Use of wastewater for irrigation and its relationship with local environmental changes in Cochabamba, Bolivia

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by

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To María de Los Ángeles and Martín Daniel…
life is full of blessings; sooner or later you will
discover that you are part of them

Abstract

The spatial relationships between the irrigation water sources and the soil degradation was evaluated in the central valley of Cochabamba, Bolivia. ASTER imagery, ground measurements and Geostatistics methods were used for the approach. Imagery was used for the location of salinity-sodicity resistant crops. Soils were sampled and analysed for salinity characteristics. Electrical conductivity (EC) and Exchangeable Sodium Percentage (ESP), were interpolated using Orindary Kriging and classified according to well known reference levels. The principal water sources were sampled an analysed for cations, anions, pH, EC and solids. Surface water in channels and groundwater sources were also measured on EC. Water sources present a trend of increasing pollution in downstream sense. EC in water present a high variability (0.1 to>6 dS m^{-1}). Variability on soil EC and ESP is also presented. Most affected areas are those located along wastewater sources, mainly saline-sodic soils, and correspond for most of the 55% of the area. Less affected areas are irrigated with better quality waters used for irrigation. When consulted about general changes in the environment, the community recognized the decreasing of yield and the cropping species changes as the main effects of waste water using.

Key words

EC, ESP, WWTP (Waste Water Treatment Plant), Rocha River, Tamborada River, La Angostura, Kriging interpolation, water quality, soil salnity, La Mayca.

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To my family and friends at home: thanks for being there, paying attention to all my movements.

Carlos Román

Enschede, 2009

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ASTER	Advanced Spaceborne Thermal Emission and reflection Radiometer
CLAS	Aero-spatial survey and GIS applications center for sustainable development of natural resources
EC	Electrical conductivity
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organization of the United Nations
HAMC	Honorable Municipality of Cochabamba
ILWIS	Integrated Land and Water Information System
MDSMA	Ministry of Sustainable Development and Environment
ME	Mean predictor error
NIR	Near infrared
OPS	Pan American Health Organization
PIL	Milk Industry Plant
RS	Remote sensing
SAR	Sodium adsorption ratio
SEMAPA	Municipal Water Supply and Sewerage System
SENAMHI	National Service of Meteorology and Hydrology
SERGEOMIN	National Service of Geology and Mines
SNR 1	National System of Irrigation 1
WHO	World Health Organizaton
WWTP	Wastewater Treatment Plant

1. Introduction

A growing population in the world demands large amounts of food and fresh water. Unfortunately, the access to water is still a critical constraint. As expressed by Molden (2007) "… a *fifth of the world's population, more than 1.2 billion, live in areas of physical water scarcity*; and *about 1.6 billion people live in water-scarce basins"*. In these places, human or financial capacities seem to be inadequate for developing water resources. It produces the reduction of water quality in every stage of its use, and, at the end, compromises the agriculture activities (Molden, 2007).

Due to the scarcity of water, wastewater for crop production as an integral part of water resources management is receiving increased attention in most parts of the world (Mutengu et al., 2007; Yang and Abbaspour, 2007). Wastewater reuse in agriculture is difficult to assess, however, it has a clear importance in arid regions, and humid environments as well. Some examples are: Hanoi, in Viet Nam, where 80 % of vegetables are irrigated with water mixed with wastewater; and Kumasi, in Ghana, where the using of wastewater reaches about 11900 ha, representing a third of the officially recorded irrigated area of the country (Molden, 2007).

According to Durán et al. (2003), urban and peri-urban agriculture is increasingly recognized and acknowledged as an important mean of achieve local food security. Many places in the world depend on production of agriculture areas inside or very close to the cities, reducing in this way the price of fresh vegetables. However, and due to the pressure on water resources, its quality faces contamination risks (Agreda, 2000), not only due to chemical contamination, but biological pollution as well.

In developing countries, wastewater is released to the environment with scarce or non treatment at all (Yang and Abbaspour, 2007). When polluted water is used in irrigation systems, features in soil can also change and become unsuitable for crop production and other human activities (Ghassemi et al., 1995). Other consequences are the increasing of nuisance, health risks and other environmental damages, including groundwater pollution (Durán et al., 2003). Despite of these degrading characteristics, wastewater is a cheap source of nutrients for plants. In fact, when the use of waste water is well planned, farmers in peri-urban areas can be greatly beneficed (Hassanli et al., 2008; Madungwe and Sakuringwa, 2007).

Bolivian major cities are growing without a clear urban and peri-urban planning. The city of Cochabamba is located on a mesotermic valley in the department of the same name. The valley is a tectonic basin anciently occupied by a lake, the bottom of the basin was formed by a sequence of Quaternary deposits beginning with Pleistocene lacustrine deposits (Anton, 1993; Huaranca and Newman-Redlin, 1998). The main activity in its surrounding areas is the agriculture production. However, the urban expansion has resulted in mixed urban-rural landscapes. One of the remaining agriculture areas in the central valley of Cochabamba is the zone known as La Mayca, located at the southwest of the city.

This area belongs to the District 9 of the municipality of Cochabamba. Its principal water sources are the Rocha River, the Tamborada River (which conducts the water from the Angostura dam), and treated waters from the sewerage system of Cochabamba city. These sources are used for agriculture activities during the dry season (March to November). Most of the farmers are dedicated to dairy cattle. The cash crops are alfalfa (*Medicago sativa*), ryegrass (*Lolium* sp.) and corn (*Zea mays*) and are used as fodder for dairy cattle. While alfalfa and ryegrass are permanent crops, the corn is cultivated from late August to April on yearly basis for selling as a fresh product and for cattle consumption. Milk is sold, mainly, to the regional Milk Industry Plant (PIL). In addition, some farmers crop legumes and vegetables that are sold in local markets as fresh products (Agreda, 2000). Recently, little and medium poultry farms have been introduced in the area.

As a result of a long period of irrigation with saline waters using a flood-gravity irrigation system, salinity has increased in soils as well. The water sources mentioned previously were studied by Agreda (2000) and Ampuero (2005); finding that irrigation in the area is made mainly with highly saline waters, specially those coming from the sewer treatment plant. Soil salinity has expanded on an approximate ratio of 7 ha per year. These waters present high organic matter contents and different pollutants, chemical and biological as well (Agreda, 2000). Assessments have been done focusing different parts of the problem, which require more "system approach" studies to address remediation or attenuation actions to it.

The accumulation of neutral soluble salts is known as **salinization**. Salts are chlorides or sulfates of sodium, magnesium or calcium, mainly. Saline soils have sufficient salt concentration to interfere with the normal growth of many plants. The response of the plants to salt-affected soils is variable. In saline and saline-sodic soils, the osmotic potential can be affected even until cellular collapse. A reduction in the water and air movements in soil can affect the normal plant growth in these soils. "*Sodic soils harm plants in five ways: (1) the caustic influence of the high pH induced by the sodium carbonate and bicarbonate, (2) the toxicity of the bicarbonate and other anions, (3) the adverse effects of the active sodium ions on plant metabolism and nutrition, (4) the low micronutrient* *availability due to high pH, and (5) oxygen deficiency due to the breakdown of soil structure"* (Brady and Weil, 1999).

Although the salinity of water and soils is a main problem, an assessment must integrate not only environmental, but also social and economical aspects involved in the situation. In the Bolivian society, the incorporation of the social interest in the assessment, and the degradation usually embedded, is the clue to achieve the success of any project at community level. Any technical research that does not include these social aspects will not be supported by any action from the local government, regional and community authorities.

Spatial attributes, like the extension of most affected areas due to the salinity and the location of point-sources of water pollution, can be added to obtain better assessment approaches for decision makers. Unfortunately no periodical records related to soil salinity exist in the area, and most of the available records don't have the spatial component for an accurate evaluation. However, under certain circumstances, remote sensing and GIS has proven to be good and cost-effective tools for monitoring salinity of soils (Masoud and Koike, 2006).

Effects of wastewater irrigation can be detected via evaluation of indicators as well. Those can be physical, biological or socio-economical, also different combinations among them. Common examples are changes in soils status, surface crusting, saline efflorescence, vegetation degradation or density of human settlements (Metternicht, 1996). Other indicators can be oriented to measure the performance of the irrigation system itself. In the last case the values obtained are compared with target values or reference levels throughout the time (Bandara, 2006; Bos et al., 2005). Local knowledge and experiences can be also valuable sources of information (Dunn, 2007)

1.1. Research identification

1.1.1. Research objectives

The main objective of this research is to assess the effects of wastewater used in irrigation producing hydrosaline degradation of lands and environmental changes in the central valley of Cochabamba, specifically the zone known as La Mayca. Complementary, a community approach is explored as a tool to gather relevant technical information and to correspond with relevant information to the community decision makers. Secondary objectives are:

- To evaluate the capability of medium resolution satellite imagery for the detection of spatial changes in soil salinity using.
- To establish relationships between the current soil salinity and information about irrigation water quality for the different sources of irrigation in the study area.

- To use a simple environmental indicator applied to irrigation in the zone of influence of the wastewater treatment plant of Cochabamba.
- To generate information about land cover related to irrigation practices in the study area to assist future monitoring, complementary, or evolutional studies.

1.1.2. Research questions

- Which areas are affected by different soil salinity severity in La Mayca?
- Can it be established a relationship between saline water irrigation and soil salinity in La Mayca?
- Is it possible to determine changes in the irrigation performance throughout the time, considering the lack of historical records in the sector?
- Is it possible to gather spatial information about environmental changes, mainly related to wastewater irrigation in the study area by combining local knowledge, remote sensing, ground measurements and historical resources?
- Which is the best way to create awareness of the environmental problems in the zone in order to promote remedial actions?

1.1.3. Hypothesis

Ground salinity measurements can be correlated to selected band combinations of medium resolution imagery. This correlation could be used to map and quantify/qualify areas affected by salinity throughout the time and to establish a monitoring approach for similar areas in the central valley of Cochabamba or regions with similar features.

Performance of irrigation has decreased in the study area due to hydro-saline land degradation and stress and other environmental changes related to water pollution processes.

Local knowledge matches spatial information generated and can be considered as a valuable source for multitemporal studies in recycled wastewater reuse issues in view of the lack of documented studies.

2. Study area

The area known as La Mayca is located in the central valley of Cochabamba, Bolivia (Figure 1); the geographical location in UTM projection is:

- X: between 793260 and 801800.
- Y: between 8074426 and 8068682.
- Zone 19 K, at the south hemisphere.

The area is an alluvial plain with flat topography composed of alluvial terraces adjacent to the Rocha and Tamborada rivers. These areas are susceptible to summer floods in rainy seasons due to the overflows of the mentioned water sources.

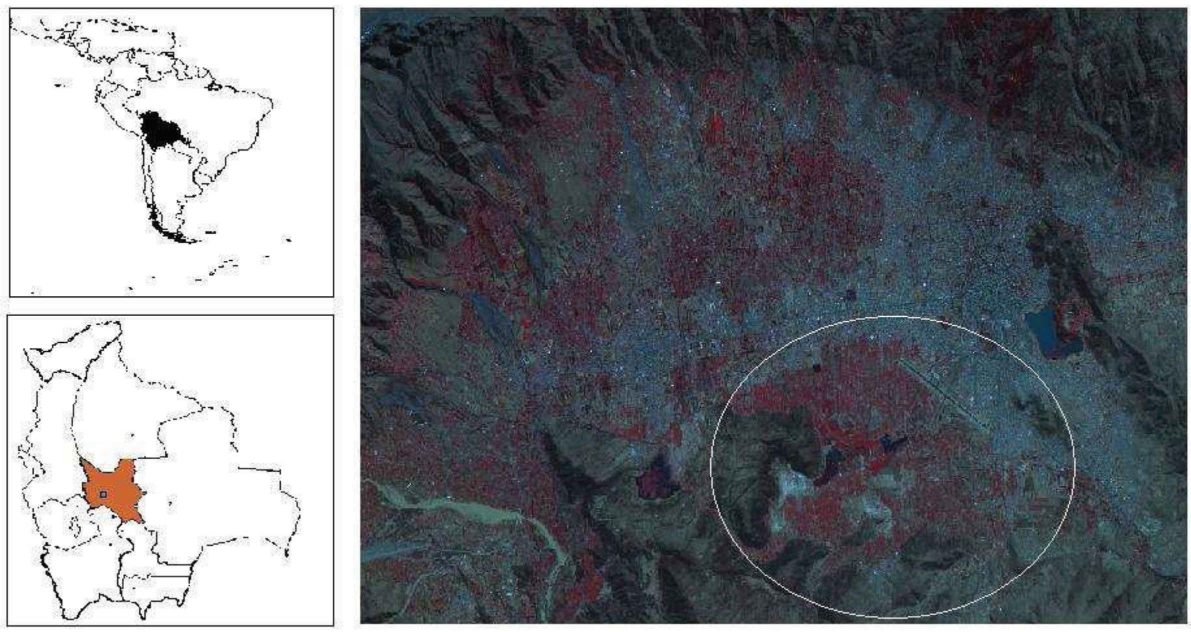


Figure 1. Location of the study area.

The total area of La Mayca considered for this study is 2876 ha. The delimitation of the area was made under the next criteria:

- Agriculture zones that belong to the district 9 of Cochabamba (surrounding the La Mayca zone).
- The areas must have similar conditions of topography and natural vegetation.
- In the area must be communities that use different sources of water for irrigation.

The annual average temperature is 18 ºC. The average annual rainfall for the last 10 years was 450 mm. The rainy season extends from November to March. The distribution of the rainfall and the average temperature is presented in the next diagram (Figure 2).

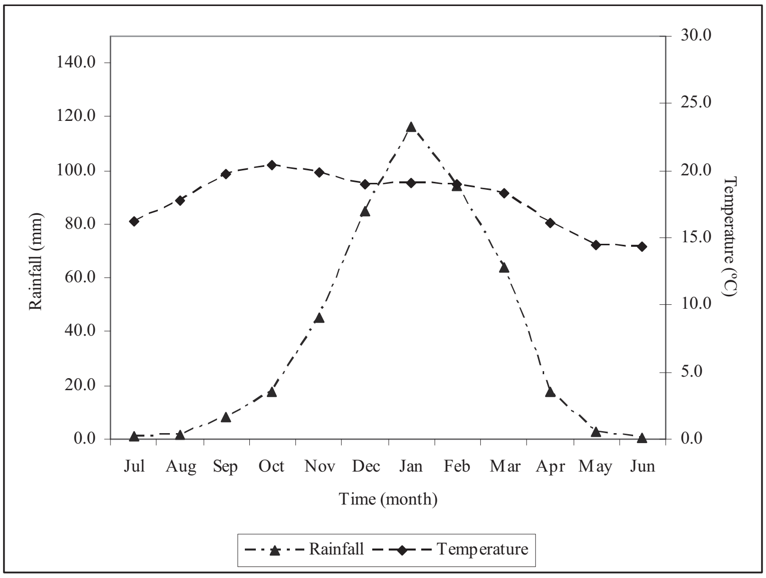


Figure 2. Rainfall and temperature diagram for the study area.
Source: (SENAMHI, 2009)

During most of the year a deficit of precipitation is recorded and the agricultural activities depend on irrigation systems and different water sources (Agreda, 2000; IDRC, 2004; OPS and CEPIS, 2002). The area is politically organized in communities that correspond to local neighbourhoods. The extension of the average cropped area for the communities is listed in the Table 1.

Table 1. Cropping area for different water sources and communities (estimated for 2002).

Community	Cropping area for different water sources (ha)					
	Angostura dam	Treatment plant	Raw water Tamborada river	Raw water Rocha river	Raw water Valverde channel	Total
Monte Canto	10	30.45				40.45
Champarrancho	8	8	8			8
Tamborada B	15	15	15			15
Tamborada C	17	17				17
Mayca Chica		10		150		150
Mayca Sud	143.3	109.9		21.98		143.3
Mayca Quenamari	77.13	77.13			77.13	77.13
Media Luna		21.33				21.33
San José	38	38				38

Table 2. Cropping area for different water sources and communities (estimated for 2002) (Cont.).

Community	Cropping area for different water sources (ha)					
	Angostura dam	Treatment plant	Raw water Tamborada river	Raw water Rocha river	Raw water Valverde channel	Total
Albarrancho	114	114				114
Kullko		56.72				56.72
Mayca Norte	400	100		160	80	400
Mayca Central	350	50		140		350
Pampa López		27.75				27.75
Quenamari		41.88				41.88
Sumunpaya	77	55				77
Total	1249.43	772.16	23	471.98	157.13	1577.56

Adapted from OPS and CEPIS (2002).

Table 3 Describes the cropping area classified per crop and community that depends entirely on irrigation from Wastewater.

Table 3. Total dependency from wastewater.

Community	Alfalfa	Grass	Maize	Salt affected	Total
	------------------------------ ha --------------------------				
Monte Canto	1.02	8.5	0.93	20	30.45
Mayca Sud	40.6	25.6	15.4	28.3	109.9
Mayca Quenamari	38.13	7.9	31.1		77.13
Media Luna	13.15	3.13	2.35	2.7	21.33
Kullko	30.66	4.36	20.33	1.37	56.72
Pampa López	1	25.75		1	27.75
Quenamari	15.65	13.49	7.26	5.48	41.88
Total	140.21	88.73	77.37	58.85	365.16

Source: OPS and CEPIS (2002).

The amount of users registered in the SNR 1 (National System of Irrigation 1) in the area is presented in the Table 4. Every user represents an average family of 5 members, which represents more than 7600 inhabitants involved in the system.

Table 4. Users of the different water sources in the area.

Community	Users	Water source	
		Primary	Secondary
Tamborada A	26	Angostura	
Tamborada B	329	Angostura	
Tamborada C	154	Angostura	
Maica Chica	145	Angostura	
Maica Sud	58	WWTP	Angostura
Maica Norte	22	Angostura	
Maica Central	80	Angostura	
Maica Quenamari	113	WWTP	Angostura
Quenemari Kullku	48	WWTP	Angostura
Monte Canto	16	Angostura	
San José	209	Angostura	
Caico Central	130	Angostura	
Albarrancho	195	Angostura	
Total	1525		

Source: SNR 1 (2008).

2.1. Principal crops

As mentioned earlier, the principal crops in the study area are maize (*Zea mays* L.), alfalfa (*Medicago sativa* L.) and ryegrass (*Lolium multiflorum* Lam.) (Figure 3). Alfalfa and ryegrass are permanent crops, renewed every 3 to 4 years. The corn is not tolerant to high concentrations of salt in the soil. Plots affected by salt are noted in different points of the study area. Alfalfa and ryegrass are registered as tolerant to soil salinity, growing without much restrictions between 2 to 18 dS m^{-1} of EC (Masters et al., 2007). Although it is certain that both are tolerant to salts, only ryegrass can support long periods with high levels of humidity in soil, being a good competitor among other grass species and weeds (Riewe and Mondart, 1985).

A) *Lolium multiflorum Lam.* **B) *Zea mays* L.** **C) *Medicago Sativa* L.**

Figure 3. Principal crops in the study area.

2.2. Soils characteristics

The recognized soil orders are Aridisol and Entisol (HAMC, 2006). The Aridisol are water deficient. Soil moisture can support 90 days of plant growth. Vegetation is sparse and its presence may affect substantially the soil properties. Its formation process brought a redistribution of soluble materials, but the water availability is not enough for a complete leaching. In some circumstances the accumulation of carbonates can produce hard layers known as *petrocalcic* horizons, impeding root development (Brady and Weil, 1999).

Entisols, in the other hand, don't have a fixed characteristic as descriptor. On its parent materials like recent alluvium (Fluvents), there has been too little time for much soil formation. When well managed, Entisols account for one of the most productive soil orders in the world, and have been the basis for ancient civilization support (Brady and Weil, 1999).

The terraces parental material was formed after alluvial and coluvio-alluvial depositions. Overlaps of textural layers with fluvial characteristics can be frequently observed. Different textural classes with predominance of clay and silt are both in top (0-30cm) and deeper horizons (30-90cm) (Agreda, 2000). The top soil textural classes are mainly loam, loam clay and loam silty clay. At the south of the study area sandy and clayey soils are also present (Figure 4).

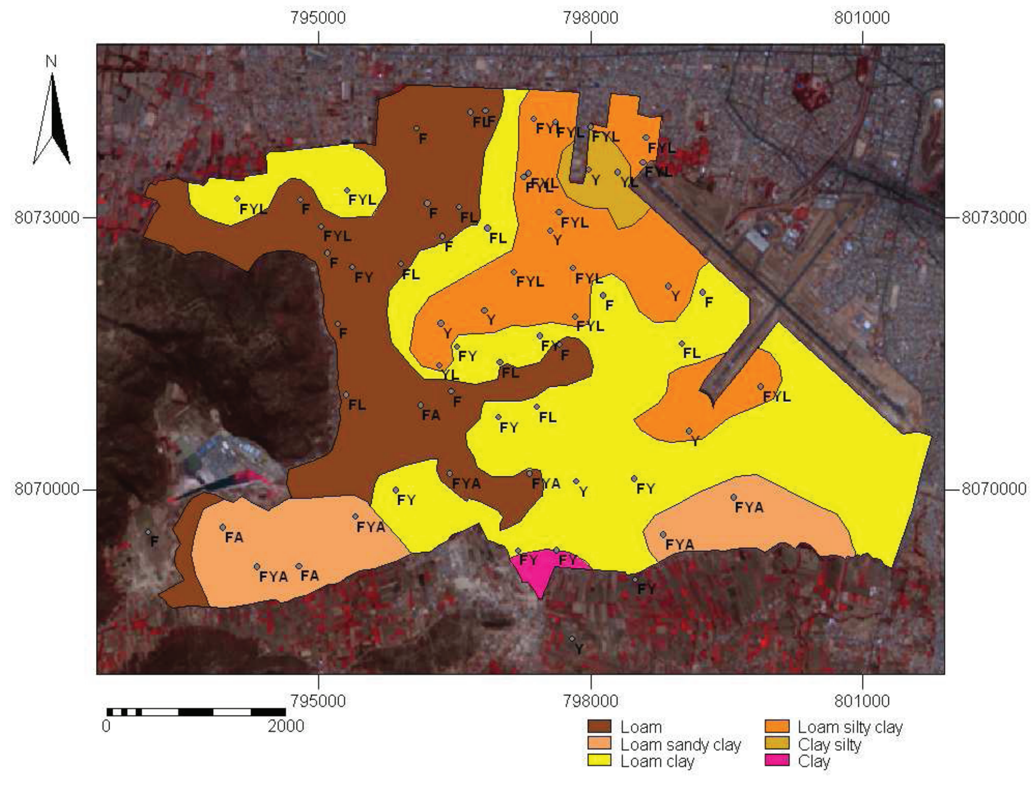


Figure 4. Textural classes in the study area.
F = Loam; A = Sand; L = Silt; Y = Clay.

The pH is slightly acid to alkaline with an average of 8, and ranking from 6 to 9. The content of cations is variable being the N^{+} the one with the highest concentrations, as it was found during this research (Table 9). The area presents dark soils in the surface and in deeper horizons. The Nitrogen levels in the soils are higher than 0.8% and the organic matter less than 2% (HAMC, 1997).

Soils are well drained in general, but there are sectors of deficient drainage. Deficiency in drainage is specially noticed at the river margins and at some natural depressions which are used as temporal reservoirs for later irrigation purposes. Some plots, especially those where ryegrass is growing, show anoxic conditions in soils (gleysolic soils), just after a considerable amount of roots and organic matter in the first 5 cm of the top soil (Figure 5). The slope is not steeper than 4%.

