Correlation of groundwater with the urban area of Piura (North - western of Peru)

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Abstract

Piura is the second department of Peru which has the biggest number of population. According to National Institute of Statistics and Informatics, this department has 1 676 315 persons, Census 2007. The area of analysis is Piura and Castilla Districts which make up the City of Piura. Across the years, the population of Piura has been using groundwater to satisfy their needs without knowledge of the aquifer and how they are relate to the urban area.This report show, such as using Geographic Information Systems (GIS) has been linked surface lithology of the study area with groundwater information. In order to raise the first foundations for future development of Water Management Plan for the city of Piura.

Keywords

Groundwater, urban area, surface lithology, geographic system information

1. Introduction

The world population is currently slightly more urban than rural. According to the United Nations is expected to increase by 84 per cent by 2050. Virtually all of the expected growth in the world population will be concentrated in the urban areas of the less developed regions [1, United Nations]. Piura is the second department of Peru, located in the semiarid coast of this country, which has the biggest number of population [2, INEI], concentrated especially in urban areas.
The city of Piura – capital of department- is made up of the districts of Piura and Castilla (Figure 1), and presents desert weather with a range high temperature of 33°C and low temperature of 16°C [3, SENAMHI]. It has low precipitation occurs except when the phenomenon “El Niño” appears. This phenomenon was varied annual rainfall of 120 mm to 3000 mm annual.

In terms of geology, Piura is located in the far north of the basin Sechura and the stratigraphy corresponds to a sequence of sediments arranged in alternating rocks. These sediments belong from Tertiary Upper Miocene to Quaternary Recent, emplaced over with basement of Cenozoic in Metamorphic Complex of the Coast [4, INGEMMET] with the presence of groundwater.

Given the emerging urban growth in the study area, an overview of the urban hydrogeology of the region is necessary, taking account their hydrological and geological characteristics, because it allows knowing how the behaviour of the water in the soil is.

In this particular research, the topic of interest is to understand the interaction of groundwater in the urban environment of Piura. Being of particular interest to know the relationship between groundwater levels and urban structures, it is also of interest the relationship between water extractions and land subsidence.

Figure 1. Map of departments of Peru. The darkest department is Piura.

1.1 Groundwater levels and urban structures

This interaction has two important aspects: how the structures modify the natural flow and quality of groundwater [5, Schimer M.] [6, Diamond M.] and how groundwater circulation threatens structures (be considered separately ascent or descent of the groundwater). [7, Poland J.]

In coastal cities, the descent of groundwater can cause an additional problem because it can facilitate saltwater intrusion, and this would imply that seawater can contact with metal foundations and buried structures causing salt water corrosion.

The presence of trembling or earthquakes in areas with high groundwater levels present can produce problems of liquefaction or siphoning. The land may experience problems siphoning are saturated sands, particularly loose sands with high porosity. [8, Fundación Centro Internacional de Hidrología Subterránea]

1.2 Water extractions and land subsidence

Subsidence is the downward movement of the ground surface where the lateral displacement is of secondary importance. Subsidence caused by consolidation, which is the reduction of soil volume due to the expulsion of water, is not instantaneous - may take up to months or years -and it should be emphasized that it is not reversible.

Damage caused by subsidence phenomenon is usually important because they can cause subsidence affecting the structures of a city if they are not adequately controlled. [9, Custodio E. and Llamas M.]

2. Groundwater in Piura

Peru has 5% of drinking water in worldwide. However, it exist a contrast in the distribution demand - supply of water and adding the mismanagement of this resource, has created shortages and lack of supply in various parts of the country.[10, Palacios Claudia]
The availability of water of adequate quality is a problem that is particularly affecting arid and semi-arid areas such as the north coast of Peru.

The intermittent availability of water and high sensitivity to extreme events such as droughts or inundation are indicative of the relevance of realise several studies. In order to understand groundwater sources, mapping, classifying aquifers; and in conjunction with surface water to achieve a responsible future urban planning of the city.

Also have to be considered, the existence of a growth trend of population in the city of Piura (Figure 2). Because the idea of water scarcity to satisfy all the necessities of a population has been questioned by Llamas Madruga almost two years, ensuring that the problem is not physical water scarcity but mismanagement.

