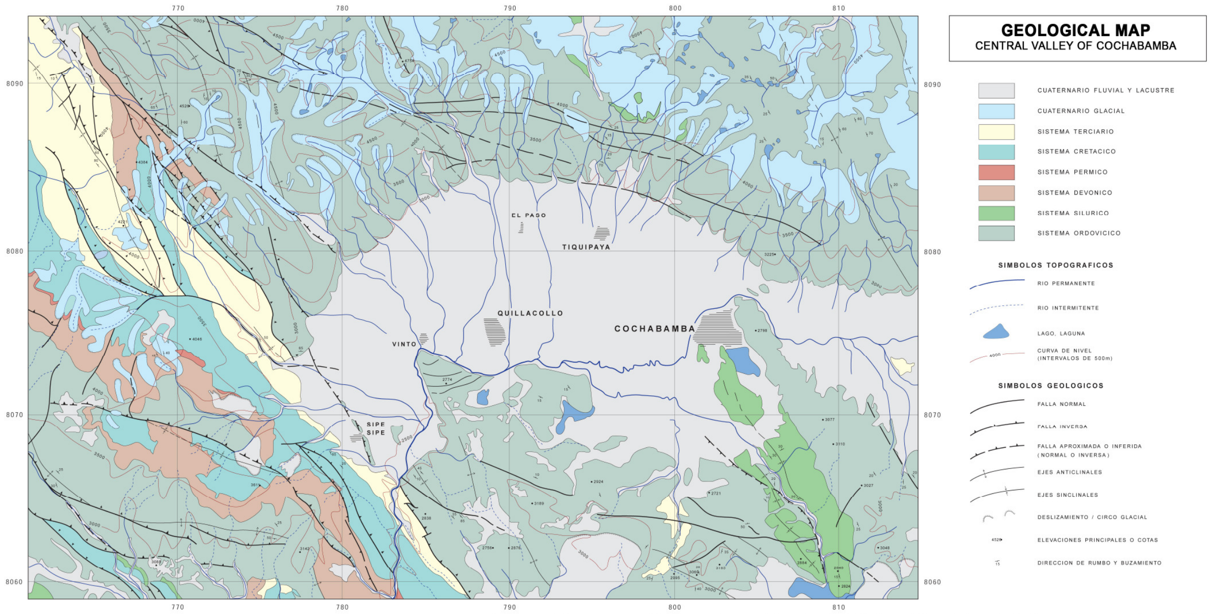
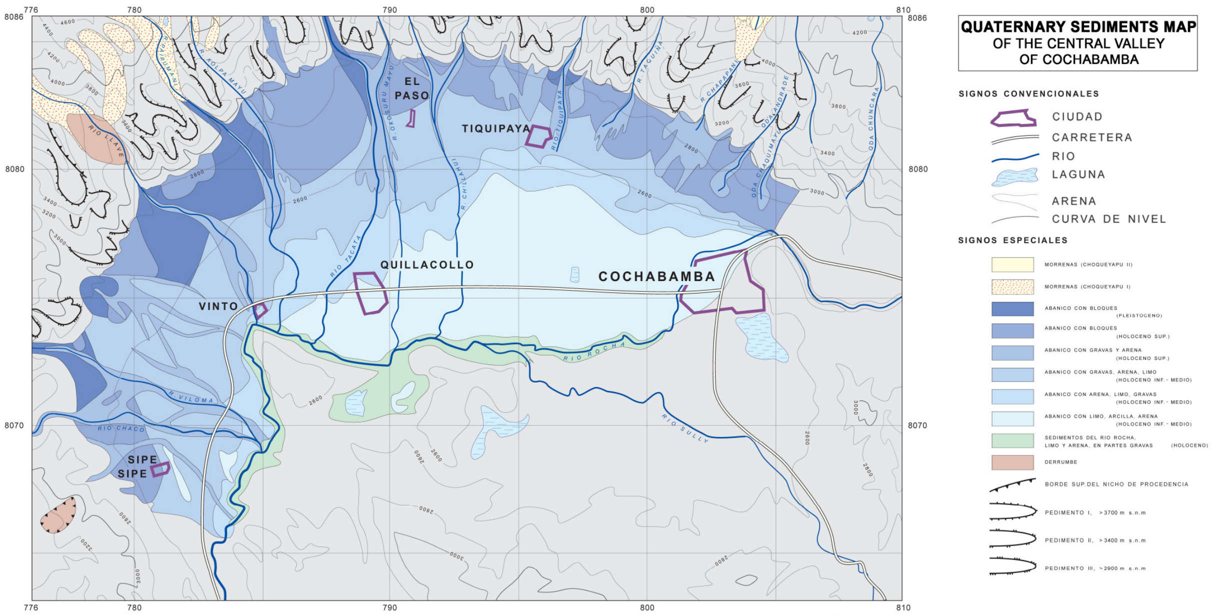
Annex Graphs and Tables