Figure 5. Flooded plot of ryegrass and a soil sample from it.

2.3. Main water sources

2.3.1. The Rocha River

The Rocha River basin drains throughout arid and semiarid zones. The hydrological regime is characterized by sudden raisings producing high discharges, reaching 31 $m^3 s^{-1}$ as a peak discharges in normal years of precipitation (Quintanilla, 2007). The amount of solids transported is very high and due to this, the physical-chemical conditions change drastically during the course of the main stream. During the dry season the flow is as low as 500 $L s^{-1}$ (Moscoso and Coronado, 2002) and most of the water in the course comes from domestic and industrial discharges. This water is used mainly for agricultural activities and eventually for laundry and car washing (Maldonado et al., 1998).

During the last two decades more than 200 industries have been established in about 30 km of course distance, from Sacaba to Quillacollo cities. More than 50% of the industries produce liquid and solid residuals. Most of the residuals are discharged to the Rocha River with scarce or without treatment (Ampuero, 2005; Maldonado et al., 1998). Some of the industries and communities treat the water using Imhoff tanks before the realising of waters to the Rocha River, however these systems are not working properly (Coronado et al., 2001). According to Romero et al. (1998) which evaluated the river course contamination in terms of NO_3^-, DO, CDO and BDO, the pollution in the main course vary in time (monthly variations) and space (Figure 6). The salinity features such as EC and TDS increase downstream and the influence of tributaries like the Tamborada River can be noticed in these parameters.

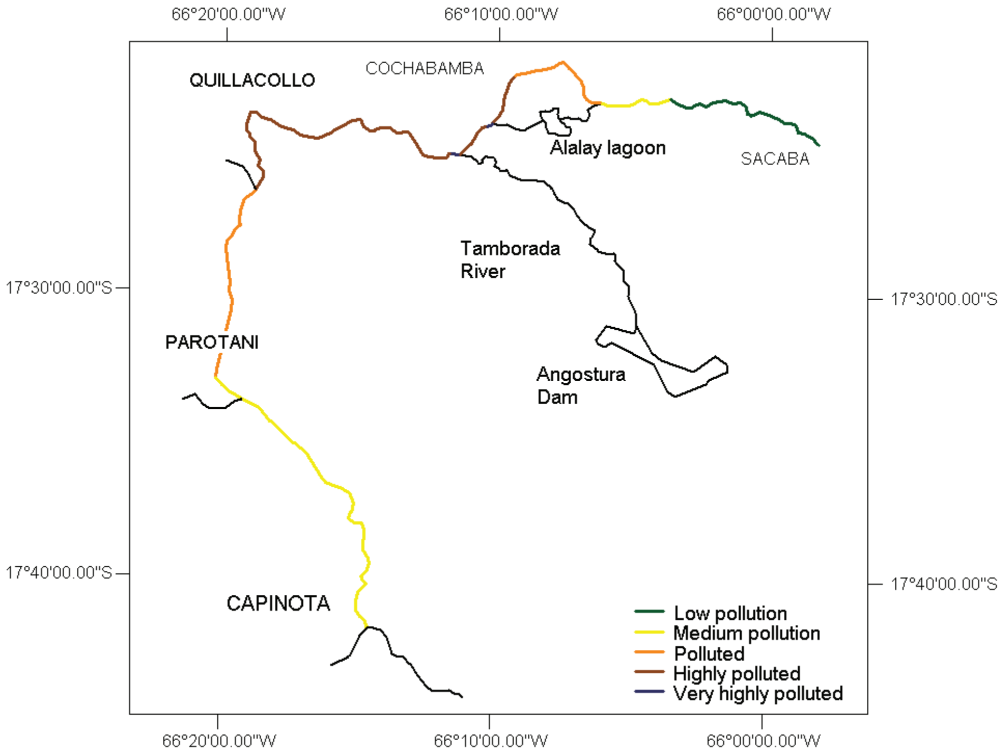


Figure 6. Rocha River pollution degree.
Source: Adapted from Romero et al. (1998).

2.3.2. The Tamborada River

The Tamborada River flows from the Angostura dam, located at 15 km to the south of the city of Cochabamba. It is one of the tributaries of the Rocha River (Plata, 1997) the junction of the two rivers occurs in La Mayca zone.

According to Coronado et al. (2001), the course of the river receives wastewaters from poultry farms, car washing activities and some human settlements. Water quality parameters are presented in the next table (Table 5).

Table 5. Quality parameters of Tamborada River.

Parameter	pH	EC	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Hardness	SS	FS	TDS
		$dS\ m^{-1}$	-------	-------	-------	-------	mg/L	-------	-------	-------
Value[1]	8	2.14	48	31	210	32	245	145	1280	1425
Permissible limit for irrigation[2]	6-8	0.7-3	300	150	200	N/R	N/R	50-100	N/R	2000

SS = Suspended solids, FS = Filterable solids, TDS = Total dissolved solids, N/R = No reference.
Adapted from [1]Coronado et al. (2001), [2]MDSMA (1995) and [2]WHO (2006b).

2.3.3. Waste water treatment plant affluent

The sewerage system of the municipality of Cochabamba, conducts wastewaters from a population superior to 200000 inhabitants. Recorded discharges overpass 500 L/s. During the rainy season, the collection network receives rainfall water as well. Water is conducted to the treatment plant of Albarrancho. The treatment consists on facultative photosynthetic lagoons. After the treatment, the water is discharged in the Tamborada River course after its junction to the Rocha River (GERENTEC, 2003). The sequence of the treatment process is presented in the next flow chart (Figure 7).

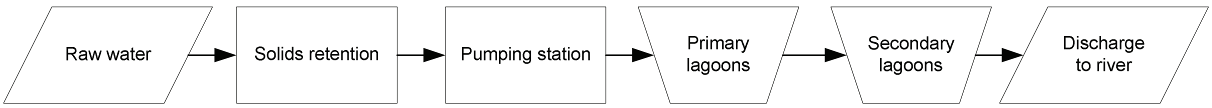


Figure 7. Flow chart of WWTP process.
Source: Adapted from GERENTEC (2003)

The affluent enters to the plant through a reception chamber, where heavy solids, such as grave, sand or rocks, are separated. After the chamber, other solids are retained by a grates system. Then, the water is pumped to the lagoons mentioned before. The discharge point of the plant is shown in the Figure 8.

Figure 8. Discharge point of WWTP to Tamborada river.

The average characteristics of the affluent of the plant (biochemical demand of oxygen, chemical demand of oxygen and total dissolved solids) are shown in the next figure (Figure 9).

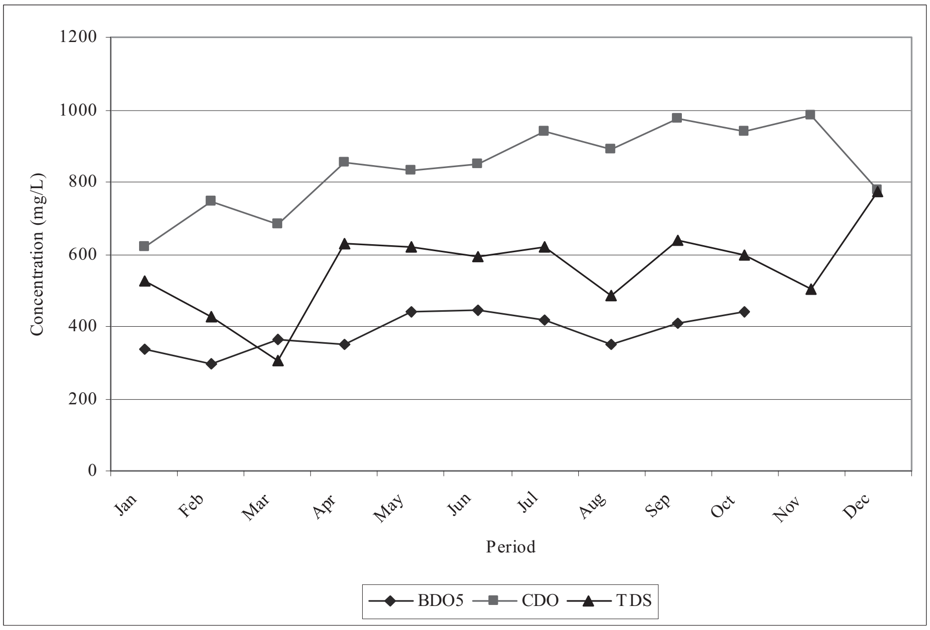


Figure 9. Characteristics of affluent waters to the treatment plant.
Source: GERENTEC (2003)

Additionally, the general characteristics of the affluent for the 2007 in the same terms are presented in the Figure 10.

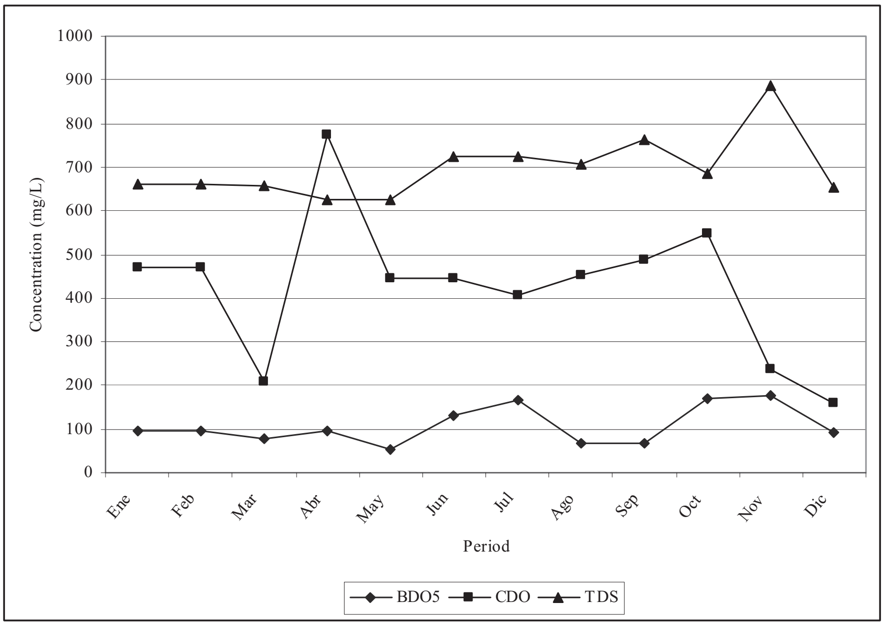
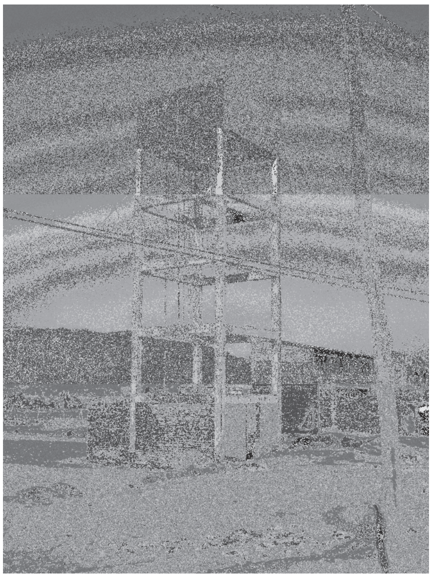


Figure 10. Characteristics of the effluent waters from the treatment plant for 2005.
Source: SEMAPA (2008)

2.3.4. Groundwater sources

Groundwater is mainly used for animal and human consumption. Most of the wells were drilled for cattle management. However, due to the increasing demands there are wells for human consumption as well. The wells are used for a determined group of families and its use is controlled by a designated responsible. Human consumption water is also purchased from tank trucks (Agreda, 2000).



Water tank **Supply point**

Figure 11. Ground water supply points.

Groundwater has dynamical relationships with soil. Salts found in groundwater depend on parental material of soil and natural or artificial processes of salt deposition. Additionally processes like evapotranspiration produce vertical movements of water from the ground to surface layers of soil, specially during dry periods (Brady and Weil, 1999; Kóvacs, 1971).

According to GEOBOL (1977) this area belongs to the lacustrine zone of the basin of Cochabamba. One of the most representative cations found in groundwaters is the Na^{+}, with values between 2.1 and 13.5 meq/L. Higher concentrations correspond to wells between 40 and 70 m deep. Ca^{++} has greater concentrations than Mg^{++}. Both cations have values between 0.8 and 2 meq/L. The K^{+} doesn't have significant variations compared with other zones in the basin. It reaches close to 0.7 meq/L values and, some times, is found as trace element during the water analysis.

The anions concentration, especially Cl^{-} and HCO_3^{-} is higher in this zone than in other parts of the basin. The concentrations fluctuate from 1.7 to 3.7 meq/L for Cl^{-}; and from 1.2 to 2.5 meq/L for HCO_3^{-}. However some records reach levels of 19 and 6.4 meq/L, for the first and the second anions mentioned, respectively. CO_3^{-2} is scarce and is found as constant trace with close to 0.1 meq/L values. The SO_4^{-2} is found in less proportion, with values between 0.04 and 0.09 meq/L (GEOBOL, 1977). This author mentions that the EC has records between 0.56 and 2.17 dS m^{-1}. The groundwater sources, especially those from deep aquifers have medium salinity, expressed on the EC. Its use is recommended with an appropriate drainage system. On the other hand, the zone close to the Tamborada River presents high salinity; with exceptional records like 4.3 dS m^{-1}, not being advisable the irrigation using common systems. National reference levels for drinking water are presented in the Table 6.

Table 6. Reference parameters for drinking water.

Parameter	pH	Cl^{-}	Ca^{++}	Mg^{++}	Na^{+}	$SO_4^{=}$	NO_3^{-}	DBO_5	TDS
		meq L^{-1}						mg L^{-1}	
Reference	6-8.5	7.1	10	8.2	8.7	6.2	0.3	<2	1000

Source: Adapted from MDSMA (1995).

3. Materials and methods

3.1. Materials

This research was developed using different materials, some were collected in a pre-fieldwork stage and the rest were obtained during the fieldwork stage.

3.1.1. Imagery and maps

The list of images used is presented in the next table.

Table 7. Basic imagery for the research.

Image	Date	Band	Spectral resolution	Spatial resolution	Source
			μm	m	
ASTER L1B	05/08/2008	1	0.52-0.6	15	ITC
		2	0.63-0.69	15	
		3	0.76-0.86	15	
ASTER L1B	20/04/2007	4	1.6-1.7	30	ITC
		5	2.145-2.185	30	
		6	2.185-2.225	30	
		7	2.235-2.285	30	
		8	2.295-2.365	30	
		9	2.36-2.43	30	
IKONOS	2004		Natural color composite	1	CLAS

Additionally the next maps were used as a reference for masking the administrative limits and obtaining basic information about the study area:

- Administrative map District 9 (HAMC, 1997).
- Geologic, geomorphologic, limits and territorial organization maps of Cochabamba (HAMC, 2006).
- Hidrogeologic maps of SERGEOMIN (Huaranca and Newman-Redlin, 1998).

3.1.2. Sampling tools

For the soils sampling the next materials were used:

- Auger, for digging and soil take up.
- Water, for cleaning the materials when needed.
- Hand shovel, for subsampling mixing and sampling bagging.
- 1m x 1m plastic piece, where the mixing was done.
- Plastic bags for soil sampling transport.

- Paper tags for labelling the samples.
- Information sheets for *in situ* information taking and note board.
- Camera.
- GPS (Garmin GPS Geko 201).

The water sampling for the EC evaluation process was done with:

- Plastic beaker.
- Distilled water for washing the beaker after the measures.
- pH/EC meter Eijkelcamp.
- Wash bottle.
- Camera.
- GPS (Garmin GPS Geko 201).
- Absorbent paper.
- Information sheets for *in situ* information taking and note board.

For the main sources water sampling the additional materials were used:

- Plastic containers (bottles) of approx. 500 mL (4 per site).
- Site information sheet (provided by the laboratory).
- Plastic cooler for sampling transportation.

3.1.3. Printed documentation consulted

- The existing quality records for the outlet of the WWTP for 2005-2008 period (SEMAPA, 2008).
- Research information about the specific topic and study area from the Wageningen University Library (Agreda, 2000; Ampuero, 2005).

3.2. Methodology approach

The methodology approach is presented in the Figure 12.

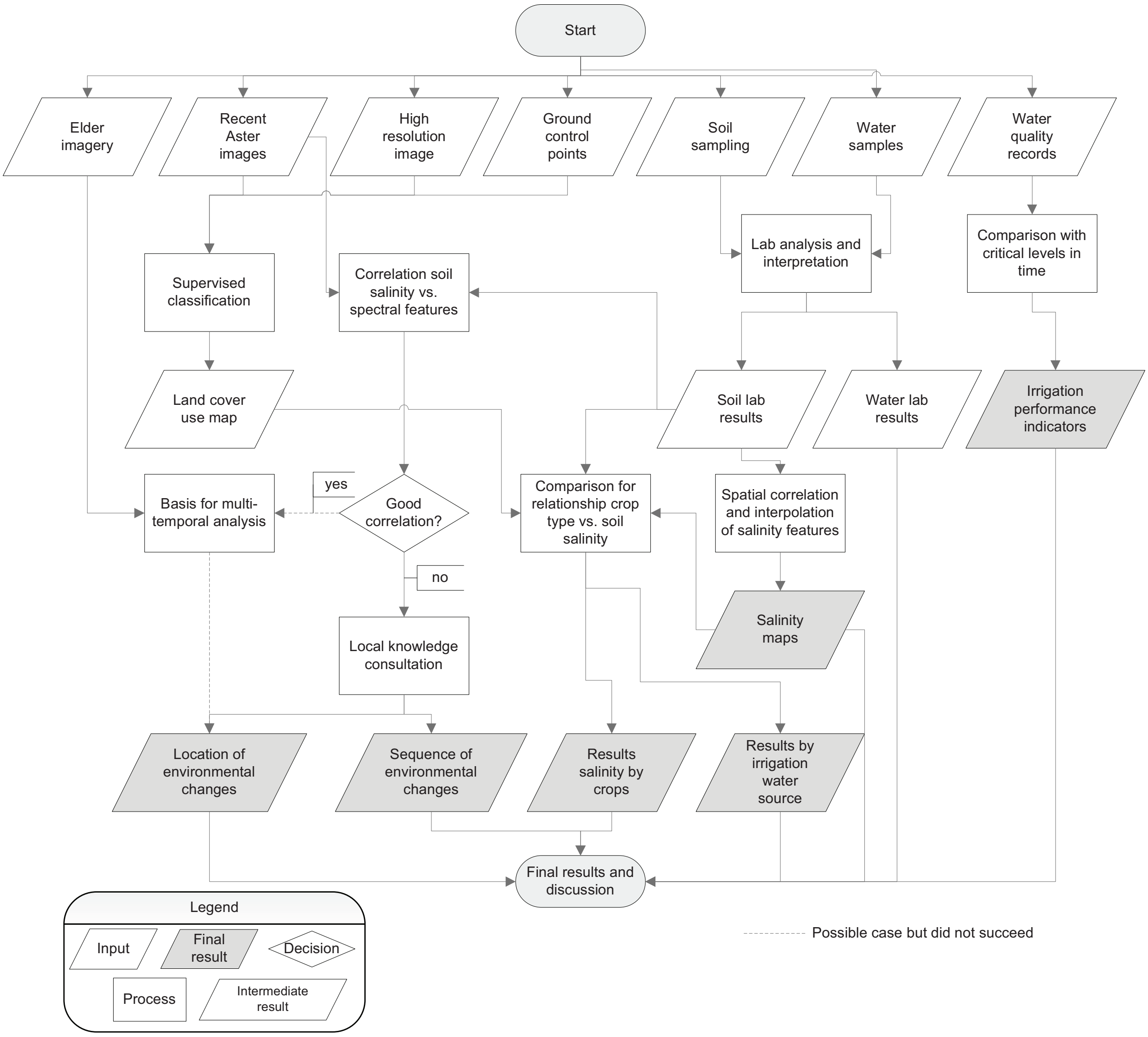


Figure 12. Methodology flow chart.

During the field period all of the inputs were collected. Additional information about the zone and other studies in the same topic were gathered as well. Once the intermediate and first final results were obtained, the possible relationships among the components were evaluated. An exhaustive essay with ground measurements and spectral values was made to attempt a basis for the multitemporal analysis. However the data was poorly correlated, which led us to base this approach in the local knowledge consultation.

On the other hand comparisons were performed crossing maps with tables and graphs as results for discussion. Water quality records compared with critical levels, and law established levels in Bolivian legislature. Nevertheless, Bolivian laws are not very detailed for all the elements analysed. In that case other references, such us WHO Guide lines for irrigation water (WHO, 2006b) were consulted.

3.3. Image classification

3.3.1. Imagery

Available ASTER (Advanced Spaceborn Thermal Emission and Reflection Radiometer) medium resolution images (L1B) were collected for the study area. Images correspond to August 5, 2008; and April 20, 2007. Aster images were selected because of their spatial and spectral resolution, also considering that several authors have used this kind of images because of its strong correlation with salinity (Al-Khaier, 2003; Douaoui et al., 2006; Metternicht, 1996; Metternicht, 2001; Metternicht and Zinck, 2003; Padilla, 1999).

Additionally, an available high spatial resolution image (Ikonos, 1 m x 1m) for 2004 was used to mask settlement areas, water courses and principal landscape elements, as well as administrative limits in the area.

For better accuracy with the GPS points, images were re-projected using the next geographical information:

- Datum: Provisional South American 1956.
- Projection: UTM, zone 19.
- Ellipsoid: International 1924.

3.3.2. Supervised classification of images

Supervised classification of Aster 2008 image was executed in Erdas Imagine program version 9.1 in order to obtain the land cover map. Classification was made using samples sets collected in the field during the soil and water sampling and several additional visits. A total of 78 points distributed in the whole study area were considered for the supervised classification. Moreover, and after a good recognition of the location of the different crops and principal features in the area, different training sets for the classification were used, extracted directly from different band combinations. As some features in the study area are grouped in large areas (in the case of alfalfa and ryegrass especially), it was not difficult to obtain a larger set sample for the validation of the classification. The final sample set accounted for 1200 pixels.

Five classes were recognized: water, ryegrass, alfalfa, agriculture bare soil and salt affected soils. For these classes the error matrix was calculated. The classification showed a general accuracy of 92 % and a Kappa index of 88 %. The error matrix is presented in the appendices section. For the complementary classification, additional classes were obtained digitizing over the high resolution image mentioned (i.e. settlement areas, river courses and main structures or recognized places).

3.4. Soil sampling, analysis and interpolation

3.4.1. Soils sampling

The top soil was sampled in the study area during the month of September 2008. A total of 63 samples were distributed in the whole area. For every sample the following aspects were registered: code, location (X and Y coordinates), crop, sample depth in cm, sample colour (simple observation), community, general observations and irrigation source. Samples were composite of 4 to 5 subsamples taken randomly within a radius of 7 m. Soil subsamples were collected using an auger, from the first 0-30 cm of the soil and mixed with a hand shovel over a piece of plastic (Figure 13). The sampling process counted with the presence of one of the representatives of La Mayca and in most of the cases the owners of the plots. It helped to complement specific information about every sampling point. The scheme of sampling depended on: a) a limited budget assigned to the sampling, b) the samples were tried to be distributed in the area, considering around 500 m of separation between sampling points, c) the permission of the owners for sampling their plots. The location of samples is presented in Figure 17.

A) Subsample taking.

B) Sample mixing.