The opinion of this author has been supported by the conclusion that was reached in 2004 during a seminar on "The Water Crisis: Myth or Reality" (seminar organized by the Marcelino Botín Foundation, Harvard University and Complutense University of Madrid).

Worth noting, a good water management must be focus on the following objectives: to meet the water needs of the population and economics activities, control water demand and respect the medium-environmental values. Focusing in a good management of aquifers is important to consider: to meet the needs of real demand, an available scientific and technical knowledge as well as trained personnel, and authority to coordinate, prioritize and act independently. [11, Fundación Internacional de Hidrología Subterránea]

In the specific case of Piura, there is a percentage of the population that is supplied by surface water and the other is supplied by groundwater. It must begin to consider, the combined use of surface and groundwater resources as a philosophy of water management. This requires a knowing of the aquifer and the quality of its water, which allow a future planning of sustainable development, and prevent groundwater contamination or depletion in the long term due to excessive extraction.

The basis of this knowledge requires knowing how to influence groundwater to the urban environment, and how the variation in groundwater levels can affect in different ways to a city.

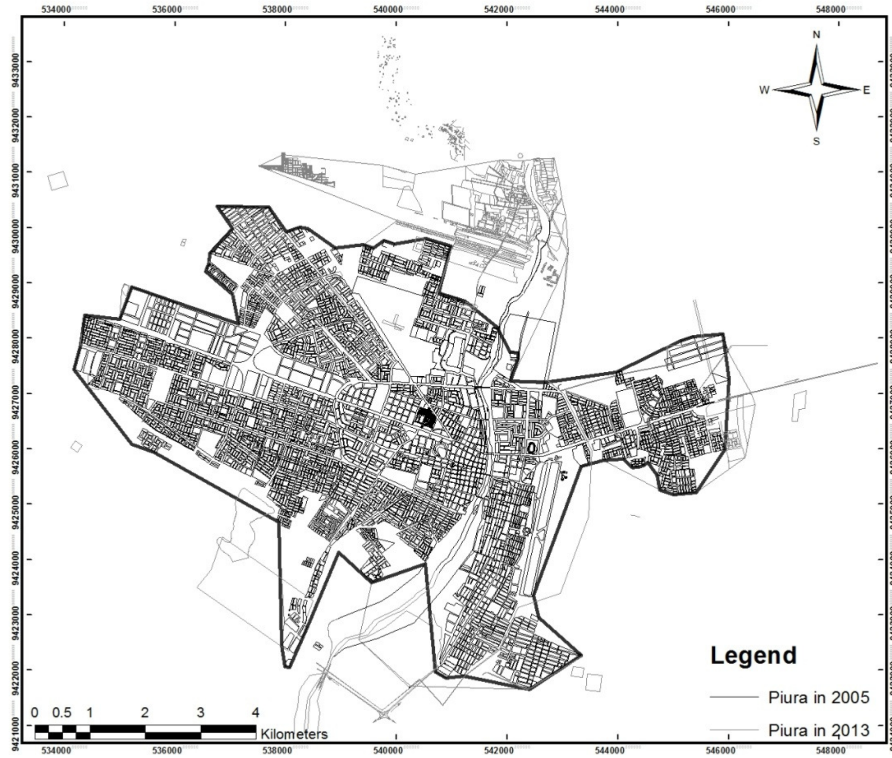

Figure 2. Development of the city of Piura. In black, it shows Piura in 2005 and in grey it is Piura in 2013.

3. Methodology of the project

For the development of this database, it has had to gather information and make a selection of it, for further structuring of the database based on the expected products. It was also necessary to perform a suitability of this information to have better control of it to enter it in ArcGIS. After entering the information analysed with precision and clarity.

To build this database, it was necessary to seek information on the lithology of the study area; so we have used the reports prepared by the Testing Laboratory for Building Materials (LEMC) University of Piura. Have also been used reports LEMC used in titling project "Implementation of GIS as a tool for prevention of geotechnical hazards in the city of Piura" made in 2008, because these reports are also available in the area analysis of this project.