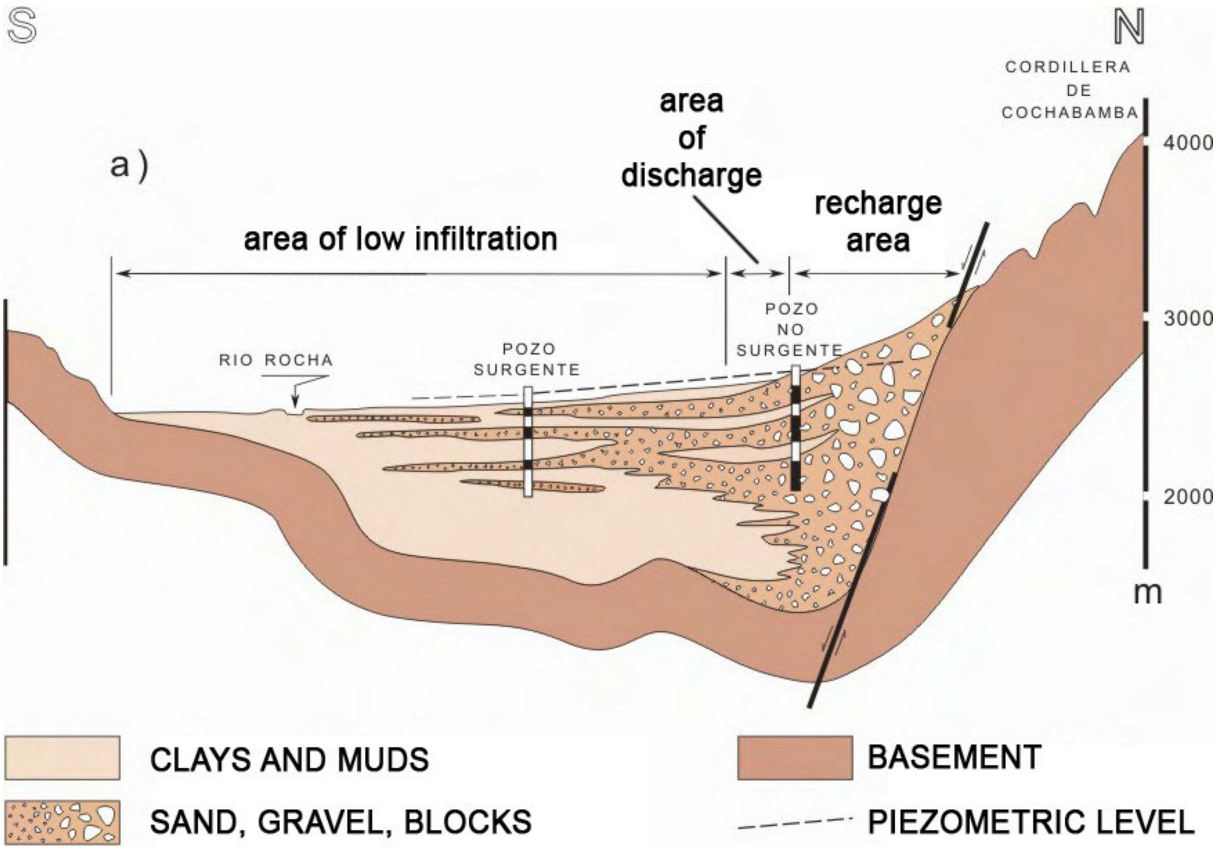
Source: "Geology and Hydrogeology of the Central Valley of Cochabamba", Sven Renner Et. Al. 2000

(1) Map: Geological Map of the Central Valley of Cochabamba



Source: "Geology and Hydrogeology of the Central Valley of Cochabamba", Sven Renner Et. Al. 2000

(2) Map: Quaternary Sediments Map of the Central Valley of Cochabamba



Source: "Geology and Hydrogeology of the Central Valley of Cochabamba", Sven Renner Et. Al. 2000

(3) Section: Schematic section of the Cordillera and Central Valley of Cochabamba

Activities ▶ ▼Objectives	Construction of hydraulic infrastructure	Water management	Erosion control	Slopes consolidation	Reforestation	Productive areas planning	Soil management/ conservation	Native grasslands management	Community training	Storm water control
• Reduce soil/ sediments washing	✓		✓	✓	✓			✓		
• Reduce slope erosion		✓			✓		✓	✓		✓
• Sustainable use of farmland						✓	✓	✓	✓	
• Native grasslands recovery						✓		✓	✓	
• Capacity building for farmers on efficient soil use						✓			✓	

Source: PROMIC project guidelines

(4) Matrix: Sustainable productive land management, activities and objectives