Figure 13. Soil sampling

3.4.2. Laboratory analysis

Samples were analysed in the Soils and Waters Laboratory at the Universidad Mayor de San Simón (UMSS) in Cochabamba. Parameters requested were: pH, Texture, EC, Na^+, K^+, Ca^{++}, Mg^{++}, Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP). The analyses were done in saturated soil paste extract. The methodologies used in the laboratory are listed in the Table 7.

Table 8. Soil analysis lab methods.

Parameter	Method
Texture	Hydrometer (Bouyoucos)
pH	Potenciometer (in water)
Electric conductivity	Conductivity meter
Ca^{++}	Complexometry
Mg^{++}	Complexometry
Na^{+}	Flame photometry
K^{+}	Flame photometry

Flame photometry, also known as flame atomic emission spectrometry, is a fast and sensitive method for determination of trace metal ions in a solution. The characteristic emission lines from the gas-phase atoms permit precise measures (±1-5 %), whereas no major interferences are present (Skoog et al., 2000).

Complexometry, or complexometric titration, is a volumetric analysis where a colored complex indicates the endpoint of a titration. The indicator used in the analysis must be capable of producing unequivocal color change, in this way the titration is very accurate (Wikipedia, 2009).

The SAR was obtained applying the next formula:

$$SAR = \frac{[Na^{+}]}{\left\{\frac{[Ca^{++}]+[Mg^{++}]}{2}\right\}^{1/2}}$$

Where the concentrations of Na^{+}, Ca^{++} and Mg^{++} are expressed in meq/L. ESP was calculated empirically from SAR values. The summary of the results obtained in the laboratory is presented in the Table 9, it presents a general idea of the data values and their distribution.

Table 9. Summary of laboratory analysis results.

Parameters		pH	EC	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	SAR	ESP
			dS m^{-1}	------------ meq L^{-1}			------------	meq/L	%
N	63								
Mean		8.10	6.56	6.37	5.75	66.43	0.26	26.51	20.09
Error		0.05	1.01	1.00	0.88	11.40	0.06	4.24	2.19
SD		0.43	8.05	7.95	7.01	90.47	0.46	33.65	17.41
Skewness		-0.27	1.80	1.93	1.99	2.24	2.70	2.23	0.84
Skewness error		0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Kurtosis		0.51	3.88	2.80	3.23	6.77	7.49	5.69	-0.59
Kurtosis error		0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
Min		6.90	0.42	1.00	0.50	2.00	0.00	1.26	0.60
Max		9.20	40.30	32.00	29.00	490.00	2.30	166.55	61.97

In general the results present a high variability, especially for EC and Na^{+}. It is well known that the EC varies both horizontally and vertically in the soil (Farifteh et al., 2008). Additionally it is affected for the presence of moisture, which produces salt movements and consequently changes in the electrical response of the soil. Except for the pH, the distribution of values is right-skewed. On the other hand, most of the distributions are flat, in terms of kurtosis, and the ESP is peaked. Values beyond ±2 for both, skewness and kurtosis, are considered extreme (Reimann et al., 2008).

3.4.3. Geostatistical analysis and spatial interpolation

3.4.3.1. Interpolation method

A soil-water system analysis requires, very often, a large amount of data. Even though, some times an extensive amount of data remains insufficient for a complete understanding of natural processes (Kitanidis, 1997). Additionally, financial constraints limit the number of samples from where an spatial analysis must be performed (Schloeder et al., 2001). From these limited known places, attempts of modelling the unknown places are a common task in environmental studies, this process is also known as interpolation. It's then advisable to exhaustively treat the known data for obtaining the less biased estimations possible. For this bias optimization several steps were followed and are explained in the following paragraphs.

The EC, pH, SAR and ESP values were explored because those were the basis for the salinity affection degree classification. Further more, SAR was excluded for the final maps due to the fact that ESP was calculated from the SAR values, and because of general salinity classifications are made accounting the ESP, EC and pH (Ghassemi et al., 1995; IDNP, 2002). The histograms for these variables are presented in the next figures.

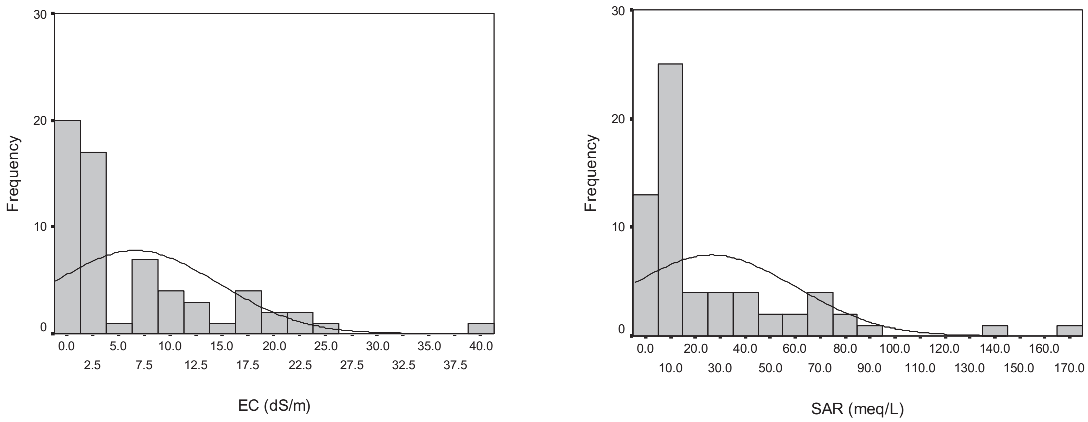


Figure 14. Histograms for EC and SAR.

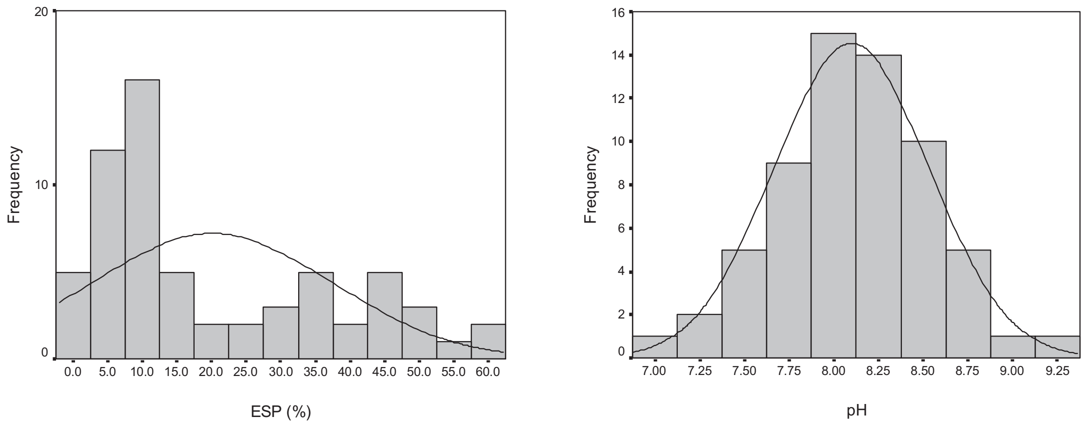


Figure 15. Histograms of ESP and pH.

Kriging interpolation was selected for being considered a Best Linear Unbiased Estimator (BLUE) (Kitanidis, 1997). Kriging output is statistically optimized and, additionally, is able to predict the quality at each point within a grid considered (Abdel-Hamid, 1990; Corstanje et al., 2006; IDNP, 2002; Reimann et al., 2008; Schloeder et al., 2001). The interpolation is based on a semi-variogram, which shows the variance (y-axis) between data points at defined distances (x-axis) (Reimann et al., 2008). According to Booker (1991) It can be calculated as:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Y(x_i + h) - Y(x_i) \right]^2$$

Where Y(x_i) represents the value of the data at location x_i; h is the displacement between the data pairs and N(h) is the number of such data pairs in the region. What is expected is that the increment in variance behaves proportional to the distance until it becomes stable (which occurs in a specific distance), indicating that the difference between the pairs are similar to the global variance. This is known as the "*spatial auto-correlation effect*" (Hengl, 2007).

There are variety forms of kriging. Some methods improve their predictions based on a relationship among different variables, like co-kriging and regression kriging (Li et al., 2007). Also, when anisotropy of the variables is present, anisotropic kriging can be executed for more accurate estimations (ILWIS, 2007). When a strong correlation between the target variables and the auxiliary information can't be differenced, the next step is to evaluate the anisotropy (Hengl, 2007). This evaluation was made calculating the variogram surface in ILWIS. Since not a clear pattern was recognized in the variogram, we explored the semi-variograms for the variables. One of the limitations of kriging is that it considers a normal distribution of the variable (Kitanidis, 1997). Hence, variables should be transformed in order to reach normality for a further model fitting.

For exploring and fitting the semi-variograms the R package was used[1], (R Development Core Team, 2008). ESP was transformed using the square root of the values for the variogram fitting. The Spherical model was well adjusted to the data, except for pH, which presented a pure nugget effect. The spherical model has a finite maximum or sill *C* and a random component expressed as the nugget C_0, the range (α) is the separation between the origin and the place where the model approaches the sill, at this point the model reaches the total variance (Assadian et al., 1998) (Figure 16).

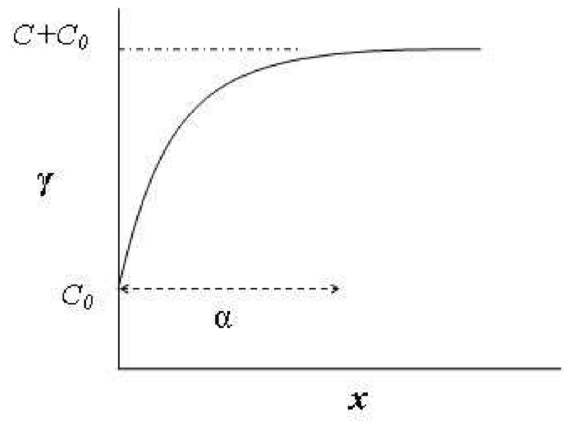


Figure 16. Spherical model.

Once the variograms were fitted, its main characteristics (i.e. nugget, sill and range) were used in ILWIS version 3.4 (ILWIS, 2007) for the Ordinary kriging interpolation. ILWIS has the advantage of producing a standard error interpolated map at the same time of the interpolation execution. Ten percent of the points from every variable (extracted randomly and by separate) were not considered for the interpolation, but were used for the validation of the results. Once interpolated, ESP values were transformed with the X^2 function.

[1] A script courtesy of Rossiter D. (2009) was adapted and used for the semi-variogram model fitting. It is presented in the appendices section.

3.4.3.2. Validation and classification

The corroboration was made in two ways: a) via leave-one-out cross-validation executed in R, and b) using a validation group of values against ILWIS interpolation results. The measures considered were the mean prediction error (ME):

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left[z'(s_i) - z(s_i)\right]$$

Where *n* is the number of validation points, *z'* is the predicted value and *z* the observed value, both at the location s_i.

And the Pearson correlation coefficient (R) between the observed and predicted values:

$$R = \frac{\mathrm{cov}(z', z)}{\sigma_{z'} \sigma_z}$$

Where *R* is the Pearson coefficient *cov(z',z)* is the covariance between the predicted values *z'* and observed values *z*, and *σ* is the standard deviation.

Afterwards, both EC and ESP were classified according to levels mentioned by Verhoeven (1977) and Ayers and Westcost (1994).

3.5. Salinity and crops comparison

Salinity maps were crossed with the final results of the image classification. As a result of the operation a summary table of different EC and ESP parameters was constructed. Parameters considered for the summary were: average, minimum and maximum values, and the standard deviation.

3.6. Ground measurements vs. Remote sensing

In order to evaluate how good the RS source fit to ground measurements in the area and to make possible to compare actual to elder images, ground measurements were correlated with isolated and combined Aster bands in the range of Visible and Near Infrared for 2008 image, and Short Wave Infrared bands (SWIR) for 2007. The last was due to problems in Aster SWIR acquisition from April to the late 2008[2].

[2]USGS-NASA. 2008. ASTER SWIR user advisory. Jul 18 2008. URL: http://igskmncnwb001.cr.usgs.gov/news/aster_user_advisory.asp. Access date: Dec. 15 2008.

Principal Components obtained in ILWIS were also correlated with ground measurements. All available bands for the 2008 image were introduced as input (i.e. Visible and NIR bands) for 3 principal components, as output. Principal Component Analysis (PCA) is often used in discriminant analysis. It aims to reduce the dimension of a data set in to a number of less correlated components that account for the majority inherent information. It also helps to reduce the noise in a multivariate data set, making easier a classification or a prediction of another variable (Reimann et al., 2008).

Indices designed to enhance features (combining the visible and near infrared spectrum) were also tested against the ground measurements (Table 10).

Table 10. Enhancement indices applied.

Index	Band combination
NDVI	$NIR - R / NIR + R$
Salinity index 1	$\sqrt{G \times R}$
Salinity index 2	$\sqrt{G^2 + R^2}$
Salinity index 3	$\sqrt{G^2 + R^2 + NIR^2}$

G = Green band, R = Red band, NIR = Near infrared band.

3.7. Water quality information

3.7.1. Water sampling

Water sources were sampled for EC using a portable pH/EC meter Eijkelkamp 18.38™. Thirty two samples were taken in the main surface sources of water and in wells. The location of water samples is shown in the Figure 17. The coordinates of every sampling point are listed in the appendices section.

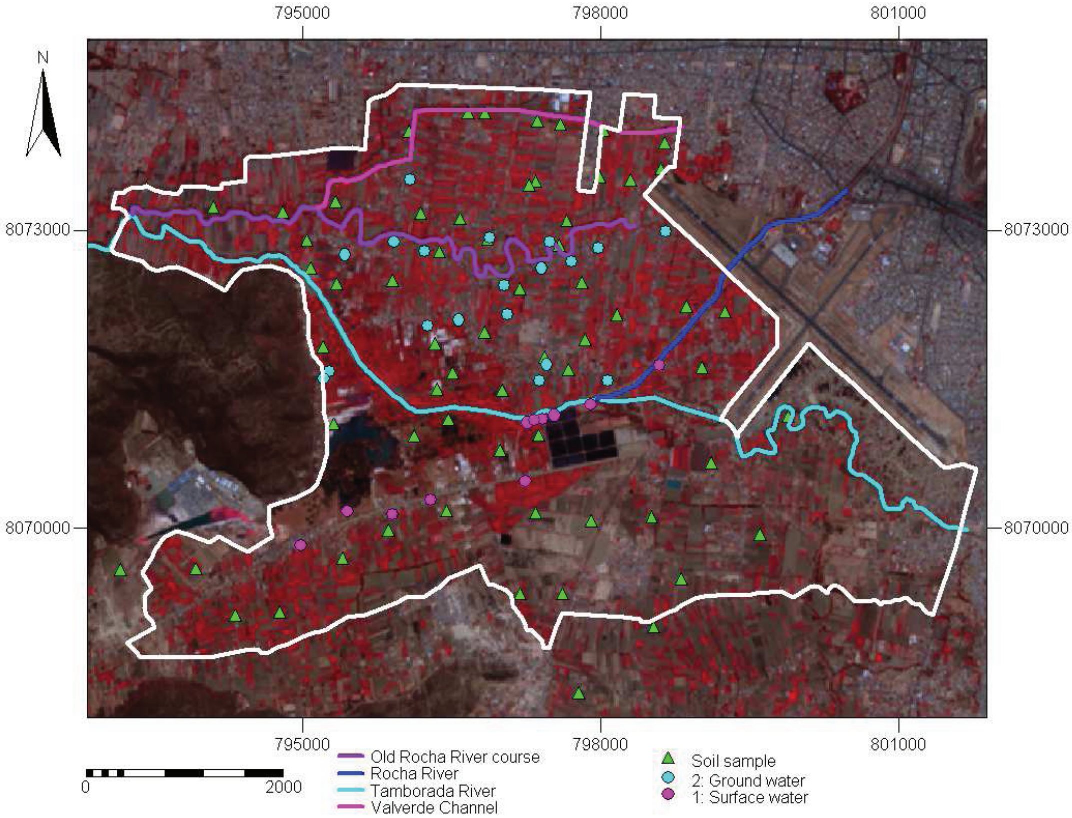


Figure 17. Soil and water samples location.

More complete analyses were made for the four main sources of irrigation in the zone: Water from La Angostura dam (805892, 8067385); water from the Rocha River (798586, 8071631); water from the junction of Rocha and Tamborada Rivers (797899, 8071236) and water from the Tamborada River just after the WWTP (797332, 8071080) discharge point. The sampling procedure was the recommended by the Centre for Water and Environmental Sanitation (CASA) in the Universidad Mayor de San Simón. The places from where the samples were taken are presented in the Figure 18.

The parameters analysed and their corresponding analysis method applied in the laboratory is presented in the next table.

Table 11. Water quality parameters for main water sources.

Parameter	Normalized method*	Unit	Method
Turbidity	2130 B	NTU	Nefelometric
pH**			Potenciometric
EC**		dS m^{-1}	Conductivimetrc
Acidity	2310 B	mg L^{-1}	Titration
Alkalinity	2320	mg L^{-1}	Titration
HCO_3^-	2320	mg L^{-1}	Calculation
$CO_3^=$	2320 B	mg L^{-1}	Calculation
Ca^{++}	2320 Ca D	mg L^{-1}	Titration-EDTA
Cl^-	4500 Cl B	mg L^{-1}	Titration
Hardness	2340 C	mg L^{-1}	Titration-EDTA
Mg^{++}	3500 Mg E	mg L^{-1}	Calculation
K^+	3500 K D	mg L^{-1}	Emission flame
Na^+	3500 Na D	mg L^{-1}	Emission flame
$SO_4^=$	4500 SO_4 E	mg L^{-1}	Turbidimetric
Total solids	2540 B	mg L^{-1}	Gravimetric
Dissolved solids	2540 D	mg L^{-1}	Gravimetric
Suspended solids		mg L^{-1}	Calculation
Volatile solids	2540 G	mg L^{-1}	Calculation
BDO_5	5210 B	mg L^{-1}	Winkler-dilution
NO_3^-	4500 NO_3	mg L^{-1}	Spectrophotometry

(*) American Water Works Association; American Public Health Association; and Water Environment Federation standards.
(**) Field directly evaluations.

A) Rocha river at the study area.

B) Water from the Angostura dam.

C) Water from Tamborada river just after WWTP outlet.

D) Junction of Tamborada and Rocha rivers.

Figure 18. Places of water sampling.

Furthermore results were compared with permissible values mentioned in Bolivian laws (MDSMA, 1995) and complemented with values mentioned by international institutes like FAO (Ayers and Westcost, 1994) and the World Health Organization (WHO, 2006a; WHO, 2006b). The comparison tables are listed below.

Table 12. Bolivian law maximum permissible values.

Parameter	Unit	Maximum permissible	
		Class C	Class D
Ca^{++}	mg L^{-1}	300	400
Cl^{-}	mg L^{-1}	400	500
Mg^{++}	mg L^{-1}	150	150
Na^{+}	mg L^{-1}	200	200
$SO4^{=}$	mg L^{-1}	400	400
TDS	mg L^{-1}	1500	1500
BDO_5	mg L^{-1}	20	30
NO_3^{-}	mg L^{-1}	50	50
Turbidity	NTU	200	10000

Bolivian laws classify the water quality according to the water body which will receive the discharge. Class C are waters of general usage, for human consumption require a complete physical-chemical treatment and a bacteriological disinfection. Class D are waters of minimal quality for human use; in extreme public necessity require pre-sedimentation process followed by a complete physical-chemical-biological treatment (MDSMA, 1995).

Table 13. Complementary parameters for irrigation water.

Parameter	Unit	Degree of restriction on use		
		None	Slight to moderate	Severe
EC_w	dS m^{-1}	<0.7	0.7-3.0	>3
TDS	mg L^{-1}	<450	450-2000	>2000
TSS	mg L^{-1}	<50	50-100	>100
SAR 0-3	meq L^{-1}	>0.7 EC_w	0.7-0.2 EC_w	<0.2 EC_w
SAR 3-6	meq L^{-1}	>1.2 EC_w	1.2-0.3 EC_w	<0.3 EC_w
SAR 6-12	meq L^{-1}	>1.9 EC_w	1.9-0.5 EC_w	<0.5 EC_w
SAR 12-20	meq L^{-1}	>2.9 EC_w	2.9-1.3 EC_w	<1.3 EC_w
SAR 20-40	meq L^{-1}	>5.0 EC_w	5.0-2.9 EC_w	<2.9 EC_w
Na^+	meq L^{-1}	<3	3-9	>9
Cl^-	meq L^{-1}	<3	4-10	>10
HCO_3^-	mg L^{-1}	<90	90-500	>500
H_2S	mg L^{-1}	<0.5	0.5-2	>2
Mn	mg L^{-1}	<0.1	0.1-1.5	>1.5
Total N	mg L^{-1}	<0.5	5-30	>30
pH		Normal range 6.5-8		

Source: Adapted from Ayers and Westcost (1994), and WHO (2006b).

3.7.2. Water quality records analysis

Indicators are often used to measure the performance of a process. Indicators are based on a series of recorded data in time and/or space, considering target values. The outputs of a performance assessment could be used to reformulate strategic or operational objectives, or implement corrective measures in the system (Bos et al., 2005). This author also recommends representing the results in a graphical format for a better understanding of the changes during the time.

Historical water quality information was collected from the Municipal Water Supply and Sewerage System (SEMAPA). Information consisted in monthly water quality evaluations done in the Waste Water Treatment Plant effluent from January 2005 to July 2008. For fulfilling the gaps in the series, the last 3 months average was considered. The time series obtained was formatted for the calculation of irrigation performance indicators.

Due to data availability and its relationship to soil salinity, the Relative EC ratio (Bos et al., 2005) was considered for this research purpose as sustainability indicator. It was calculated for the time series gathered from the WWTP. The critical values considered were those mentioned by Ayers and Westcost (1994) as limits of irrigation water with slightly to moderate degree of restriction of use. Relative EC ratio is calculated as:

$$\text{Relative EC Ratio} = \frac{\text{Current EC value}}{\text{Critical EC value}}$$

Where: Current EC value = Measured EC in irrigation water (dS m^{-1}); Critical EC value = Reference values for evaluation (0.7 and 3 dS m^{-1}, in this case).

The time series for the suspended and dissolved solids were also considered in the analysis. The suspended solids were contrasted with the reference values presented in the Table 13. The monthly discharge of salts was calculated for the period of WWTP monitoring. This amount was calculated based on the TDS and the discharge values recorded at the effluent outlet.

3.8. Workshop with community

In the Bolivian society, as in many South American countries, stakeholders are fundamental pillars on an integrated program of water use (i.e. irrigation systems, recycling water use, industrial water use, etc.). People can help to understand the problem as a whole, fulfil gaps and suggest and execute plans. The success or failure of many projects related to water reuse rely most of the times in the social component (Urkiaga et al., 2008). Considering the social aspects is essential for this research, community's representatives and interested people were invited for a workshop about water pollution and soil salinity. The idea was to gather complementary information for the RS and the geostatistical approach and use this information to help to explain results obtained.

The workshop took place on October 12th, 2008. The list of participants is presented in the appendices section. The general workshop agenda was the next:

- 1st A brief introduction to the research objectives and the current activities that were done at that time in the area. During this activity a brief explanation about soil salinity aspects and their relationships with water quality and production systems was also done. This instance was also useful because the participants had the opportunity to share their own knowledge on the problem.

- 2nd A work activity to describe and number the perceived changes in the environment during the time, considering the waste water use in the zone.
- 3rd A work activity to recognize the most affected areas due to salinity increasing in the study area.
- 4th An activity to interpret water and soil lab results concerning to salinity.