Other interesting and necessary information, for this database, was information on wells that are located in the city of Piura, in order to have data for water levels in the deep aquifer formations, as well as quality same.

That is why; it has resorted to state enterprises and private companies, in order to have a greater amount of information for further analysis to be performed. While searching for information on various institutions, it has been observed that the existing information on the wells that are currently located in the city of Piura is scarce.

Likewise, it has been based on the Cadastral and Urban Piura plane provided by the Municipality of Piura; in order to geo-reference all information in this database. Regarding the altimetry information, this project has employed the same plane Contour that was used in the titling project

"Implementation of GIS as a tool for prevention of geotechnical hazards in the city of Piura" made in 2008.

Maps of the city of Piura, was also digitized at different periods of time in order to show more clearly the growth of this city. This is due to urban expansion was made mostly of disorganized and often without a study of this medium.

3.1 Selection of information

All information gathered has been selected using different criteria, depending on the objectives in this research.

The first selection process by which spent LEMC reports has been under the criterion of belonging or not to the area of study in this project. The second step was performed, was a cross-checking to avoid repetition of information because the information came from various sources. This cross-checking has been tedious and complicated because the information was in different formats and when repeated information was prevailed information coming from the source that had higher degree of reliability over the other.

The Cadastral and Urbanisation Piura plane is the union of several plats of the various areas of Piura, made at different times depending on how the city was expanding. And it is for this reason that had given up a lot of layers within the AutoCAD program; not afforded all relevant information for this project. Hence they have been refined certain layers, so that they can only observe the most important information in this case being developments with names.

3.2 Structuring of the information

The GIS will provide added value to the information generated, because they allow better control and management of the same, will also serve as a source of information for future studies. This better control of information is that the information must be organized in several tables to be admitted to the program.

The methodology followed to extract information from stratigraphic profiles in two steps: First, you have to see that type of information provides each stratigraphic profile; if the value of its surface elevation is counted as is the distribution of the different stratigraphic layers present in the profile.

Secondly, one can determine the thickness of these stratigraphic layers and you can also see if the profile is has a greater distribution of sand, clay or gravel. Could also appreciate the existence of areas of filler in said profiles, which is an indication that some areas before they have been used as built-up deposits. Figure 3, shows one example of the stratigraphic profiles that have been part of the information used.

All this information has been extracted from the stratigraphic profiles, has been structured database table so that you can have better control and management of the same. Also were obtained from reference coordinates via Google Earth.

Regarding the information wells, these are organized in a matrix table. This matrix table is has a unique ID assigned to each well, which allows us to relate this matrix table with other tables containing more detailed information from the wells.

Also this matrix table allows us to know the coordinates of the wells, the year of drilling, the kind of well, if these wells have water quality data, groundwater levels and profiles. Using the ID of the parent table, we have related the overview of wells with more specific information regarding water quality and levels are organized in other tables according to the year in which the test was performed.