For the steps mentioned, the group was split in two subgroups. After every activity, a secretary selected by his/her own group was in charge to share the discussion results with his/her peers. The complete program, included a list of materials used in the workshop is presented in the appendices section. It is expected that this material is reuse in future monitoring reassignments in the area.

4. Results and discussion

4.1. Land cover classification

The land cover classification for 2008 is presented in the Figure 19. In the classification the presence of ryegrass along the Tamborada River can be noticed. The grassland areas begin at the south of the WWTP and extend to the west, just along the principal way. Ryegrass was established on these areas due to a constant presence of water coming from the treatment plant for its irrigation.

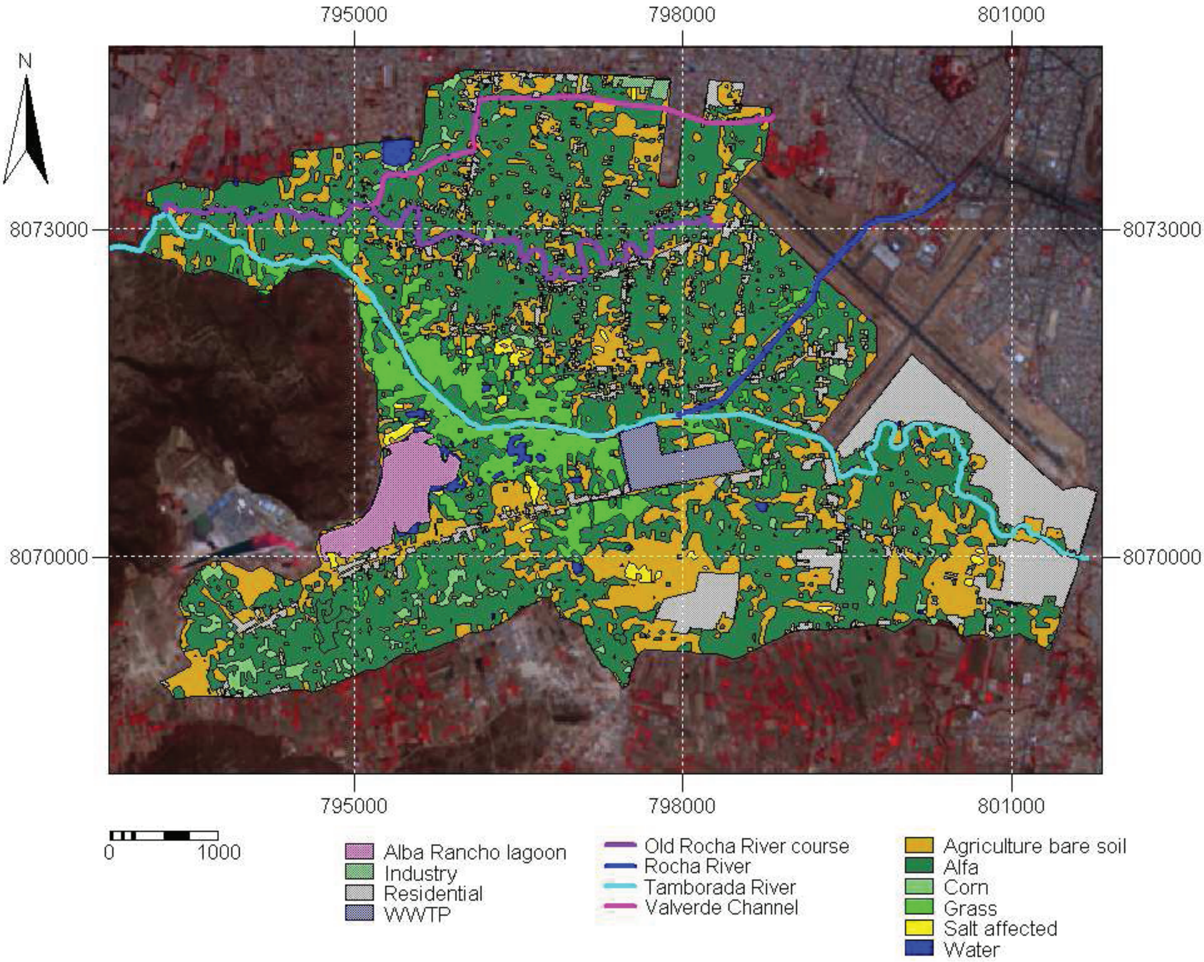


Figure 19. Supervised classification results for La Mayca for 2008.

Most of the area is dedicated to alfalfa. The agriculture bare soil corresponds to resting fields and prepared soils ready for seeding. Only some plots were already growing corn. During the fieldwork time of this research, more maize plots were seeded. For the date of the image acquisition (August 5th), according to farmers in the study area, is possible that none of the plots were seeded or already were growing corn, indicating that corn is in the planting to initial stages of grow. The location of the maize areas in the map is a result of a general inspection and the extension doesn't reflect the maximum maize coverage that the zone reaches every year. In this case, part of the bare soil presented should be considered together with maize and further classified.

The vegetal species in the area give us a general idea of the salinity situation in the soil. In the area, the alfalfa and the ryegrass are distributed and used as fodder for the cattle, and according to the farmers, they are the only species that keep producing enough food for their animals. Even if these species can be extracted from RS sources, they couldn't be used for obtaining detailed situations of the level of salinity, not even sodic situations of soils. It is because the broad tolerance that they have to salinity-sodic situations.

Even though the area has been declared by law as "Agriculture purposes zone" (OPS and CEPIS, 2002), the constant pressure of the city has increased the settlement areas. During the different visits to the field, an evident presence of new buildings, probably posterior to the high resolution image acquisition, was observed.

4.2. Ground measurements vs. remote sensing

Correlation coefficients can be seen in the Table 14.

Table 14. Pearson correlation coefficients for ground measurements vs. ASTER bands and indices.

Image values	Ground measurements							
	EC	SAR	ESP	Na+	K+	Ca++	Mg++	pH
B1	0.38	0.19	0.26	0.36	0.53	0.29	0.48	-0.05
B2	0.35	0.20	0.24	0.34	0.47	0.24	0.42	-0.08
B3	0.11	-0.08	-0.01	0.06	0.23	0.25	0.26	0.02
PC1	0.22	0.11	0.15	0.20	0.33	0.15	0.30	0.03
PC2	0.10	0.19	0.12	0.13	0.11	-0.15	-0.03	0.04
PC3	-0.09	0.07	-0.04	-0.04	-0.25	-0.21	-0.22	-0.15
NDVI	-0.20	-0.20	-0.19	-0.23	-0.23	-0.03	-0.17	0.09
SWIR4	-0.29	-0.16	-0.21	-0.25	-0.28	-0.26	-0.30	-0.04
SWIR5	-0.18	-0.09	-0.11	-0.15	-0.18	-0.19	-0.19	-0.05
SWIR6	-0.18	-0.07	-0.11	-0.14	-0.20	-0.24	-0.23	-0.05
SWIR7	-0.23	-0.13	-0.16	-0.20	-0.21	-0.25	-0.25	-0.05
SWIR8	-0.19	-0.10	-0.13	-0.15	-0.18	-0.23	-0.21	-0.05
SWIR9	-0.16	-0.06	-0.10	-0.12	-0.14	-0.22	-0.19	-0.04
SI1	0.37	0.20	0.25	0.35	0.50	0.26	0.45	-0.07
SI2	0.37	0.20	0.25	0.35	0.50	0.27	0.46	-0.06
SI3	0.35	0.13	0.21	0.32	0.51	0.33	0.49	-0.04

PC=Principal component, SI=Salinity index, SWIR=Short wave infrared Aster, B1=Green Aster, B2=Red Aster, B3=Near infrared Aster.

It can be seen that correlations among ground measurements and image extracted values are low. The highest correlations correspond only to K^+ concentration and the salinity indices mentioned by Douaoui et al. (2006), who found relatively higher correlations for EC values. Even when samples from the non vegetated areas with saline crusts are used, the highest Pearson correlation coefficient was 0.53 (Figure 20).

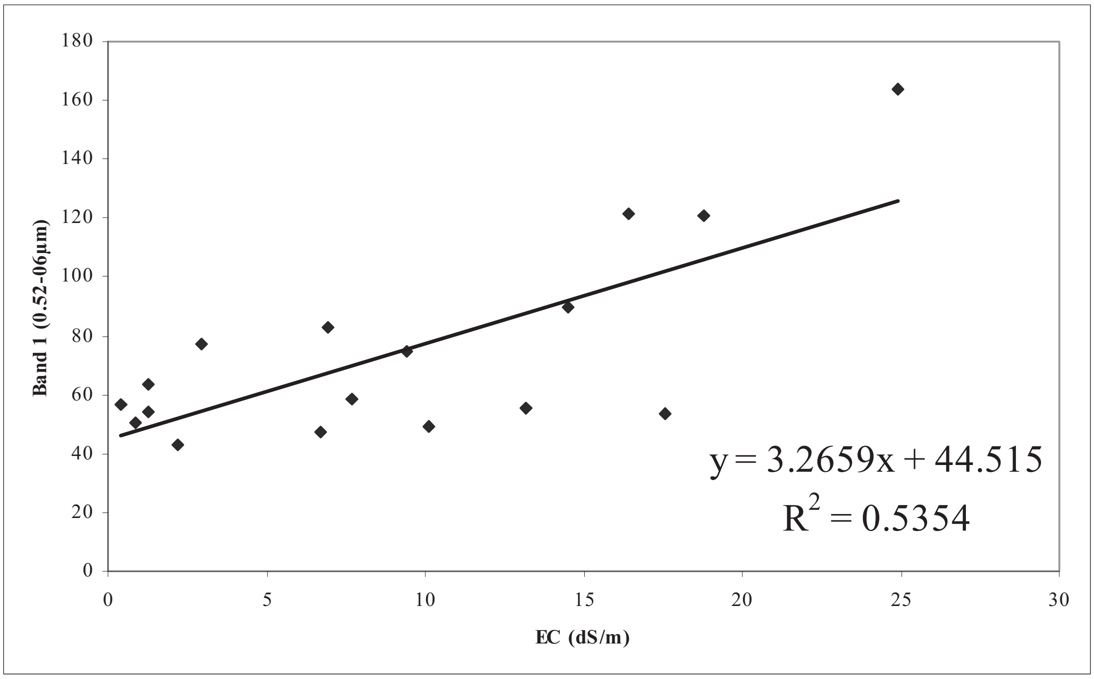


Figure 20. Comparison of EC ground measurements vs. ASTER digital number values and correlation coefficient.

It seems that local conditions like soil moisture and salt-tolerant plants presence produce interference in RS data acquisition (Farifteh et al., 2007; Metternicht and Zinck, 2003). In the field it's possible to find mixed features plots (Figure 21). In addition, the high variability in the ground measurements for salinity components (cation components), could also be present as high temporal variability (Bennett et al., 2009), producing interference in the correlation calculation.

Figure 21. Mixed features plots in La Mayca.

4.3. Geostatistical results and salinity features

The cells in a variogram surface represent distance classes, they contain the semi-variogram values of the point pairs whose separation vector ends up in each pixel (ILWIS, 2007). The origin is located at the centre of the graphic. The interpretation is made visually. When there is not anisotropy, the values decrease from the origin to the outer areas gradually, generally forming a circle-like shape. On the other hand, an ellipse-like shape of low semi-variogram values, going trough the origin (blue colored pixels) reveals anisotropy in that direction. The variogram surfaces for EC and ESP are presented in the Figure 22.

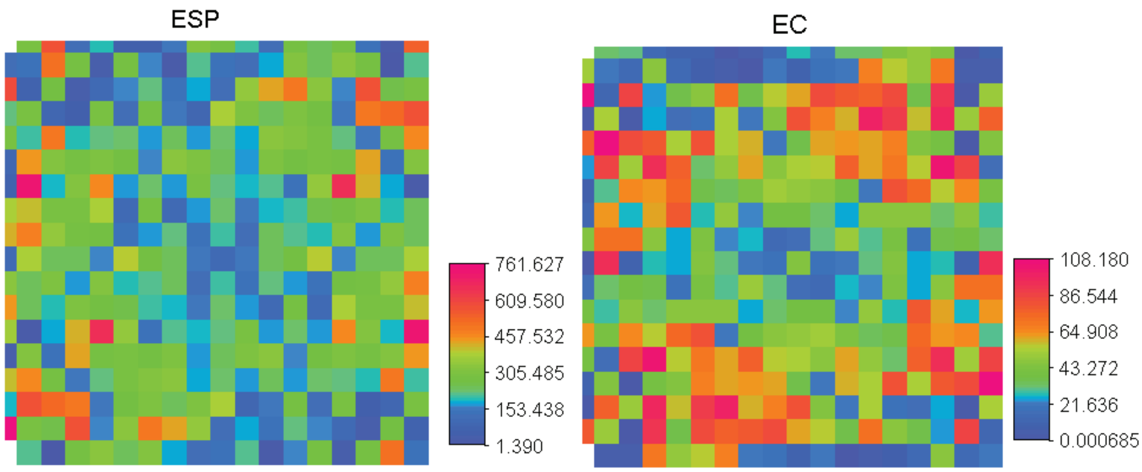


Figure 22. Semi-variogram surfaces for ESP and EC.

As it can be seen, the presence of the ellipse-like shape was not recognized for the EC and ESP. Hence, we discarded the anisotropy case, and proceed to the semi-variogram evaluation. This was expected after a general review of laboratory results plotted in the area, in that process an erratic distribution of high values surrounding low values and vice versa was noted. The experimental semi-variograms are presented in the Figure 23.

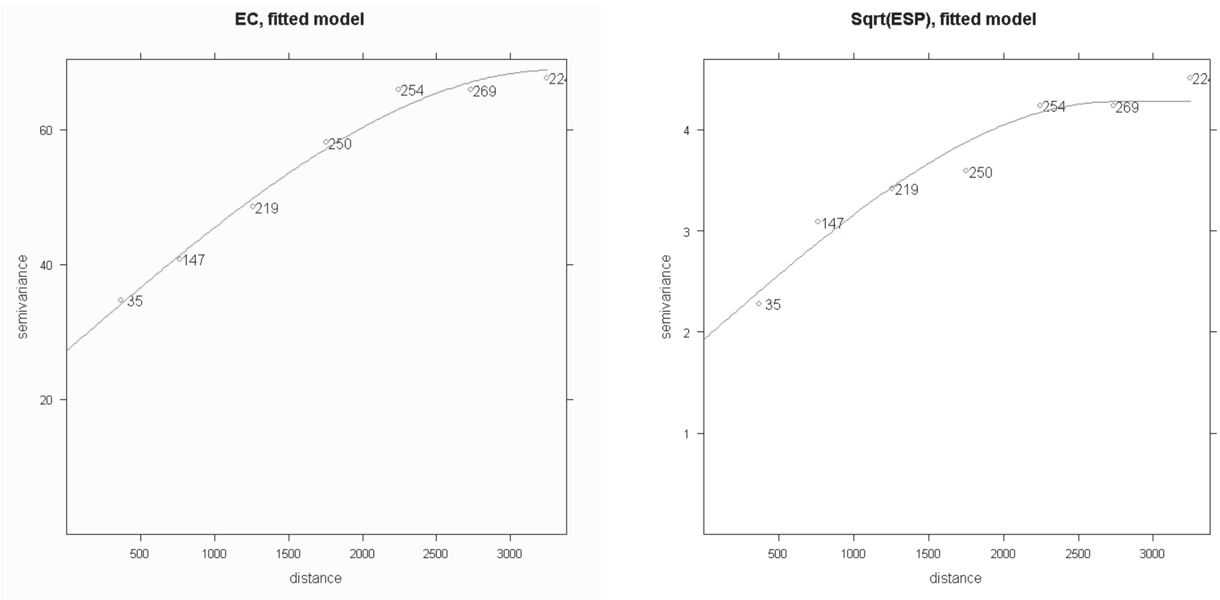


Figure 23. Semi-variogram fitted models for EC and sqrt (ESP).

The nugget effect accounted for 39 % and 45 % of the total variance in the case of EC and sqrt(ESP), respectively. It indicates that even if a spatial correlation exists, it is not strong, which further more influenced the interpolation process. The pH presented a pure nugget effect semi-variogram, and, as stated by (Hengl, 2007) its mean value (8.1±0.05) was considered as representative of the whole valley.

In the figures 23 and 24 the results of kriging interpolation are presented. In the case of EC (Figure 24) the interpolation results seem to be in agreement with the punctual evaluations. There is an accumulation of high values in the centre and western part of the study area. However, a closer view of the values reveals that the process overestimated low values and underestimated the higher ones. It can be simply looking at the two legends, where the ranks differ in 9 dS m^{-1} in the upper bound and 0.8 dS m^{-1} in the lower bound. Additionally the standard error of the estimate present high values.

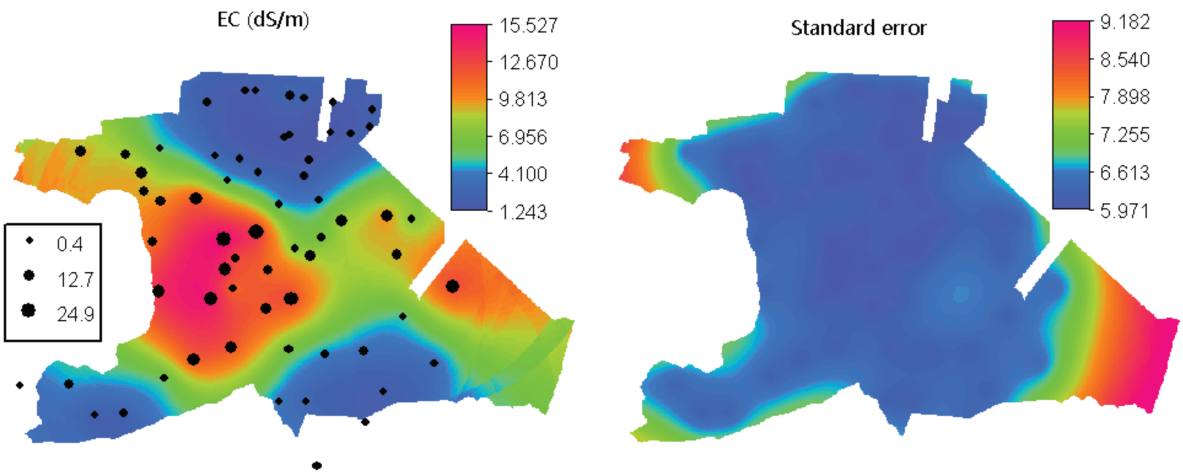


Figure 24. Ordinary kriging results for EC, punctual values of EC and standard error map.

The validation results were coincident in terms of correlation for both, the one-leave-out process and the validation set (R^2=0.43 and 0.49). The ME for the validation set was -2.2 and for the leave-one-out process much lower (0.041). This difference can be due to the size of the validation set and the way it was taken (randomly), which could be coincident with specific higher (or lower) differences between estimator and observed value. Since the leave-one-out process validate the accuracy of the interpolation using the whole set of observations, hence, the probability of reducing the value of the EM increases.

Despite of a high variability of EC, and low results in the validation process, there still a spatial relationship which allowed us to model the variable distribution (Navarro-Pedreño et al., 2007).

The Figure 25 presents the interpolation results for Sqrt (ESP). As the EC is a measure of the amount of salts that are present in the soil, is natural for the ESP to follow a similar pattern to the first variable. However, in this case there are some differences in the areal distribution. It's noted that the distribution of relatively higher values reaches a bigger surface in the area. Additionally, at the north and at the southwest, there are areas where the value of ESP rises. In the field, these places were relatively more difficult to sample than other places because of a hardened layer in the soil, which has a concordance with the soils descriptions presented.

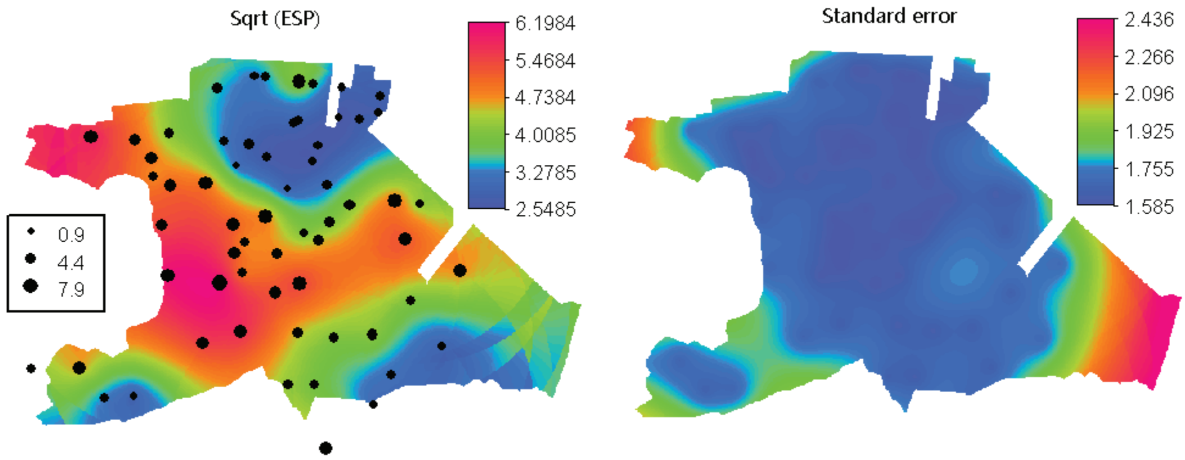


Figure 25. Ordinary kriging results for sqrt(ESP), original values of sqrt(ESP) and standard error map.

When compared to the EC results, the ME is lower for validation set (-0.79), as well as for the one-leave-out process (0.017). However, the correlation values are considerably lower than the EC case (R^2=0.24 and 0.23 for the first and the second procedures mentioned). In this case, the overestimation and underestimation were also present, but in smaller rank. However, as the variable is the square root of ESP we must consider an increasing of this differences once the variable is transformed to its original units. The variability of salinity specially at the surface layer is very high (Amezketa, 2007; Farifteh et al., 2008), hence is difficult to model, even with larger amount of samples or continuous measurements (geophysical approaches) (Amezketa, 2007). However, ancillary data with a good relationship to these variables could be used for improving the results of the interpolation (Hengl, 2007; Li et al., 2007; Madyaka, 2008).

4.3.1. Salinity features

The less affected areas, considering the EC, are located at the central north and the southeast and southwest of the study area. Most affected areas are crossing the study area from east to west, especially in the middle part. The Figure 26 shows the distribution of EC in the study area. The highest values on EC (>15 dS m^{-1}) coincide to natural depressions in the terrain observed during the fieldwork.