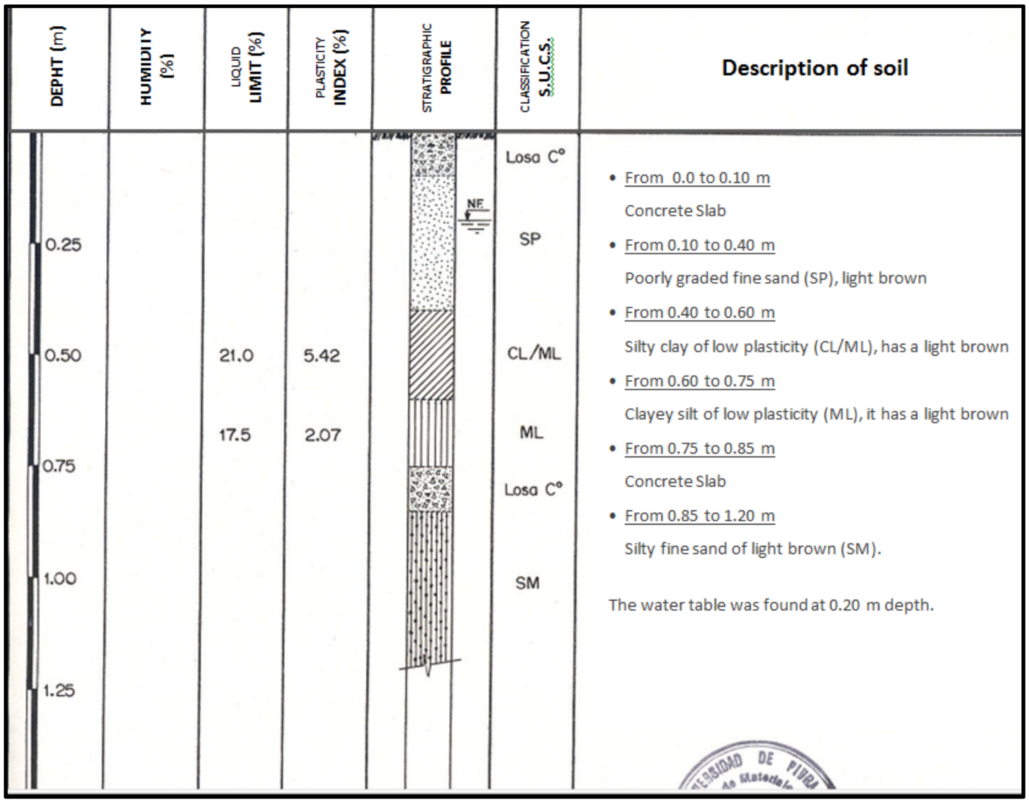

Figure 3. Example of the stratigraphic profiles used in this project.

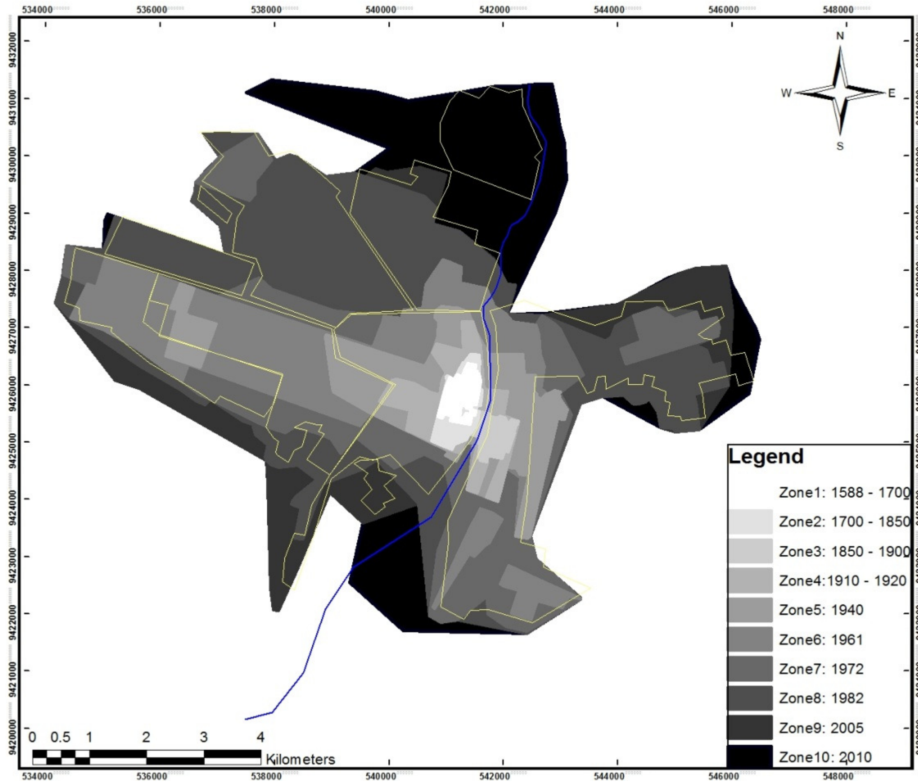

Figure 4. Expansion zones of the city of Piura

Digitized information growth of the city was structured into zones, with each zone representing Piura in a different time period and this be seen as it has been expanding. The time periods chosen zones are: Zone 1 (between 1588-1700), Zone 2 (Between 1700-1850), Zone 3 (Between 1850-1900), Zone 4 (1940), Zone 5 (1961), Zone 6 (1972), Zone 7 (1982), Zone 8(1999), Zone 9 (2005) and Zone 10 (2013) like it shows Figure 4.