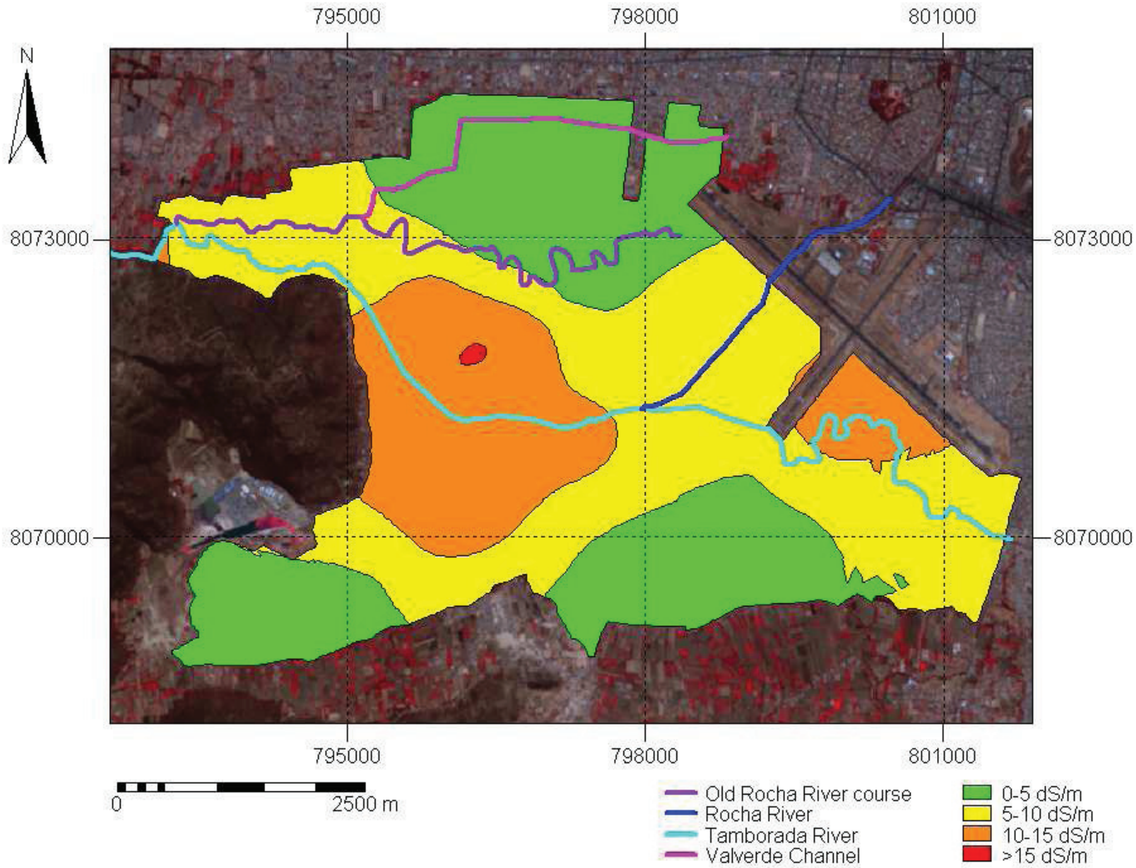


Figure 26. Classification of EC distribution in La Mayca, after interpolation process.

ESP distribution is showed in the next figure (Figure 27). As it can be seen in the map, most of the sodic soils are distributed along the study area from east to west. Less values of ESP coincide with non saline areas showed in the Figure 26.

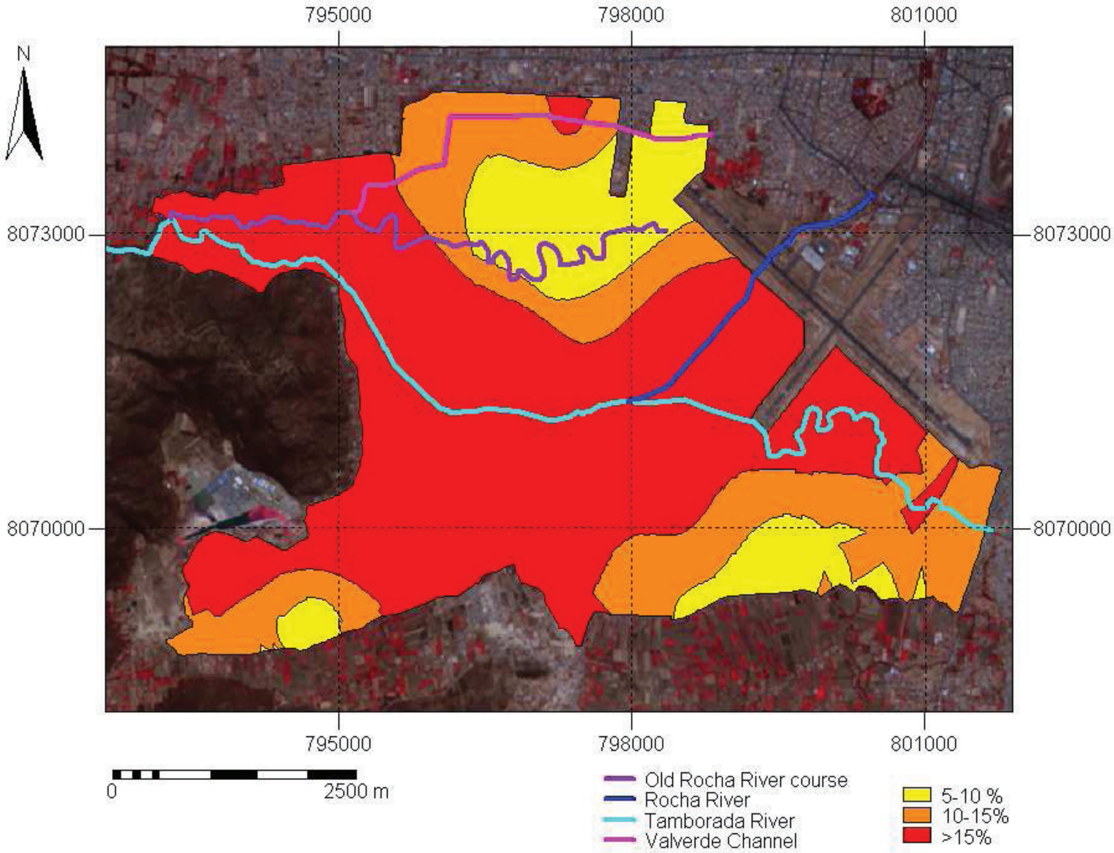


Figure 27. Classification of ESPdistribution in La Mayca, after interpolation process.

Being this variable a dependent one (affected by de SAR values, which are also affected by the concentrations of Na^{+}, Ca^{++} and Mg^{++}), is expected to have a high variability, which can make its modelling not totally accurate. However its distribution is based in the spatial correlation presented in the variograms described in a previous section.

The salinity and sodicity spatial distribution is presented in the Figure 28. According to this model, most affected areas are located along the river courses. At the south of the Tamborada River, chanels at the border of the main road conduct water from the WWTP and, if available, are mixed with La Angostura waters for irrigation. However, since samples from plots irrigated only with La Angostura water were taken, the influence of wastewaters is not completely clear. What seems to be clear is an areal correspondence between less affected areas and best drained areas, considering the textural classes presented in the Figure 4, where areas with higher concentration of sand coincide with the non affected areas at the south.

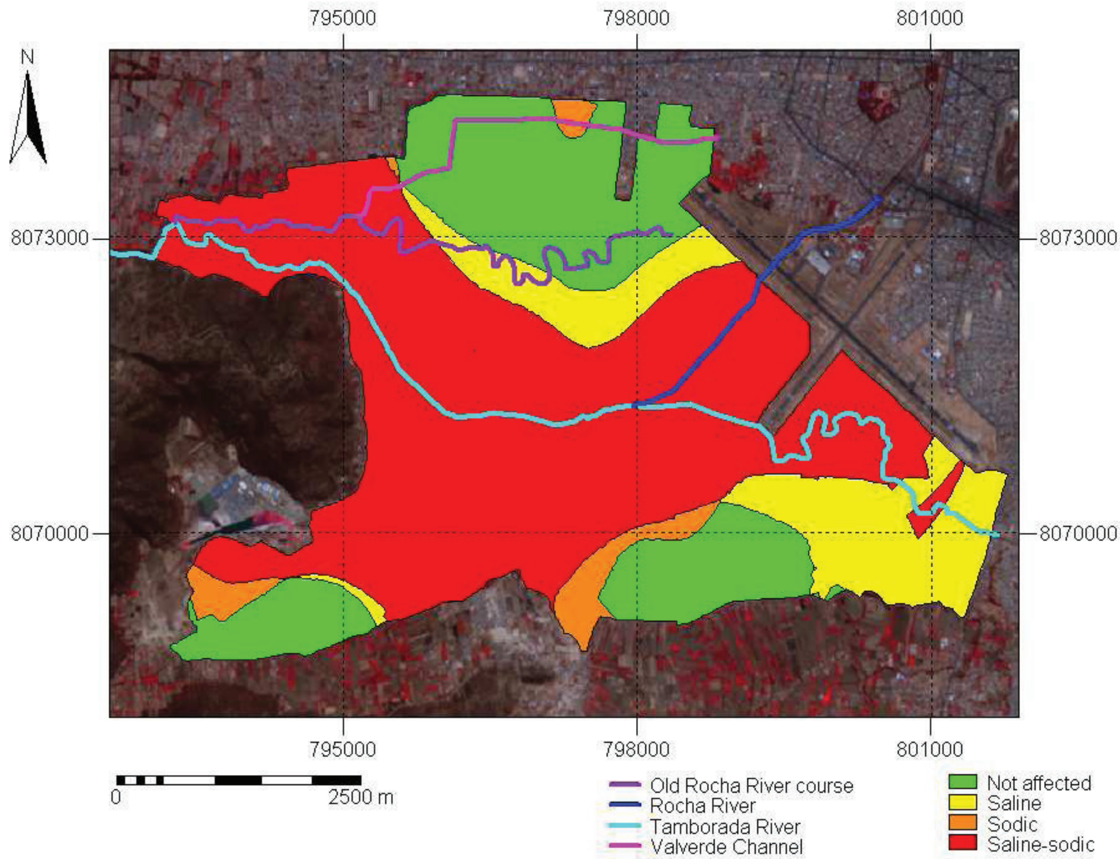


Figure 28. Salinity and sodicity distribution in La Mayca, combinig the EC and ESP maps.

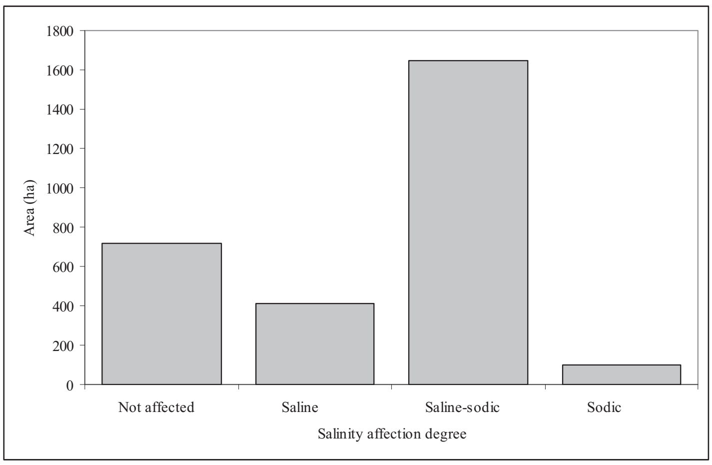


Figure 29. Salinity-sodicity area distribution.

The area distribution for each category is presented in the Figure 29. 57% of the area are saline-sodic soils (approximately 1650 ha); 14% are saline, 4% are sodic soils; and 24% are not affected from the salinity point of view. Although the results present a broad distribution of saline-sodic soils, the appearance of the crops, in general, doesn't seem to be affected, especially for the alfalfa and the ryegrass cases, which apparently are well adapted to these conditions. If water and nutrients are available, despite the salinity, the production is affected, but not the ability to produce. The sodium effects are very complex and depend on many local and interacting factors (Leal et al., 2009). Rangesami and Walters (1994) mention that productive crops can be found on lands with deeper sodicity problems and also the plants strategy to expand their roots can also be a factor for the missing of stronger signs of soil problems. Although, this can mask a chronicle problem in the soil, and different physical, chemical and biological properties could be in a deteriorating process (Walker and Lin, 2008).

4.4. Salinity areas by community

The different locations (communities) present EC values that differ according to their dependence on wastewater for irrigation (see appendices section). The communities that are not dependant at all from reused water present average values less than (or close to) 4 dS m^{-1}. Even though highest values are presented in zones where irrigation with wastewater is regular, there are other areas, like Mayca Arriba (which is not completely dependant of wastewater) or Mayca Central that present higher values of EC than those from close dependence of this water source, such as Mayca Sud. Differences can be seen in the Figure 30.

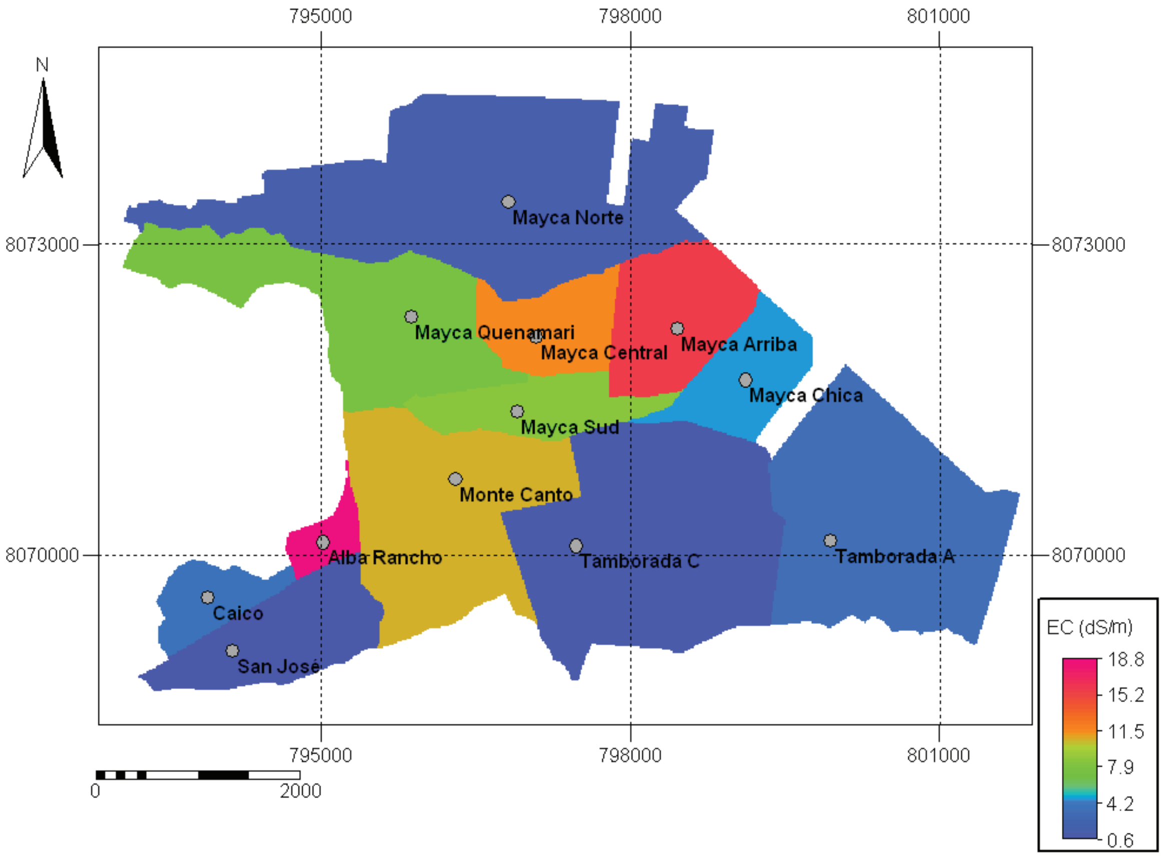


Figure 30. Average EC values by community.

The last results seem to indicate that in addition to the problems in the quality of water for irrigation, process like an excessive evaporation together with the soil properties produce high levels of salt accumulation in the top soil, which is also mentioned by Padilla (1999).

4.5. Salinity by crops

The Table 15 shows the values extracted from the maps of EC and ESP corresponding to the different crops and features in the study area. Maximum values of EC are similar for the classes considered. Ryegrass has the highest average followed by the salt affected areas, the bare soil, the alfalfa and the maize at the end, with about 5 dS m^{-1}.

Table 15. EC and ESP by crops in La Mayca.

Class	EC				ESP			
	Max	Min	Avg	SD	Max	Min	Avg	SD
	-------- dS m-1---------				--------- % ---------			
Agriculture bare soil	15.4	1.3	6.5	3.3	38.4	6.6	18.2	7.6
Alfa	15.4	1.2	6.4	3.4	38.4	6.5	18.9	8.4
Maize	14.8	1.7	5.6	3.3	34.6	6.9	16.9	6.1
Ryegrass	15.4	1.7	11.6	2.5	38.5	7.0	27.8	4.9
Salt affected	15.5	1.9	8.7	4.9	37.6	9.0	22.6	8.7

The ESP follows the same pattern, being the ryegrass the feature that records a highest value and the corn the lowest. However, all of the classes listed in the table present very high maximum values (>4 dS m^{-1} and >15 ESP). This values can also induce the nutrient deficiency, specially for the maize (Mehrotra et al., 1986), being this a very sensitive crop to physical-chemical properties, specially in early stages of growth (Fortmeier and Schubert, 1995). Plots with growing affected maize are spread out in the study area and can be found next to plots without apparent problems.

Maize plot

Plant affected

Figure 31. Maize plot and plant affected by salinity.

4.6. Irrigation indicators

The Figure 32 shows the relative EC ratio calculated for the WWTP discharges from 2005 to 2008. When the relative EC ratio surpasses the value of 1, it indicates that the system has exceeded the critical values considered. Indicators are designed to locate strategic periods for mitigation measurements or replanting of objectives and are better understood when plotted in a graph (Bos et al., 2005). In this case the relative EC ratio, considering the lowest critical value (0.7 dS m^{-1}) has been always surpassing the value of 1. However, a tendency to reduce, at least in the period evaluated, is noticed. This reduction could be related to different factors such as the day and the time when the samples were taken, and improvements in the treatment like a mechanical grates system installed in 2007[3]. When compared with the critical value 2, (3 dS m^{-1}), the relative EC ratio remains under the reference value of 1.

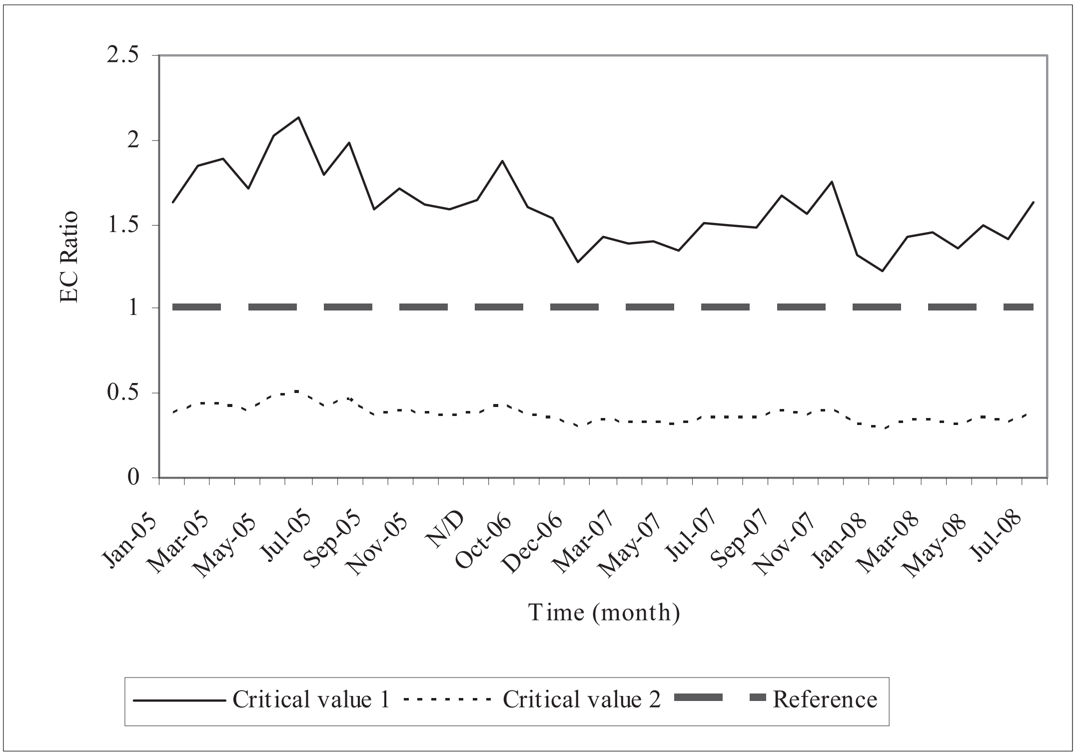


Figure 32. Relative EC ratio for the WWTP.
N/D = No data in this period.

[3]Honourable Municipality of Cochabamba. 2007. SEMAPA installs a new grate system. May 12, 2007. URL: http://www.cochabamba.gov.bo/Noticias/detalleNoticia/id/37. Access date: Sep. 15 2008.

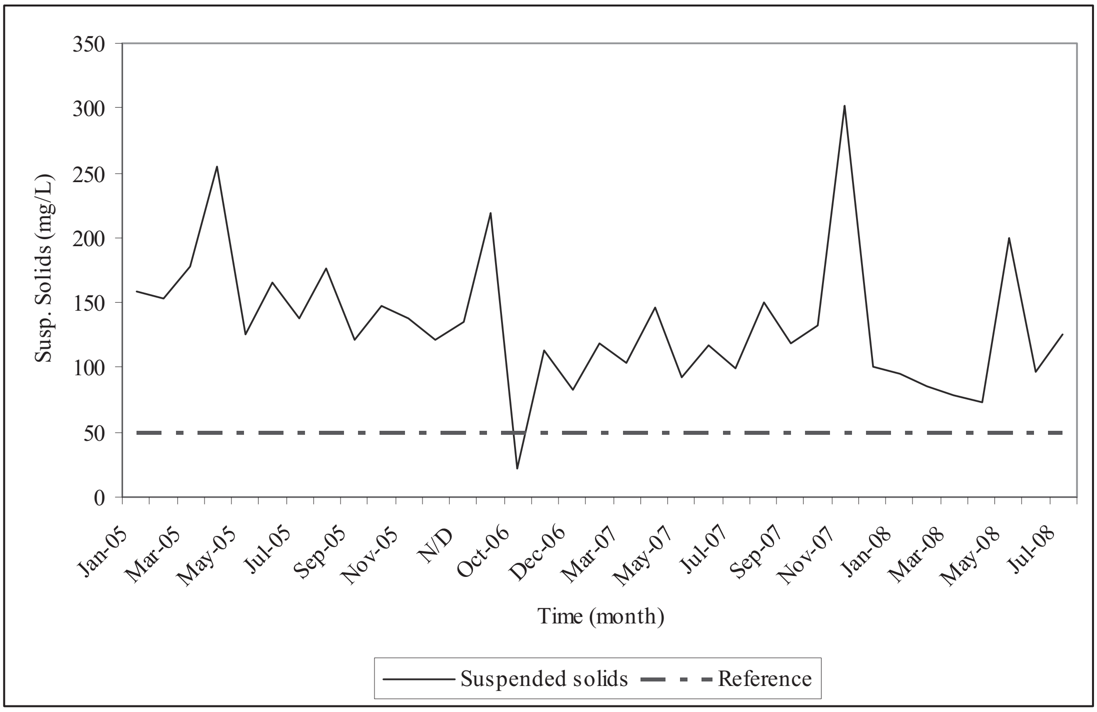


Figure 33. Suspended solids fluctuation.
N/D = No data in this period

The Figure 33 represents the fluctuation of suspended solids contained in the discharged water from the WWTP. When compared with the reference level is easy to note that the degree of restriction of use for the water has been moderate to severe. Different pollutants can be attached to the particles of suspended solids (e.g. heavy metals or pesticides) which adds complexity to soil reactions (Udeigwe and Wang, 2007) and can affect infiltration of water and reduce its probability of use by different forms of irrigation than flooding and furrows (Capra and Scicolone, 2007). Moreover, the opportunities for leaching during the rainy season can also be impaired.