3.3 Adaptability of information

To enter the information to GIS was necessary to convert everything to the same coordinate system because the information was collected in different coordinate systems.

Our country has officially adopted the system of Universal Transverse Mercator (UTM) for the lifting of the National Mapping at different scales. [12, Instituto Nacional Geográfico] Therefore, in this project we have worked under the WGS84 coordinate system

3.4 Incorporation of information

At this GIS database are incorporated, first, the Cadastral and Urbanisation Piura plane to any other information which may come to be added relates to the urban environment of Piura.
To incorporate information from stratigraphic profiles has had to split the structured information in the base table by type of land found: sand, filling areas, clay, gravel, and colluvial soils.

For each type of terrain have built a table that gives us more accurate information for each stratum of land found. It should be noted that not all reports had the data of the surface level of the ground, which is the reason why we have used the tool "Add" of ArcGis to calculate these values and thus have the coordinates of all strata analysed.

Once the surface heights of all stratigraphic profiles are known, we know the upper and lower bounds for each of the strata founded. This will allow us to draw the layers of different soil types in ArcGIS and be able to better evaluate available under the City of Piura and how water is inside them.

To draw these strata was used IDW interpolation tool (Inverse Distance Weighted) of the toolkit because AcrGis and graphical results are different when different types of interpolation are applied, explain how the method works.

To incorporate information from the wells, he added first Matrix table so you can see the position of these wells on the Cadastral and Urbanisation Piura plane. The ID that is assigned to each well depends on your location, if the well belongs to the district of Piura your ID is a number from the number 100 and if it belongs to the district of Castilla your ID is a number from the number 200.
The best way to add to our database the most detailed information on water quality from the wells, was using different tables where each had quality values found in the different years of analysis.

4. Analysis of the information

In any study it is just not enough a good organization of the information obtained, it is necessary to analyse this information so you can provide some contribution to the knowledge with which it previously had. Being something special of study of groundwater, the object of study is not within sight and interpretations are made through data points.

4.1 Surface lithology

Taking into account the information obtained from stratigraphic profiles we have found the following types of terrain: sand, fill areas, clay, silts, gravel and colluvial soils. In the following analysis will not be considered colluvial soils and gravel due to the little information found on these.

Type of terrain	Found close to the surface in	Expansion zones
Sands	North - western	Zone 6,7,8 and 9
Filling areas	North - western	Zone 8
Clays	North - western	Zone 6,7 and 8
Silts	West	Zone 3 and 4

Table 1. Types of terrain and their position close to the surface.

Table 1 shows the different types of land, the part of town where they are closer to the surface and the expansion area where belongs the part near surface.

It can be seen in Figure 5 that, the highest level of the upper layer is 41.63 m.a.s.l. and as we approach the river (south-east side of the city) this layer is deeper and deeper until you reach the lowest level of the lower layer is 7.95 m.a.s.l. In the stratum thickness keep uneven, generally has an average thickness of 1.81 meters, but there are areas where the thickness is greatly increased, has come to find a maximum thickness of 9.80 meters.

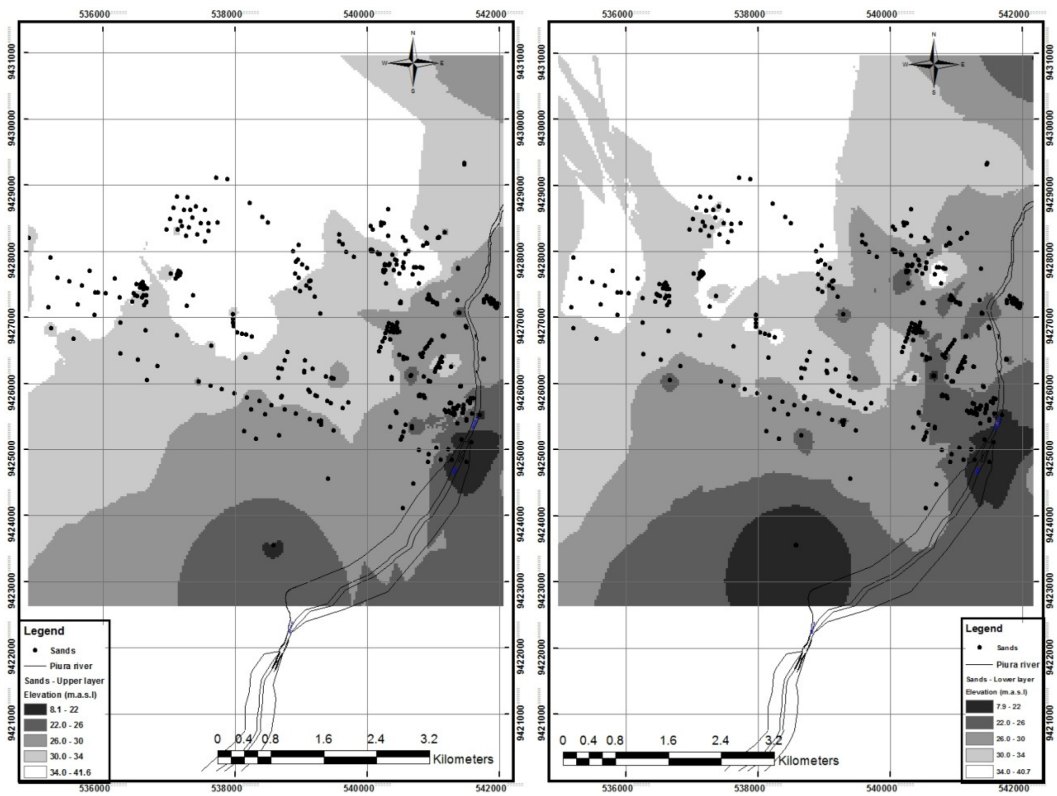

Figure 5. Comparison between the upper and lower layer of sand stratum.

It is observed in Figure 6 that, this stratum is close to the surface and not as deep as the stratum of sand, with a maximum height of 41.75 m.a.s.l. of the upper layer and the minimum height of the lowest layer 19.06 m.a.s.l. The average thickness of this stratum is 0.64 meters, which indicates that it is less than the sand layer thickness. This may be due to infill areas are generally anthropogenic.