Concerning to the WWTP, several aspects must be considered. According to the last census, the urban area of Cochabamba is growing at a yearly rate of 4.21 % (INE, 2008), which implicates the necessity of water treatment from an increasing demand of service. On 2003, the amount of connections to the sewerage system was more than 58000 (GERENTEC, 2003). Moreover, the sources of the connections are domestic, industrial, commercial, public and special. With such a variety of water origins is expected to have a variety of concentrations of different pollutants during the year. Therefore, the plant is not capable of standardize its discharge during the time, although, the waters from the plant are likely to have less concentration of pollutants than the water in the natural courses in the study area.

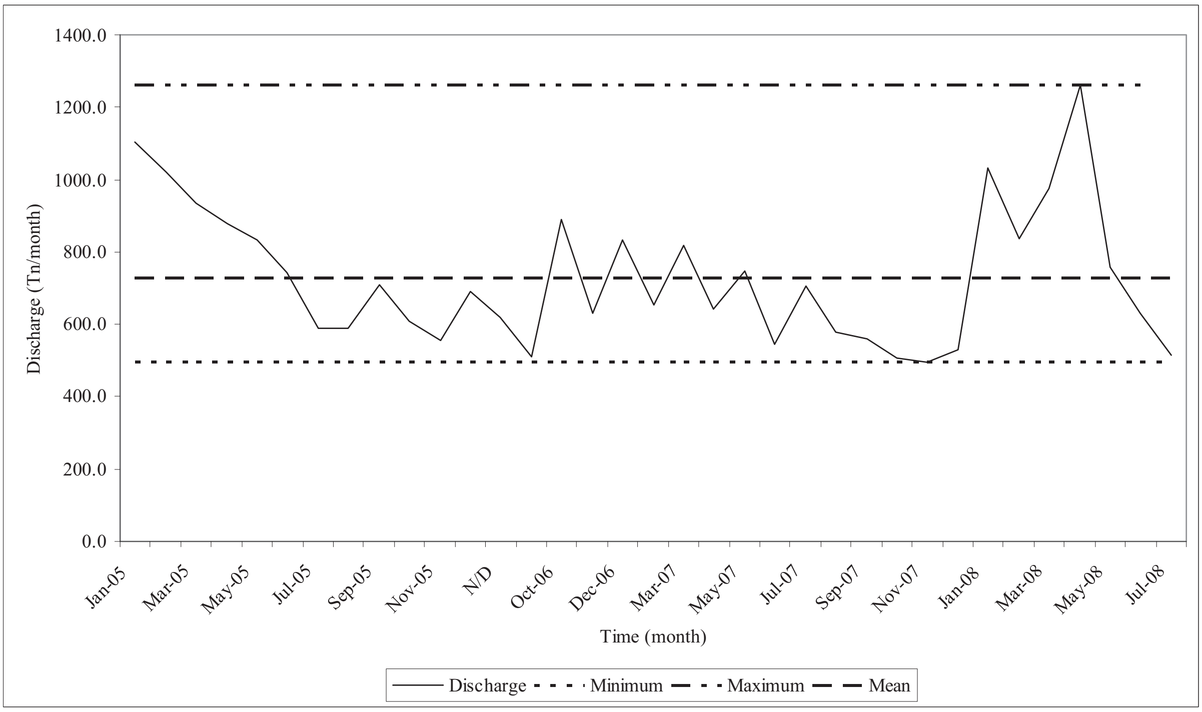


Figure 34. WWTP monthly salt discharge.
N/D = No data in this period.

The estimated salt discharge to the aquatic system from the treatment plant is presented in the Figure 34. The average monthly discharge is about 730 t, with a minimum discharge of 500 t and a maximum, for the last 3 years, of 1260 t. In the figure, average values are recorded during most of the time with a climbing tendency for the early months of 2008. We must consider that the total amount of salts discharged to the system is higher than the mentioned, because here the other water sources are not considered.

4.7. Water quality

4.7.1. Main water sources

The water quality results are presented in the following tables and are listed in downstream sense in the study area. Table 16 shows clear differences among La Angostura water and the other 3 sources evaluated. According to this results, La Angostura water has none degree of restriction of use, while the other sources have moderate restriction of use, in terms of EC. The alkalinity and total hardness increase downstream, while the BDO_5 decrease downstream due to a dilution process when the rivers are joined and the WWTP discharge occurs, increasing the velocity of the water movements and introducing oxygen to the system by the waterfall. The BDO_5 overpasses the maximum permissible level indicated by the national laws (20 mg L^{-1}).

Table 16. Water quality results.

Water source	pH	EC	Alkalinity	Total Hardness	Total BDO_5	Acidity
		dS m^{-1}	-------------------- mg L^{-1} -----------------------			
La Angostura	8.1	0.302	77.28	68.5	5	1.4
Rocha River	7.74	1.07	354.72	142.5	243	44.95
Tamborada and Rocha Rivers	8.08	1.93	483.84	207.5	107	33.71
Tamborada and WWTP	8.18	1.6	522.24	235	89	30.2

In the case of the anions and cations (Table 17), except for the K^- and Na^+, La Angostura waters show the lowest concentrations. The rest of the ions increase their concentration downstream. According to the lab staff, this is an unexpected anomaly (specially the outstanding value for Na^+). A further analysis for samples taken from the same place revealed much lower values for both cations (34.63 and 11.63 mg L^{-1}, for Na^+ and K^+, respectively).

Table 17. Water quality results (anions and cations).

Water source	Ca^{++}	Mg^{++}	Na^+	K^+	Cl^-	NO_3^-	$SO_4^=$	HCO_3^-
	--------------------------------- mg L^{-1} --------------------------------							
La Angostura	16.83	6.46	2289	446.5	5.67	0.04	22.5	77.28
Rocha River	40.08	10.37	576	51.5	53.88	<0.01	53.36	354.7
Tamborada and Rocha Rivers	44.09	23.79	928.75	67.5	163.07	0.01	63.28	483.8
Tamborada and WWTP	58.12	21.96	448.5	365.5	241.06	<0.01	71.33	522.2
Maximum permissible by law	300	150	200	NR	400	50	400	NR
Reference value*	NR	NR	207	NR	354	NR	NR	500

(*) Reference for inferior limit of severe hazard, NR = No reference.

The values presented allow us to calculate the SAR for the different water sources. The values obtained are 20, 28, 13 and 120 for the Rocha River; Tamborada and Rocha Rivers; Tamborada River and WWTP; and La Angostura, respectively. According to these values, while the waters from La Angostura and the association Tamborada + WWTP present a moderate threat of sodification of soils, the two other sources represent a severe sodicity hazard. These results are higher than the reported by Agreda (2000) and Ampuero (2005) for similar evaluations.

The solids increase downstream as well (Table 18). The total amount of solids, which concords with the ions tendency, is influenced in the water course sense. Turbidity, instead, decreases with the addition of discharged water downstream.

Table 18. Water quality results (solids and turbidity).

Water source	Solids				Turbidity
	Suspended	Dissolved	Volatile	Total	
	----------------- mg L^{-1}	---------------------			NTU*
La Angostura	95	295	130	390	280
Rocha River	345	495	450	840	140
Tamborada and Rocha Rivers	105	855	275	960	90
Tamborada and WWTP	135	1105	275	1240	50
Maximum permissible by law	100**	1500	NR	NR	50

(*) Nefelometric Turbidity Units, (**) Level for a severe hazard, NR = No reference.

According to the guidelines considered in this research, the suspended solids present a severe degree of restriction of use, except for La Angostura waters, which has none restriction of use. The dissolved solids have moderate restriction of use, even when the Bolivian normative allows its deposition in water courses. The volatile solids, which represent a rough estimation on the organic matter content, are related with high BDO_5 presented in Table 16.

Water quality results, in general, exceed the reference levels stated by the national and international standards. When compared with other studies made in the area several years ago, the water pollutants seem to be increased. Additionally, is probably that the even production system is increasing the pollution status in the water (e.g. by adding fertilizers), which is seen in the increasing in pollutants in downstream sense.

4.7.2. EC on water distribution

The EC distribution of surface and ground water sources is presented in the Figure 35. The average values (Table 19) have moderate restriction of use. However there are places that represent a severe risk of salinization, like at the southwest of the area. Both type of waters evaluated presented a high variability. It is expected that the ground water characteristics will mildly change during the time, but the surface water will always be directly influenced by compulsive human activities and environmental factors (e. g. precipitation, temperature and wind). Since surface water is used for irrigation, the perspective to improve the management, especially when no spatial monitoring of water and soils is done in the area, is limited.

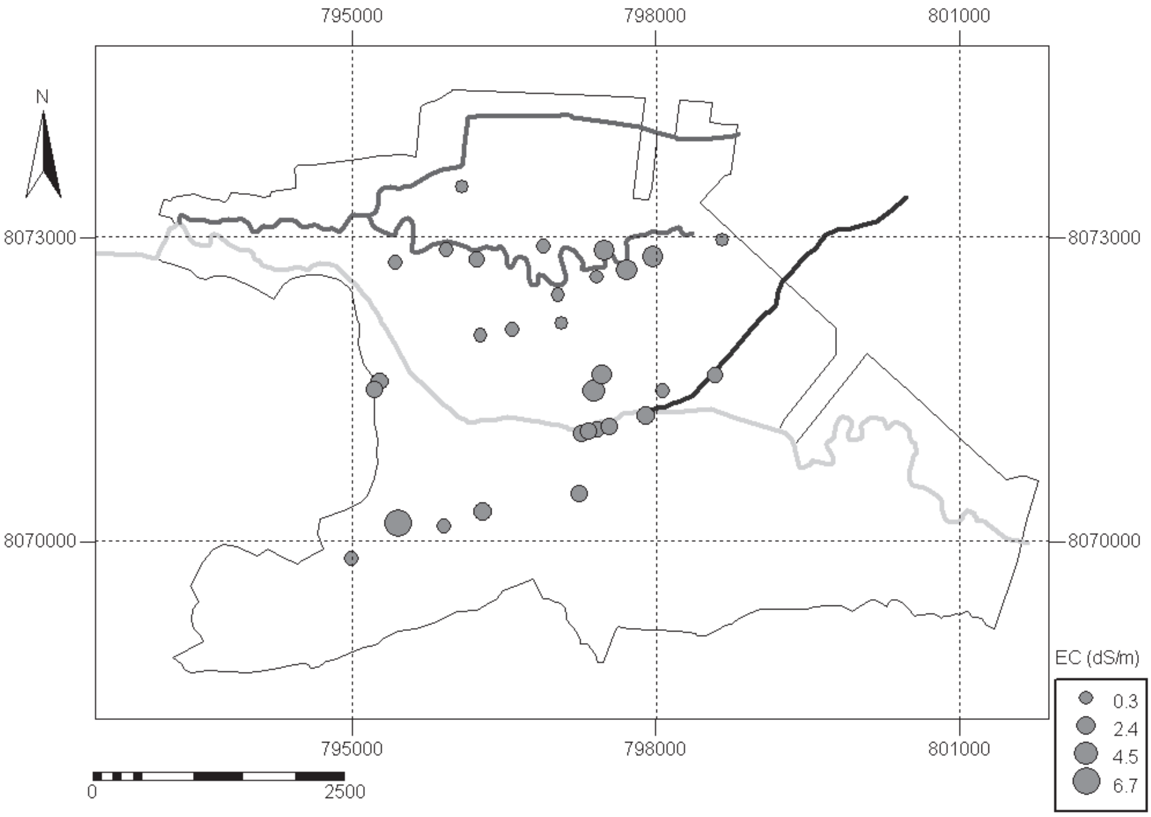


Figure 35. EC distribution in water sources.

On the other hand the quality of the waters (slightly saline), indicates also a parental material of soils with elevated content of soluble salts that can be transported throughout the soil profile.

Table 19. EC values for water sources in the area.

Source	N	Average	SD	Min	Max
		---------- dS m^{-1} ----------			
Groundwater	20	1.46	1.3	0.272	4.09
Surface water	12	1.801	1.7	0.302	6.65

Candela et al. (2007) demonstrated that in a relative short period of time the use of a moderate saline water can transform soil properties at different depths. Furthermore the continuous application of wastewater also increased the NO_3^- and Na^+ in ground waters, broadly used for drinking purposes.

4.8. Workshop results

4.8.1. Location of changes

The next figure (Figure 36) shows the location of salinity affections in the study area, recognized by the community. As the legend explains, the green dots locate areas without salinity affections; the red dots indicate historical places where the salinity has been present in noticeable levels; the orange dots show recently affected areas, recognized as a consequence of the production system and water quality used. The non affected zones are concentrated at the north and at the southwest of the area. Historically affected problems are concentrated in the area centre; the recently affected areas are distributed in the zone with a concentration at the northwest, a region where the main outlet of the water courses is located.

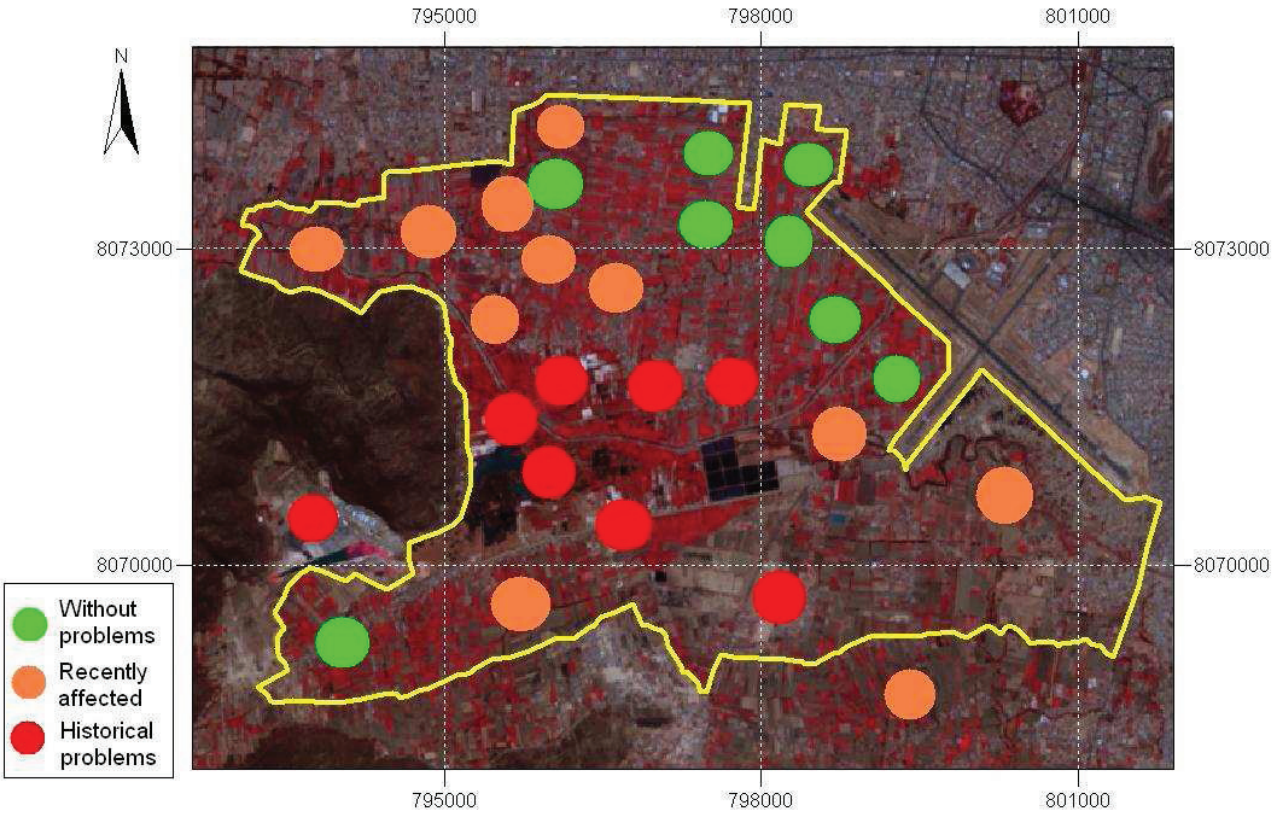


Figure 36. Location of salinity changes in the area.

Considering the total affected places (historical and recent), the general trend obtained via field evaluation is very similar (Figure 28).

4.8.2. Sequence of changes

The sequence of changes described by the farmers is presented in the Figure 37.

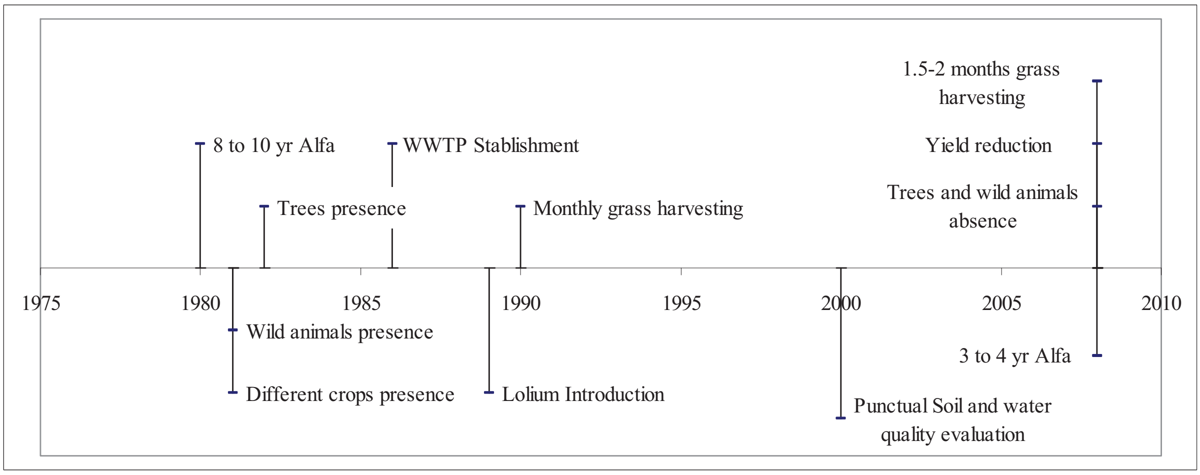


Figure 37. Time sequence of environmental changes related to waste water use in la Mayca zone.

According to the people consulted during the workshop, before the frequent use of waste water a variety of vegetal species were found in the study area, some destined for cropping and other were part of the landscape. The remaining cropping species from early 80's are the alfalfa and maize. At that time, the alfalfa used to last for about 10 years, without the needing of renewal. The presence of trees, such as some species of *Salix* sp., *Prosopis* sp. or *Schinus molle*, was common in the area.

With the establishment of the treatment plant on 1986, a more frequent use of this source of water was possible due to: a constant supply of a scarce resource, a cleaner option (compared with a direct use of water from the constantly polluted Rocha River), and a low-cost source of fertilizer (contained as organic matter in the water). However, its use had a law and "health-related" restriction for the irrigation of fresh vegetables (MDSMA, 1995), which induced the cropping modifications. These changes produced the need of testing new crop options in the area, as a result, and by initiative of the Milk Industry Plant (PIL), ryegrass was introduced around 1989.

Nowadays the annual yields have reduced in the different cash crops. It is related to a reduction on the permanence of the crops as well (3 to 4 years in the case of alfalfa), and longer harvest turns for forage. Due to a lack of records about the production during the time, the farmers couldn't assure the amount of yield reduction, even though there are cases where the milk production has increased, but it was mentioned that this is more an effect of improvements in the cattle genetics, and the use of complementary nutrition in order to be competitive in the market.

Different factors appear influencing the salinity affections in the area. On one side the origin of the soils and their natural characteristics; the absence of a planned drainage, together with a non favourable natural one; the weather; the irrigation system; and the water quality applied in the production. Exploring the spatial relationships and characteristics of different components in the system can represent an adequate way to aware different levels of decision makers. Further more, the information flow should integrate the different stakeholders in order to address solutions in an Integrated basin management approach, specially considering that the risks are not only relying on agricultural aspects, even though in health and aquatic ecosystems as well (Madramootoo et al., 1997).

5. Conclusions

Different degrees of salinity-sodicity are distributed in the study area. An overview of the areal distribution of the salinization problem can be obtained trough the mapping of the presence of alfalfa and ryegrass, tolerant species to salinity-sodicity affections, which can be done using remote sensing sources. However, the RS source used seem to be limited for a deeper discrimination revealed in low correlation with ground measurements ($R^2<0.53$).

The geostatistical approach demonstrated a link between the variables selected and the spatial distribution, permitting the spatial modelling of the EC and ESP. However, modelling produced low correlation between observed and predicted values (0.43 and 0.24 of R^2 for EC and ESP respectively) for involving short-range changing variables.

The spatial modelling reveals a distribution of the affected areas as related to the main water sources of irrigation. Being the most affected areas the irrigated with water coming from the WWTP and the Rocha River. However, the affection is also noted in areas irrigated with less polluted waters, which indicates different factors acting on the soil degrading process.

In general the different main sources of water demonstrated a permanent risk of salinization of soils and an increasing pollution trend downstream sense. The salinity values expressed in EC throughout the area present a high variability. Even the groundwater sources present levels of high concentration of salts, which indicates that the site specific characteristics can also be influencing in the presence of soluble salts in the soil profile.

Local knowledge, in addition, can be a source for fulfilling information in spatial and temporal terms. It is quick, inexpensive but qualitative. However a lack of numerical information (e.g. irrigation appraisals, water quality and water table monitoring, annual and temporal yields) is still a constraint for modelling, planning and decision making about the production system in the area. The evolution or involution of the salinization requires monitoring and involvement with the major stakeholders. A very dedicated and valuable database (both technical and social) is available after this thesis. The compilation was done after intensive fieldwork effort and the quantitative evaluation was expedite and under standard lab procedures. It is expected that this effort will help to repeat the experience for future comparison research.

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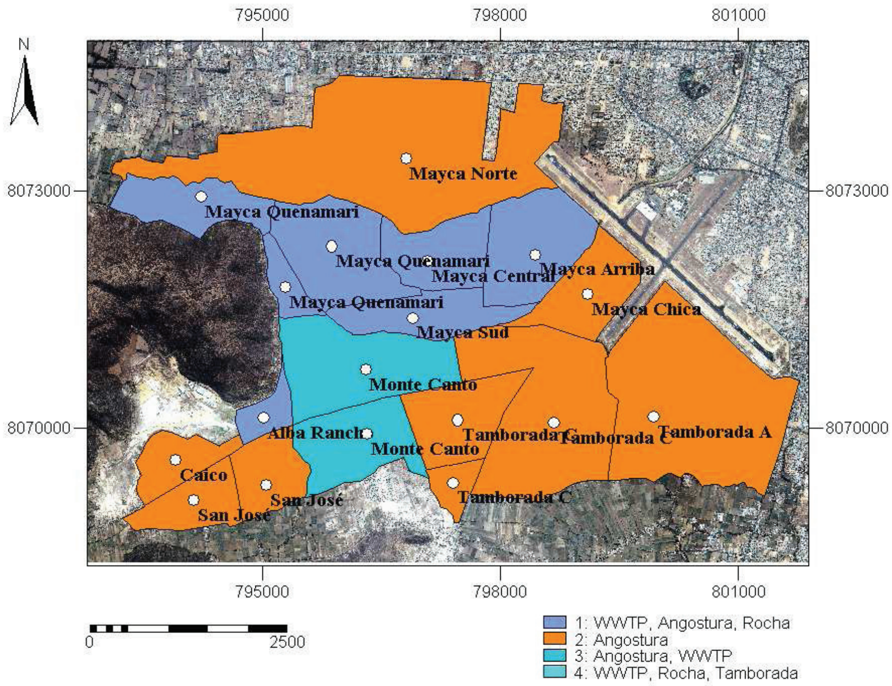
Appendices

Appendix 1. Spatial dependence of water sources



Appendix 2. Error matrix of supervised classification of ASTER image 2008.