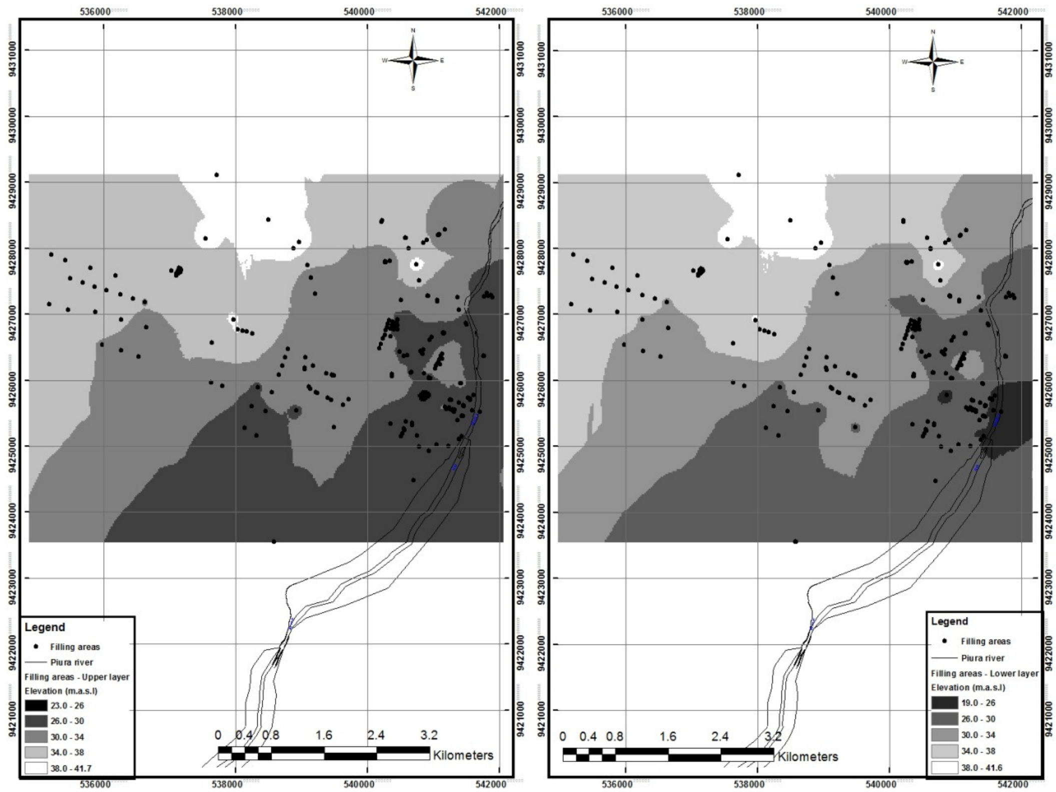

Figure 6. Comparison between the upper and lower layer of filling areas.

It can be seen in Figure 7, that this stratum is close to the surface in the north west of the city and do not deeper very far as we go south-east of the city, except for a certain part of the river where we found the lowest levels. The average thickness of this stratum is 1.00 meters, and a layer thicker than the areas of filler but thinner than the sand. The maximum high of the upper layer of this stratum is 40.71 m.a.s.l. and the minimum height of the lower layer is 4.15 m.a.s.l.

From what can be seen in Figure 8, this stratum is near the surface on the west side of town and deepened significantly in some area of the river south-east of the city. The average thickness of this stratum is 1.19 meters, where the maximum height of the top layer is 38.99 m.a.s.l. and the minimum height of the lower layer is 1.55 m.a.s.l.

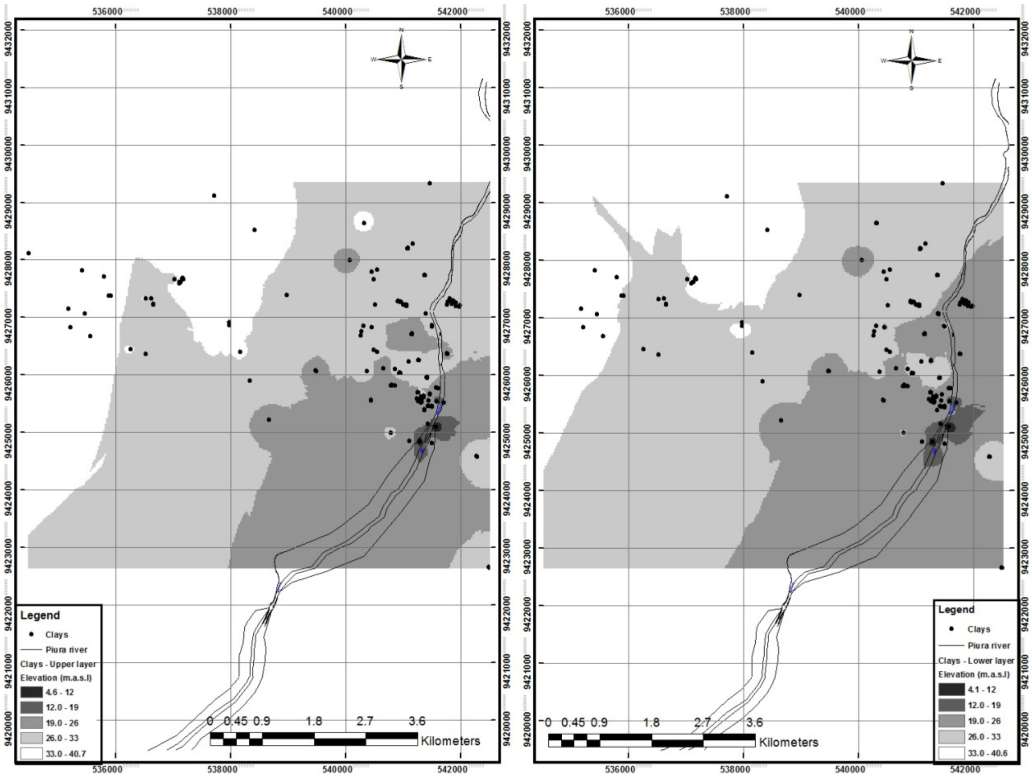

Figure 7. Comparison between the upper and lower layer of clays stratum.