Classified data	Reference data						User accuracy
	Water	Ryegrass	Alfa	Ag. Bare soil	Salt affected	Row Total	
	Number of pixels						
Water	146	0	0	0	0	146	100%
Ryegrass	0	505	64	0	0	569	89%
Alfa	0	28	403	0	0	431	94%
Ag. Bare soil	0	0	0	43	0	43	100%
Salt affected	0	0	0	0	11	11	100%
Total	146	533	467	43	11	1200	
Producer accuracy	100%	95%	86%	100%	100%		
Kappa index							88%
Total accuracy							92%

Appendix 3. List of participants to workshop

Full name	Community	Charge	ID number	Contact phone
Rivelino Salazar	M. Quenamari		5288732	4370370
Wilbert Villegas	M. Quenamari	Popular Health Committee representative	5151801	4370370
Justo Zerda	M. Quenamari		949562	4268543
Yerko Zerda Rocha	M. Quenamari		5237626	7645757
Wilma V. Zerda Quiroz	M. Quenamari	Vice president San Miguel Water System	3794754	4268566
Juan Aguilar	M. Quenamari	Order and security encharged	937330	4268956
René Hinojoso	M. Quenamari		3757335	7148560
Elsa Isabel Medrano	M. Quenamari		3607497	4377029
Orlando Rocha	M. Quenamari		5261216	4378424
Edwin Padilla Q.	M. Quenamari		3563310	4375224

Appendix 4. Workshop program

Activity	Time	Objective	Brief description	Materials
Introduction and presentation about the research project	20’	To produce a confidence environment and explain the main goals expected in the research	A brief introduction on the research purposes was done. The activities developed until the date of the Workshop were listed (sampling procedures, gathering information).	Flip chart, paper, computer, data display, extension socket.
Work activity about salinity	20’	To scout the local knowledge about salinity in soils	The Group was divided in 2 subgroups. Every group worked answering the next questions: What is soil salinity? Which signs present the soil when there is a problem of salinity? Which signs present the plants when the soil is saline?	Flip chart, adhesive tape, paper, markers, copies of the questions for every participant, pens and pencils
Plenary	25’		The Group secretaries were asked to share	Flip chart, papers, Photo

			the results and discussion points to the other group	camera, markers, adhesive paper
Work activity about salinity	30’	To scout the local knowledge about salinity in soils and the location of affected areas	Every Group counted with a map of the zone, the groups were requested to point the zones that are without problems of salinity (bellow dots), with historical problems of salinity (red dots), and areas with recently problems of salinity (orange dots).	Printings of Ikonos image in A3 size, glue, colored paper dots (Yellow, orange and red).
Plenary	15’		The same as before	The same as before
Salinity concepts	20’	To introduce to the group to technical concepts about salinity	Basic Concepts about salinity were discussed: origin, salt types, units of measurement, standards, classification of soils.	Proyector, extensor de corriente, computadora, papelógrafos. Pantalla o fondo blanco, marcadores, fotografías impresas
Individual work	10’	To interpret soil analysis results about salinity	A copy of a series of soil analysis results was given to each participant, participants learned how to look in to a results chart and compare the important values to standards, at the end, the participants where able to classify the results for saline, sodic and saline-sodic soils.	Copies of soil analysis results for every participant, pen, pencils, copies of reference material for each participant
Water quality for irrigation	20’	To introduce to the participants to water analysis interpretation in relation to salinity problems	The importance of water monitoring was explained and material about water quality was shared and discussed, partial results of EC measurements in water was evaluated against standards,	Computer, screen, flip chart, paper, copies of material to every participant, copies of *in situ* EC measurements for every Group, extension socket
Time line of changes	20’	To interact with the participants	The importance of records of different	Flip chart and paper, screen,

		to establish important changes in the agro-ecosystem during the time	elements of the production system was discussed (yield, irrigation needs, appraising flows). After that, a time line with the principal changes recognized by the participants was done. Every participant had the opportunity to pronounce statements. The establishment of *Lolium* was one of the points discussed.	markers, printed images, photo camera
Amendments	15’	To introduce to the Group to possible amendments in the soil	Preventive actions and amendments were discussed with the group.	Information copies for each participant
Grateful and goodbye act	10’		A simple close pointing the further stages on the research was done, and a deep appreciation for the supporting of the community was expressed	Drinks (the community brought them)

Appendix 5. Water analysis results

UNIVERSIDAD MAYOR DE SAN SIMON
FACULTAD DE CIENCIAS Y TECNOLOGIA
CENTRO DE AGUAS Y SANEAMIENTO AMBIENTAL

LABORATORIO REGIONAL DE CONTROL DE CALIDAD DE AGUAS
LABORATORIO PILOTO A NIVEL NACIONAL
REPORTE DE ANALISIS FISICOQUÍMICO DE AGUAS RESIDUALES

NUMERO DE REGISTRO 25612-SC-17577
NUMERO DE MUESTRA 1547/08

PRESTATARIO : CARLOS ROMAN
TELEFONO : 4236163

DATOS DE LA MUESTRA:
DEPARTAMENTO : COCHABAMBA
PROVINCIA : CERCADO
LOCALIDAD : MAYCA SUD
TIPO DE FUENTE : AGUA SUPERFICIAL
PUNTO DE MUESTREO : A 50 cm DE LA ORILLA
LUGAR DE MUESTREO : CANAL DE RIEGO EN EL PUENTE PEATONAL A 15 m DE LA Av. PETROLERA
LOCALIZACION GPS : 19 K805892, 8067385
PRESERVADA : SI
APARIENCIA : TURBIA , AMARILLA
TIPO DE ANÁLISIS : ESPECIAL
MUESTREADOR : CLIENTE

REUNE LAS CONDICIONES DE TOMA Y PRESERVACION DE MUESTRAS

FECHA DE MUESTREO : 08/09/24 HORA DE MUESTREO :13:10
FECHA INGRESO LAB. : 08/09/24 HORA INGRESO LAB. :14:05
FECHA ANALISIS LAB. : 08/09/24 HORA ANALISIS :15:00
FECHA CONTROL : 08/10/13 HORA CONTROL :11:30

RESULTADOS

ANALISIS FISICOQUIMICO

PARÁMETRO	METODO NORMALIZADO AWWA APHA,WEF	TECNICA	LIMITE DE DETECCION	UNIDADES	CONCENTRACION	LIMITES MAXIMOS PERMISIBLES EN CUERPOS RECEPTORES LEY 1333, CLASE D
TURBIEDAD	2130 B	NEFELOMETRICO	0,10	NTU	280,00	<200 – 10000

PARÁMETRO	METODO NORMALIZADO AWWA APHA,WEF	TECNICA	LIMITE DE DETECCION	UNIDADES	CONCENTRACION	LIMITES MAXIMOS PERMISIBLES EN CUERPOS RECEPTORES-LEY 1333, CLASE D
ACIDEZ	2310 B	TITULACION	0,01	$mgCaCO_3/L$	1,40	-
ALCALINIDAD	2320	TITULACION	0,01	$mgCaCO_3/L$	77,28	-
BICARBONATOS	2320	CALCULO	0,01	$mgCaCO_3/L$	77,28	-
CARBONATOS	2320 B	CALCULO	0,25	$mgCaCO_3/L$	0,00	
CALCIO	2320- Ca D	TITULACION – EDTA	0,01	$mgCa^{++}/L$	16,83	400
CLORUROS	4500-Cl B	TITULACION	0,10	$mgCl^-/L$	5,67	500
DUREZA	2340 C	TITULACION – EDTA	0,10	$mgCaCO_3/L$	68,50	-
MAGNESIO	3500-Mg E	CALCULO	0,10	$mgMg^{++}/L$	6,46	150,00
POTASIO	3500-K D	A.A. LLAMA –EMISION	0,02	mgK^+/L	446,50	-
SODIO	3500-Na D	A.A. LLAMA –EMISION	0,02	$mgNa^+/L$	2289,00	200,00
SULFATOS	$4500\text{-}SO_4$ E	TURBIDIMETRIA	0.01	$mgSO_4/L$	22,50	400,00
SÓLIDOS TOTALES	2540 B	GRAVIMETRICO 105°C	0,001	mg/L	390,00	
SÓLIDOS DISUELTOS	2540 C	GRAVIMETRICO 105°C	0,001	mg/L	295,00	1500,00
SÓLIDOS SUSPENDIDOS	-	CALCULO	0,001	mg/L	95,00	
SÓLIDOS VOLATILES	2540 G	CALCULO	0,001	mgSTV/L	130,00	
D.B.O.	5210 B	DILUCION – WINKLER	-	mgO_2/L	5	<30
NITRATOS	$4500\text{-}NO_3$	ESPECTROFOTOMETRIA	0,10	$mgNO_3/L$	0,04	50

ANALISIS DE LOS RESULTADOS

Según los límites máximos permisibles en cuerpos receptores de la Ley 1333, para aguas de clase D se observa elevada concentración de sodio y exceso en el parámetro de turbiedad.

Cochabamba, 14 de octubre de 2008

Lic. MSc. Rosario Montaño M.
RESPONSABLE LABORATORIOS CASA

Lic. M.Cs. Ana Maria Romero J.
DIRECTORA

UNIVERSIDAD MAYOR DE SAN SIMON
FACULTAD DE CIENCIAS Y TECNOLOGIA
CENTRO DE AGUAS Y SANEAMIENTO AMBIENTAL

LABORATORIO REGIONAL DE CONTROL DE CALIDAD DE AGUAS
LABORATORIO PILOTO A NIVEL NACIONAL
REPORTE DE ANALISIS FISICOQUÍMICO DE AGUAS RESIDUALES

NUMERO DE REGISTRO:21610-SC- 17575
NUMERO DE MUESTRA:1545/08

PRESTATARIO : **CARLOS ROMAN**
TELEFONO : **4236163**

DATOS DE LA MUESTRA:
DEPARTAMENTO : COCHABAMBA
PROVINCIA : CERCADO
LOCALIDAD : MAYCA SUD
TIPO DE FUENTE : AGUA SUPERFICIAL
PUNTO DE MUESTREO : A 80cm DE LA ORILLA DEL RIO ROCHA
LUGAR DE MUESTREO : 30 m ANTES DEL PUENTE A MAYCA
LOCALIZACION GPS : 798586, 8071631
PRESERVADA : SI
APARIENCIA : OSCURA *
TIPO DE ANÁLISIS : ESPECIAL
MUESTREADOR : CLIENTE

REUNE LAS CONDICIONES DE TOMA Y PRESERVACION DE MUESTRAS

FECHA DE MUESTREO : 08/09/24 HORA DE MUESTREO :11:20
FECHA INGRESO LAB. : 08/09/24 HORA INGRESO LAB. :14:05
FECHA ANALISIS LAB. : 08/09/24 HORA ANALISIS :15:00
FECHA CONTROL : 08/10/13 HORA CONTROL :11:30

RESULTADOS

ANALISIS FISICOQUIMICO

PARÁMETRO	METODO NORMALIZADO AWWA APHA,WEF	TECNICA	LIMITE DE DETECCION	UNIDADES	CONCENTRACION	LIMITES MAXIMOS PERMISIBLES EN CUERPOS RECEPTORES LEY 1333, CLASE D
TURBIEDAD	2130 B	NEFELOMETRICO	0,10	NTU	140,00	<200 – 10000

PARÁMETRO	METODO NORMALIZADO AWWA APHA,WEF	TECNICA	LIMITE DE DETECCION	UNIDADES	CONCENTRACION	LIMITES MAXIMOS PERMISIBLES EN CUERPOS RECEPTORES-LEY 1333, CLASE D
ACIDEZ	2310 B	TITULACION	0,01	$mgCaCO_3/L$	44,95	-
ALCALINIDAD	2320	TITULACION	0,01	$mgCaCO_3/L$	354,72	-
BICARBONATOS	2320	CALCULO	0,01	$mgCaCO_3/L$	354,72	-
CARBONATOS	2320 B	CALCULO	0,25	$mgCaCO_3/L$	0,00	
CALCIO	2320- Ca D	TITULACION - EDTA	0,01	$mgCa^{++}/L$	40,08	400
CLORUROS	4500-Cl B	TITULACION	0,10	$mgCl^{-}/L$	53,88	500
DUREZA	2340 C	TITULACION - EDTA	0,10	$mgCaCO_3/L$	142,50	-
MAGNESIO	3500-Mg E	CALCULO	0,10	$mgMg^{++}/L$	10,37	150,00
POTASIO	3500-K D	A.A. LLAMA –EMISION	0,02	mgK^{+}/L	51,50	-
SODIO	3500-Na D	A.A. LLAMA –EMISION	0,02	$mgNa^{+}/L$	576,00	200,00
SULFATOS	$4500-SO_4$ E	TURBIDIMETRIA	0,01	$mgSO_4^{=}/L$	53,36	400,00
SÓLIDOS TOTALES	2540 B	GRAVIMETRICO 105°C	0,001	mg/L	840,00	
SÓLIDOS DISUELTOS	2540 C	GRAVIMETRICO 105°C	0,001	mg/L	495,00	1500,00
SÓLIDOS SUSPENDIDOS	-	CALCULO	0,001	mg/L	345,00	
SÓLIDOS VOLATILES	2540 G	CALCULO	0,001	mgSTV/L	450,00	
D.B.O.	5210 B	DILUCION – WINKLER	-	$mg\ O_2/L$	243	<30
NITRATOS	$4500-NO_3$	ESPECTROFOTOMETRIA	0,10	$mgNO_3/L$	<0,01	50

** tiene presencia de materia orgánica en suspensión, desprendimiento de burbujas que salen de la base del canal y de los lodos de la orilla.*

ANALISIS DE LOS RESULTADOS

Según los límites máximos permisibles en cuerpos receptores de la Ley 1333, para aguas de clase D se observa elevada concentración de sodio y carga orgánica expresada en la DBO_5.

Cochabamba, 14 de octubre de 2008

UNIVERSIDAD MAYOR DE SAN SIMON

FACULTAD DE CIENCIAS Y TECNOLOGIA

CENTRO DE AGUAS Y SANEAMIENTO AMBIENTAL

LABORATORIO REGIONAL DE CONTROL DE CALIDAD DE AGUAS
LABORATORIO PILOTO A NIVEL NACIONAL
REPORTE DE ANALISIS FISICOQUÍMICO DE AGUAS RESIDUALES

NUMERO DE REGISTRO:25611-SC-17576
NUMERO DE MUESTRA:1546/08

PRESTATARIO : **CARLOS ROMAN**
TELEFONO : **4236163**

DATOS DE LA MUESTRA:

DEPARTAMENTO : COCHABAMBA
PROVINCIA : CERCADO
LOCALIDAD : MAYCA SUD
TIPO DE FUENTE : AGUA SUPERFICIAL
PUNTO DE MUESTREO : A 1 m DE LA ORILLA
LUGAR DE MUESTREO : 20 m DE LA UNION DE LOS RIOS TAMBORADA Y ROCHA
LOCALIZACION GPS : 797899, 8071236
PRESERVADA : SI
APARIENCIA : VERDE *
TIPO DE ANÁLISIS : ESPECIAL
MUESTREADOR : CLIENTE

REUNE LAS CONDICIONES DE TOMA Y PRESERVACION DE MUESTRAS

FECHA DE MUESTREO :	06/09/24	HORA DE MUESTREO	:11:50
FECHA INGRESO LAB. :	06/09/24	HORA INGRESO LAB.	:14:05
FECHA ANALISIS LAB. :	06/09/24	HORA ANALISIS	:15:00
FECHA CONTROL :	06/10/13	HORA CONTROL	:11:30

RESULTADOS

ANALISIS FISICOQUIMICO

PARÁMETRO	METODO NORMALIZADO AWWA APHA,WEF	TECNICA	LIMITE DE DETECCION	UNIDADES	CONCENTRACION	LIMITES MAXIMOS PERMISIBLES EN CUERPOS RECEPTORES LEY 1333, CLASE D
TURBIEDAD	2130 B	NEFELOMETRICO	0,10	NTU	50,00	<200 – 10000

PARÁMETRO	METODO NORMALIZADO AWWA APHA,WEF	TECNICA	LIMITE DE DETECCION	UNIDADES	CONCENTRACION	LIMITES MAXIMOS PERMISIBLES EN CUERPOS RECEPTORES-LEY 1333 CLASE D
ACIDEZ	2310 B	TITULACION	0,01	$mgCaCO_3/L$	30,20	-
ALCALINIDAD	2320	TITULACION	0,01	$mgCaCO_3/L$	522,24	-
BICARBONATOS	2320	CALCULO	0,01	$mgCaCO_3/L$	522,24	-
CARBONATOS	2320 B	CALCULO	0,25	$mgCaCO_3/L$	0,00	
CALCIO	2320- Ca D	TITULACION – EDTA	0,01	$mgCa^{++}/L$	58,12	400
CLORUROS	4500-Cl B	TITULACION	0,10	$mgCl^-/L$	241,06	500
DUREZA	2340 C	TITULACION – EDTA	0,10	$mgCaCO_3/L$	235,00	-
MAGNESIO	3500-Mg E	CALCULO	0,10	$mgMg^{++}/L$	21,96	150,00
POTASIO	3500-K D	A.A. LLAMA –EMISION	0,02	mgK^+/L	365,50	-
SODIO	3500-Na D	A.A. LLAMA –EMISION	0,02	$mgNa^+/L$	448,50	200,00
SULFATOS	$4500\text{-}SO_4$ E	TURBIDIMETRIA	0,01	$mgSO_4/L$	71,33	400,00
SÓLIDOS TOTALES	2540 B	GRAVIMETRICO 105°C	0,001	mg/L	1240,00	
SÓLIDOS DISUELTOS	2540 C	GRAVIMETRICO 105°C	0,001	mg/L	1105,00	1500,00
SÓLIDOS SUSPENDIDOS	-	CALCULO	0,001	mg/L	135,00	
SÓLIDOS VOLATILES	2540 G	CALCULO	0,001	mgSTV/L	275,00	
D.B.O.	5210 B	DILUCION – WINKLER	-	mgO_2/L	89	<30
NITRATOS	$4500\text{-} NO_3$	ESPECTROFOTOMETRIA	0,10	$mgNO_3/L$	<0,01	50

* la muestra presenta partículas suspendidas de materia orgánica, existe cerca área agrícola, residuos sólidos (botellas, plásticos, gomas).

ANALISIS DE LOS RESULTADOS

Según los límites máximos permisibles en cuerpos receptores de la Ley 1333, para aguas de clase D se observa exceso en el parámetro de sodio y carga orgánica expresada en la DBO_5

UNIVERSIDAD MAYOR DE SAN SIMON
FACULTAD DE CIENCIAS Y TECNOLOGIA
CENTRO DE AGUAS Y SANEAMIENTO AMBIENTAL

LABORATORIO REGIONAL DE CONTROL DE CALIDAD DE AGUAS
LABORATORIO PILOTO A NIVEL NACIONAL
REPORTE DE ANALISIS FISICOQUIMICO DE AGUAS RESIDUALES

NUMERO DE REGISTRO:25609-SC-17574
NUMERO DE MUESTRA:1544/08

PRESTATARIO : CARLOS ROMAN
TELEFONO : 4236163

DATOS DE LA MUESTRA:
DEPARTAMENTO : COCHABAMBA
PROVINCIA : CERCADO
LOCALIDAD : MAYCA SUD
TIPO DE FUENTE : AGUA SUPERFICIAL
PUNTO DE MUESTREO : A 80 cm DE LA ORILLA SOBRE EL RIO TAMBORADA
LUGAR DE MUESTREO : 80 m DE LA DESCARGA DE LA PLANTA DE TRATAMIENTO DE ALBA RANCHO
LOCALIZACION GPS : 797332, 8071080
PRESERVADA : SI
APARIENCIA : VERDE OLOR PENETRANTE
TIPO DE ANALISIS : ESPECIAL
MUESTREADOR : CLIENTE

REUNE LAS CONDICIONES DE TOMA Y PRESERVACION DE MUESTRAS

FECHA DE MUESTREO : 08/09/24 HORA DE MUESTREO :10:25
FECHA INGRESO LAB. : 08/09/24 HORA INGRESO LAB. :14:05
FECHA ANALISIS LAB. : 08/09/24 HORA ANALISIS :15:00
FECHA CONTROL : 08/10/13 HORA CONTROL :11:30

RESULTADOS

ANALISIS FISICOQUIMICO

PARÁMETRO	METODO NORMALIZADO AWWA APHA,WEF	TECNICA	LIMITE DE DETECCION	UNIDADES	CONCENTRACION	LIMITES MAXIMOS PERMISIBLES EN CUERPOS RECEPTORES LEY 1333, CLASE D
TURBIEDAD	2130 B	NEFELOMETRICO	0,10	NTU	90,00	<200 – 10000

PARÁMETRO	METODO NORMALIZADO AWWA APHA,WEF	TECNICA	LIMITE DE DETECCION	UNIDADES	CONCENTRACION	LIMITES MAXIMOS PERMISIBLES EN CUERPOS RECEPTORES-LEY 1333, CLASE D
ACIDEZ	2310 B	TITULACION	0,01	$mgCaCO_3/L$	33,71	-
ALCALINIDAD	2320	TITULACION	0,01	$mgCaCO_3/L$	483,84	-
BICARBONATOS	2320	CALCULO	0,01	$mgCaCO_3/L$	483,84	-
CARBONATOS	2320 B	CALCULO	0,25	$mgCaCO_3/L$	0,00	
CALCIO	2320- Ca D	TITULACION – EDTA	0,01	$mgCa^{++}/L$	44,09	400
CLORUROS	4500-Cl B	TITULACION	0,10	$mgCl^-/L$	163,07	500
DUREZA	2340 C	TITULACION – EDTA	0,10	$mgCaCO_3/L$	207,50	-
MAGNESIO	3500-Mg E	CALCULO	0,10	$mgMg^{++}/L$	23,79	150,00
POTASIO	3500-K D	A.A. LLAMA –EMISION	0,02	mgK^+/L	67,50	-
SODIO	3500-Na D	A.A. LLAMA –EMISION	0,02	$mgNa^+/L$	928,75	200,00
SULFATOS	4500-SO_4 E	TURBIDIMETRIA	0,01	$mgSO_4^=/L$	63,28	400,00
SÓLIDOS TOTALES	2540 B	GRAVIMETRICO 105°C	0,001	mg/L	960,00	
SÓLIDOS DISUELTOS	2540 C	GRAVIMETRICO 105°C	0,001	mg/L	855,00	1500,00
SÓLIDOS SUSPENDIDOS	-	CALCULO	0,001	mg/L	105,00	
SÓLIDOS VOLATILES	2540 G	CALCULO	0,001	mgSTV/L	275,00	
D.B.O_5	5210 B	DILUCION – WINKLER	-	mgO_2/L	107	<30
NITRATOS	4500-NO_3	ESPECTROFOTOMETRIA	0,10	$mgNO_3/L$	0,01	50

ANALISIS DE LOS RESULTADOS

Según los límites máximos permisibles en cuerpos receptores de la Ley 1333, para aguas de clase D se observa elevada concentración de sodio y carga orgánica expresada en la DBO_5.

Cochabamba, 14 de octubre de 2008

Lic. MSc. Rosario Montaño M.
RESPONSABLE LABORATORIOS CASA.

Lic. M.Cs. Ana María Romero J.
DIRECTORA

Appendix 6. Water EC evaluations

Nº	T (ºC)	Date	Source	X	Y	EC (dS/m)	Remarks
1	19	16-Sep	Well	795430	8072741	0.752	90 people served
2	19	16-Sep	Well	795922	8072872	0.539	
3	18.5	16-Sep	Well	796230	8072773	0.75	
4	19	16-Sep	Well	796264	8072030	0.499	
5	18	16-Sep	Well	796576	8072087	0.546	
6	18	16-Sep	Well	797061	8072149	0.502	
7	17	16-Sep	Well	797032	8072433	0.471	
8	19	16-Sep	Well	796230	8072773	1.02	
9	19	16-Sep	Well	795269	8071570	1.93	
10	21	16-Sep	Spring	795218	8071494	1.85	
11	23	16-Sep	Well	797406	8072608	0.455	
12	22.5	16-Sep	Well	797709	8072674	3.63	
13	23	16-Sep	Well	797972	8072807	3.64	
14	21	16-Sep	Well	798652	8072970	0.567	
15	20.5	16-Sep	Well	798071	8071478	0.709	
17	20.5	16-Sep	Well	797384	8071479	4.09	
18	27	16-Sep	Well	797462	8071638	3.16	
19	27.5	16-Sep	Well	797486	8072867	3.29	
20	23.5	16-Sep	Well	796885	8072911	0.522	
21	24.5	16-Sep	Well	796082	8073494	0.272	
22	21	17-Sep	Angostura	794990	8069824	0.449	Channel close to road
23	19	17-Sep	WWTP	795457	8070169	6.65	Lagoon
24	18.5	17-Sep	WWTP_Angostura	795910	8070140	0.6	Mixed waters
25	23	17-Sep	WWTP	796293	8070281	2.41	WWTP water diversion
26	18	17-Sep	WWTP	797242	8070468	1.67	Channel close to road
27	20	17-Sep	WWTP	797415	8071095	1.55	Effluent of WWTP

28	20.5	17-Sep	Tamborada	797533	8071129	1.75	100m before effluent
29	21	17-Sep	WWTP_Tamborada	797263	8071058	1.63	100m after effluent
30	21	23-Sep	WWTP_Tamborada	797332	8071080	1.6	100m after effluent
31	24.5	23-Sep	Rocha	798586	8071631	1.07	30m before bridge
32	26.5	23-Sep	Rocha_Tamborada	797899	8071236	1.93	River junction
33	24	23-Sep	Angostura	805892	8067385	0.302	Santa Vera cruz zone
34	23	30-Sep	Angostura	797670	8074082	0.316	Canal close IMBA
35	25	30-Sep	Valverde	797053	8074181	1.94	Canal close to Imba, under the bridge

Appendix 7. R Script

Note: The “points_values” is a csv file (it can be saved as this format in Excel) with the next columns: x, y, ec, ph and esp, with the information for the 63 sampling points. Under the line comes the script.

```
ds <- read.csv("points_values.csv")
summary(ds)
attach(ds)
## examine distributions
stem(ph); hist(ph); rug(ph)
# symmetric
stem(ec); hist(ec); rug(ec)
# skew, one very high value
# replace with highest value otherwise observed
ds[which(ec == max(ec)),"ec"] <- sort(ec)[length(ec)-1]
detach(ds); attach(ds)
stem(ec); hist(ec); rug(ec)
# still skew but consistent
hist(log(ec)); rug(log(ec))
# log not much better
stem(esp); hist(esp); rug(esp)
# skew
hist(sqrt(esp)); rug(sqrt(esp))
# sqrt is better
detach(ds)
```

```
## postplots
require(gstat)
coordinates(ds) <- ~e + n
plot(coordinates(ds), cex=3*ds$ec/max(ds$ec), main="EC"); grid()
# looks like some hot/cold spots
plot(coordinates(ds), cex=2*ds$ph/max(ds$ph), main="pH"); grid()
# not much variability, hard to tell
plot(coordinates(ds), cex=3*ds$esp/max(ds$esp), main="ESP"); grid()
# looks like no dependence

## variograms
# 1 - EC
v.ec <- variogram(ec ~ 1, loc=ds); plot(v.ec, pl=T)
# not too bad, try with wider bins to get more point-pairs per bin
v.ec2 <- variogram(ec ~ 1, loc=ds, width=500, cutoff=3500); plot(v.ec2, pl=T, main="EC")
# sure, we can model this one!
(vm.ec <- fit.variogram(v.ec2, vgm(40, "Sph", 2000, 25)))
plot(v.ec2, pl=T, model=vm.ec, main="EC, fitted model")
# I'm happy with this
# proportion of nugget effect
vm.ec$psill[1]/sum(vm.ec$psill)*100
# 39% is nugget!
# 2 - pH
v.ph <- variogram(ph ~ 1, loc=ds, width=500, cutoff=3500); plot(v.ph, pl=T, main="pH")
# pure nugget, interpolate with average value for whole valley
# 3 - ESP
v.esp <- variogram(sqrt(esp) ~ 1, loc=ds, width=500, cutoff=3500); plot(v.esp, pl=T,
main="Sqrt(ESP)")
# also not bad
(vm.esp <- fit.variogram(v.esp, vgm(2.5, "Sph", 2000, 2)))
plot(v.esp, pl=T, model=vm.esp, main="Sqrt(ESP), fitted model")
# proportion of nugget effect
vm.esp$psill[1]/sum(vm.esp$psill)*100
# 45% is nugget!
```

```
## make a grid
# dimensions of study area
diff(bbox(ds)["e",])
diff(bbox(ds)["n",])
# 50m cell size seems OK
grid <- expand.grid(e = seq(793100, 800000, by=20), n=seq(8068300, 8074300, by=20))
coordinates(grid) <- c("e", "n")
gridded(grid) <- T
str(grid); bbox(grid)
plot(coordinates(grid), cex=0.1, asp=1)

## interpolation
k.esp <- krige(sqrt(esp) ~1, loc=ds, newdata=grid, model=vm.esp)
spplot(k.esp, zcol="var1.pred", col.regions=bpy.colors(64), main="Sqrt(ESP), OK")
spplot(k.esp, zcol="var1.var", main="Sqrt(ESP), kriging prediction variance")

## cross-validation
k.esp.cv <- krige.cv(sqrt(esp) ~1, loc=ds, model=vm.esp)
summary(k.esp.cv)
bubble(k.esp.cv, zcol="residual", main="Cross-validation errors, sqrt(ESP)")

# can do the same for EC, no use for pH

#following instructions
k.ec<-krige(ec~1,loc=ds,newdata=grid,model=vm.ec)
spplot(k.ec,zcol="var1.pred",col.regions=bpy.colors(64),main="EC Ordinary Kriging")
spplot(k.ec,zcol="var1.var",main="EC, kriging prediction variance")

#Cross validation for EC
k.ec.cv<-krige.cv(ec~1,loc=ds,model=vm.ec)
summary(k.ec.cv)
bubble(k.ec.cv,zcol="residual", main="Cross-validation errors, EC")

#The end, but... let's make a summary for interpretation?
## Aditional info for EC
x=data.frame(k.ec.cv)
```

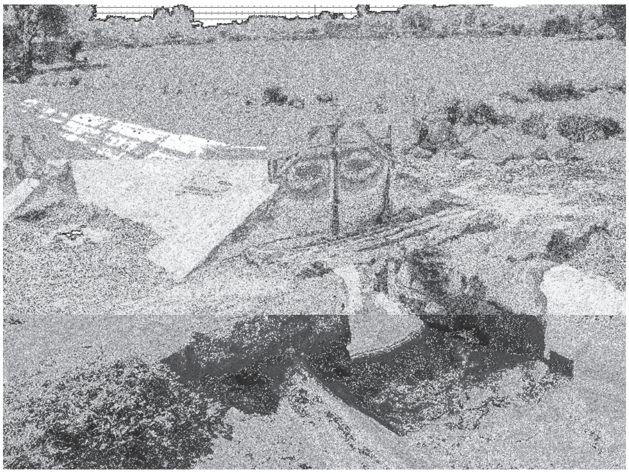
```
kk=data.frame(ME=c(0,mean(x$res)),MSNE=c(1,sqrt(sum(x$zscore^2)/length(x$res))),cor1=c(1,cor(
x$obs, x[,1])),cor2=c(0,cor(x[,1], x$res)))
row.names(kk)=c("expected EC", "estimated EC")
print(kk)

#Aditional info for sqrt(ESP)
y=data.frame(k.esp.cv)
mm=data.frame(ME=c(0,mean(y$res)),MSNE=c(1,sqrt(sum(y$zscore^2)/length(y$res))),cor1=c(1,cor
(y$obs, y[,1])),cor2=c(0,cor(y[,1], y$res)))
row.names(mm)=c("expected sqrt (ESP)", "estimated sqrt (ESP)")
print(mm)
#End
```

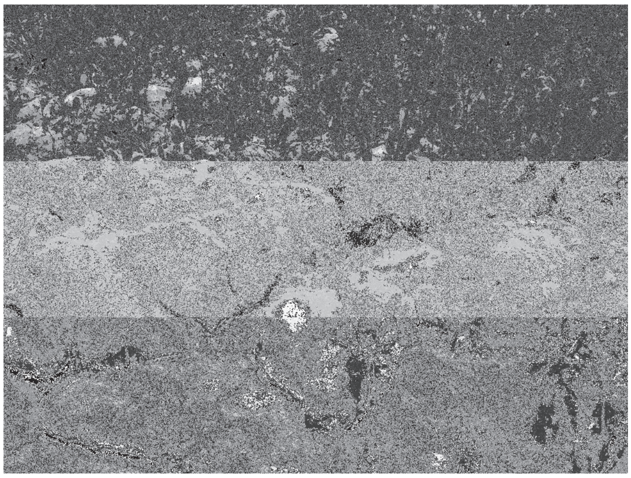
Appendix 8. Additional photos

Valverde chanel

Affected zone at the north of La Mayca



Current improvements in the irrigation infrastructure



Alfalfa plot with hardened surface

Affected zone at the Mayca Quenemari

Ryegrass beside the WWTP

Workgroup in workshop

Workgroup in workshop

Appendix 9. Field and lab data of soil sampling points

Field data

ID	XY	Cover_crop_1	Angostura	WWTP	Rocha	Tamborada	Valverde	Color
1	(798642.21, 8073866.68)	Alfa	1	0	1	0	0	Light brown
2	(798600.06, 8073601.67)	Rest	1	0	0	0	0	Light brown
3	(798305.82, 8073492.84)	Rest	1	0	0	0	0	Light brown
4	(797985.29, 8073518.50)	Alfa	1	0	0	0	0	Dark_brown
5	(798032.25, 8073986.71)	Corn	1	0	0	0	1	Dark_brown
6	(797590.49, 8074047.80)	Rest	0	0	0	0	1	Dark_brown
7	(797365.50, 8074083.93)	Rest	0	0	0	0	1	Dark_brown
8	(797348.24, 8073477.95)	Alfa	0	0	0	0	1	Dark_brown
9	(797282.81, 8073436.61)	Alfa	1	0	0	0	0	Light brown
10	(797659.94, 8073089.54)	Alfa	0	0	1	0	0	Dark_brown
11	(796863.40, 8072901.24)	Alfa	1	0	0	0	0	Light brown
12	(796833.84, 8074163.98)	Corn	1	0	0	0	1	Dark_brown
13	(796664.44, 8074167.99)	Grass	0	0	0	0	1	Dark_brown
14	(796584.41, 8073102.29)	Alfa	1	0	0	0	0	Dark_brown
15	(796190.12, 8073156.09)	Alfa	1	0	0	0	0	Light brown
16	(796077.90, 8073983.81)	Alfa	0	0	0	0	1	Light brown
17	(795341.15, 8073275.30)	Alfa	1	0	0	0	1	Dark_brown
18	(794805.51, 8073173.24)	Bean	1	0	0	0	1	Dark_brown
19	(794105.46, 8073219.76)	Rest	1	0	0	0	1	Dark_brown

20	(795050.17, 8072885.67)	Rest	1	0	0	0	1	Dark_brown
21	(795084.34, 8072607.82)	Rest	1	0	1	0	0	Yellow, grey
22	(795351.09, 8072449.84)	Rest	1	1	1	0	0	Grey
23	(795906.01, 8072483.56)	Alfa	1	1	1	0	0	Brown, redish
24	(796337.25, 8071847.79)	Rest	0	1	1	0	0	Dark_brown
25	(796382.94, 8072771.98)	Alfa	1	0	0	0	0	Light brown
26	(796835.57, 8071966.17)	Rest	1	0	0	0	0	Dark_brown
27	(797187.04, 8072402.47)	Alfa	1	0	1	0	0	Dark_brown
28	(797583.57, 8072840.91)	Corn	1	0	0	0	0	Light brown
29	(797439.53, 8071710.50)	Alfa	1	1	1	0	0	Dark_brown
30	(797841.59, 8071887.23)	Alfa	1	1	1	0	0	Light brown
31	(797807.71, 8072467.08)	Grass	1	1	1	0	0	Dark_brown
32	(798160.47, 8072141.71)	Alfa	1	1	1	0	0	Dark_brown
33	(798864.17, 8072224.86)	Grass	1	0	1	0	0	Grey_redish_spots
34	(797672.60, 8071592.84)	Grass	1	1	1	0	0	Dark_brown
35	(797015.38, 8071380.78)	Rest	0	1	0	0	0	Dark_brown
36	(796351.61, 8071393.73)	Rest	0	1	0	0	0	Grey
37	(796512.98, 8071561.89)	Rest	0	1	0	0	0	Dark_brown
38	(799024.22, 8071616.01)	Grass	1	1	0	0	0	Dark_brown
39	(799242.52, 8072168.73)	Alfa	1	1	0	0	0	Dark_brown
40	(797379.56, 8070929.70)	Rest	0	1	0	0	0	Grey
41	(796986.98, 8070778.56)	Rest	0	1	0	0	0	Grey_red_brown_spots
42	(796468.51, 8071088.18)	Grass	0	1	0	0	0	Grey
43	(796126.83, 8070922.92)	Rest	0	1	0	1	0	Dark_brown
44	(795217.25, 8071823.42)	Rest	0	1	0	0	0	Grey

45	(795314.20, 8071044.47)	Rest	0	1	0	0	0	Dark_brown
46	(793933.26, 8069597.66)	Alfa	1	0	0	0	0	Dark_brown
47	(793173.36, 8069583.08)	Corn	1	0	0	0	0	Light brown
48	(794329.98, 8069127.88)	Rest	1	0	1	0	0	Light brown
49	(794775.61, 8069157.04)	Alfa	1	0	0	0	0	Dark_brown
50	(795405.16, 8069699.67)	Alfa	1	0	0	0	0	Dark_brown
51	(795864.69, 8069980.27)	Rest	1	0	0	0	0	Dark_brown
52	(796445.56, 8070172.50)	Rest	1	0	0	0	0	Dark_brown
53	(797344.10, 8070150.88)	Grass	1	1	0	0	0	Dark_brown
54	(799597.64, 8069931.03)	Corn	1	0	0	0	0	Light brown
55	(798535.79, 8069011.21)	Rest	1	0	0	0	0	Dark_brown
56	(797784.15, 8068340.57)	Corn	1	0	0	0	0	Dark_brown
57	(797613.51, 8069337.57)	Rest	1	0	0	0	0	Dark_brown
58	(797188.50, 8069336.76)	Alfa	1	0	0	0	0	Dark_brown
59	(797903.63, 8070072.16)	Rest	1	0	0	0	0	Light brown
60	(798514.60, 8070116.95)	Rest	1	0	0	0	0	Light brown
61	(798813.32, 8069485.54)	Corn	1	0	0	0	0	Light brown
62	(799108.04, 8070659.15)	Alfa	1	0	0	0	0	Dark_brown
63	(799881.68, 8071118.20)	Rest	1	0	0	1	0	Dark_brown

Lab results

ID	XY	pH	EC (dS/m)	Ca (meq/L)	Mg (meq/L)	Na (meq/L)	K (meq/L)	SAR	ESP	Clay	Silt	Sand
1	(798642.21, 8073866.68)	8.3	1.252	3	2	11.97	0.17	7.57	8.83	36	52	12
2	(798600.06, 8073601.67)	7.4	0.869	3	1.5	5.19	0.07	3.46	3.66	32	57	11
3	(798305.82, 8073492.84)	8.3	1.466	2.5	1.5	13.17	0.02	9.31	10.82	46	47	7
4	(797985.29, 8073518.50)	8	0.617	2	1	3.2	0.13	2.61	2.51	52	33	15
5	(798032.25, 8073986.71)	7.6	0.669	2	2	5.6	0.33	3.96	4.33	40	47	13
6	(797590.49, 8074047.80)	8.3	1.639	3	2.5	16	0.07	9.65	11.2	36	45	19
7	(797365.50, 8074083.93)	8.7	6.955	1.5	0.5	82	0.02	82	49	36	51	13
8	(797348.24, 8073477.95)	8.4	1.622	4	2.5	12	0.2	6.66	7.74	38	45	17
9	(797282.81, 8073436.61)	8.3	1.423	3	1.5	13.2	0.05	8.8	10.25	38	43	19
10	(797659.94, 8073089.54)	8.1	0.866	2	1	7.2	0.01	5.88	6.79	32	55	13
11	(796863.40, 8072901.24)	8.4	0.873	2	2	6	1.17	4.24	4.7	24	51	25
12	(796833.84, 8074163.98)	7.7	1.063	2	1	9.2	0.03	7.51	8.76	18	47	35
13	(796664.44, 8074167.99)	7.2	0.957	2.5	1.5	7.2	0.08	5.09	5.8	19	54	27
14	(796584.41, 8073102.29)	8.1	1.93	3	3	13.4	0.01	7.74	9.03	24	55	21
15	(796190.12, 8073156.09)	8.2	1.194	2	1.5	10.4	0.01	7.86	9.17	22	49	29
16	(796077.90, 8073983.81)	8.6	1.474	2	1.5	15.6	0.01	11.79	13.48	25	48	27
17	(795341.15, 8073275.30)	8.1	1.065	1.5	1.5	12	0.03	9.8	11.36	36	46	18
18	(794805.51, 8073173.24)	8.2	10.134	18	9	100	0	27.22	26.44	20	45	35
19	(794105.46, 8073219.76)	8.7	9.405	1.5	3	116	0.03	77.33	47.8	34	47	19
20	(795050.17, 8072885.67)	8.4	13.161	13	17	148	0.8	38.21	33.08	31	46	23

21	(795084.34, 8072607.82)	8.5	7.07	26	13	31.92	0.27	7.23	8.43	13	39	48
22	(795351.09, 8072449.84)	8.8	8.28	3	4	75.81	0.07	40.52	34.28	29	46	25
23	(795906.01, 8072483.56)	8.7	18.4	3.5	6.5	160.6	0.8	71.82	46.27	23	55	22
24	(796337.25, 8071847.79)	7.9	24.9	22	28	240	2.3	48	37.81	45	37	18
25	(796382.94, 8072771.98)	8.3	0.784	1.5	3	3.6	0.03	2.4	2.21	23	48	29
26	(796835.57, 8071966.17)	7.9	40.3	9	14	490	1.83	144.49	59.64	57	30	13
27	(797187.04, 8072402.47)	8.1	0.664	2	1	2.8	0.02	2.29	2.05	33	50	17
28	(797583.57, 8072840.91)	8.4	0.846	1.5	1.5	5.5	0.25	4.49	5.03	43	40	17
29	(797439.53, 8071710.50)	8.1	0.91	1	2	6.2	0.03	5.06	5.76	35	44	21
30	(797841.59, 8071887.23)	8.4	2.51	2.5	2.5	19	0.2	12.02	13.71	35	52	13
31	(797807.71, 8072467.08)	8.4	2.31	3.5	2.5	15	0.03	8.66	10.09	35	54	11
32	(798160.47, 8072141.71)	7.9	13.27	32	21	88	0.03	17.09	18.56	23	48	29
33	(798864.17, 8072224.86)	7.9	17.53	32	23	128	1.17	24.41	54.46	56	37	7
34	(797672.60, 8071592.84)	8.2	10.32	10	10	92	0.77	29.09	27.7	16	43	41
35	(797015.38, 8071380.78)	7.4	10.07	19	16	80	0.13	19.12	20.31	16	51	33
36	(796351.61, 8071393.73)	8	18.78	21	29	190	1.3	38	32.97	50	43	7
37	(796512.98, 8071561.89)	8.4	2.2	3.5	3.5	13	0.05	6.95	8.09	32	45	23
38	(799024.22, 8071616.01)	8.9	8.65	2	2	92	0.02	65.05	44.21	26	51	23
39	(799242.52, 8072168.73)	7.8	0.869	3	1.5	4.8	0.03	3.2	3.31	24	49	27
40	(797379.56, 8070929.70)	8.4	21.5	5	8	240	0.01	94.14	51.76	26	53	21
41	(796986.98, 8070778.56)	8.2	12.198	14	10	111.72	1.27	32.25	29.69	38	39	23
42	(796468.51, 8071088.18)	6.9	1.667	6	4	12.77	0.2	5.71	6.58	12	38	50
43	(796126.83, 8070922.92)	9.2	19.765	1.5	3.5	263.34	0.01	166.55	61.97	12	34	54
44	(795217.25, 8071823.42)	7.9	6.73	11	7	72	0.02	24	24.15	12	44	44
45	(795314.20, 8071044.47)	8	16.425	8	7	200	0.01	73.03	46.62	20	65	15

46	(793933.26, 8069597.66)	8.3	6.741	2.5	2	88	0.03	58.67	42.03	18	22	60
47	(793173.36, 8069583.08)	7.8	1.263	2	2	14	0.02	9.9	11.47	26	36	38
48	(794329.98, 8069127.88)	7.2	0.717	1	2	6	0.1	4.9	5.55	24	26	50
49	(794775.61, 8069157.04)	7.4	0.44	1	3	2	0.05	1.41	0.82	18	20	62
50	(795405.16, 8069699.67)	7.8	0.548	2.5	2.5	2	0.1	1.26	0.6	23	17	60
51	(795864.69, 8069980.27)	7.8	17.567	20	14.5	195	0.27	46.95	37.34	37	41	22
52	(796445.56, 8070172.50)	8.2	14.488	6	8	175	0.1	66.14	44.55	29	22	49
53	(797344.10, 8070150.88)	7.8	2.943	4	3.5	25	0.05	12.91	14.62	32	20	48
54	(799597.64, 8069931.03)	7.6	0.498	1	2	3.2	0.1	2.61	2.51	24	20	56
55	(798535.79, 8069011.21)	7.7	0.415	1	1	2.5	0.17	2.5	2.35	30	38	32
56	(797784.15, 8068340.57)	8.7	7.682	2.5	2	90	0.13	60	42.51	68	16	16
57	(797613.51, 8069337.57)	8.1	1.337	1	2	12	0.03	9.8	11.36	40	26	34
58	(797188.50, 8069336.76)	8	1.465	1	2	15	0.1	12.25	13.95	38	20	42
59	(797903.63, 8070072.16)	7.7	2.953	5	4	25	0.07	11.79	13.47	41	20	39
60	(798514.60, 8070116.95)	8.3	4.804	4.5	3.5	58.5	0.27	29.25	27.8	35	38	27
61	(798813.32, 8069485.54)	8.2	1.562	3	1.5	14	0.37	9.33	10.85	23	22	55
62	(799108.04, 8070659.15)	8.2	0.8	1	1	7.5	0.33	7.5	8.75	47	39	14
63	(799881.68, 8071118.20)	7.8	21.25	25	25	205	0.07	41	34.52	33	51	16