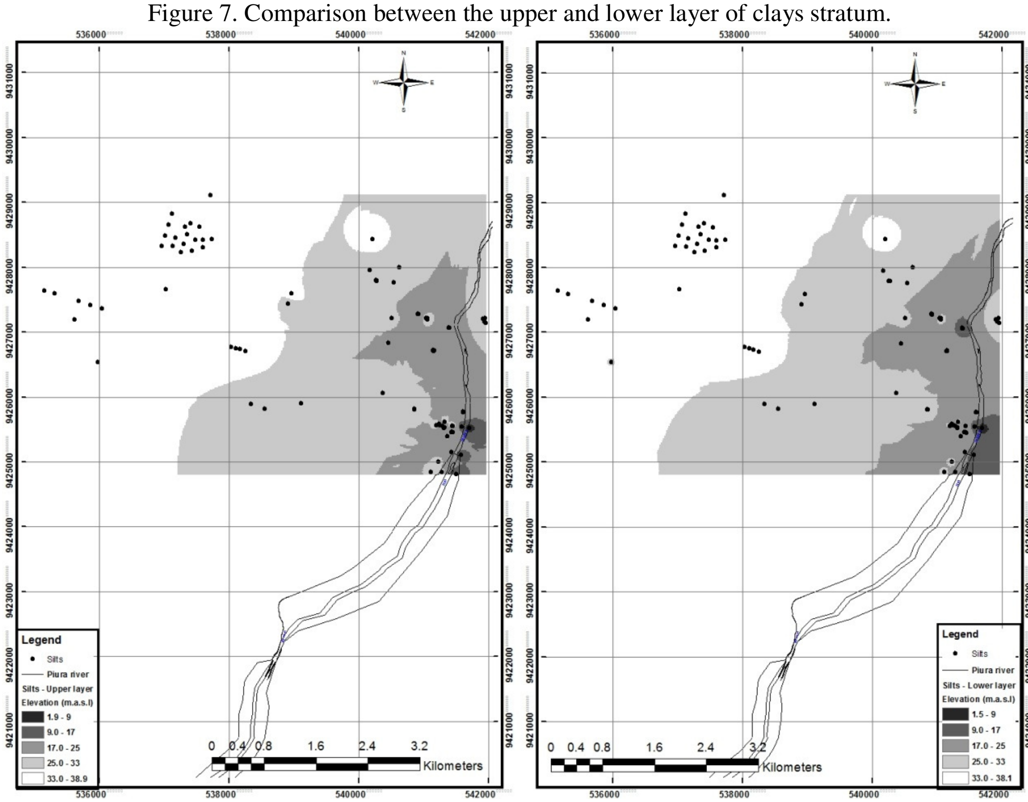

Figure 8. Comparison between the upper and lower layer of silts stratum.

4.2 Relationship: Groundwater levels – Surface lithology

Analysing groundwater levels taken during 1994 in Piura with the geomorphology of the study area. It has been found that the values of groundwater levels range from 1 meter deep in the nearest to the centre of Piura areas up to 8 meters deep in remote areas such as urbanization Piura, urbanization “Los tallanes” and human settlement “Santa Julia”. In the urbanization Los AVIFAP Gardens (area surrounding the University of Piura) the water table near the average value to 4.53 m depth was found.

Significantly, in 1992 occurred the phenomenon El Niño in Peru, so these values of groundwater levels are affected by the phenomenon occurred two year before the groundwater levels were taken.

In addition, we analysed the study area two meters deep to see which types of land are at that depth. Analysis is important at this depth, since most of the foundations of the various built structures reach a depth of two meters in the experience of different consulted sources that are dedicated to the construction of buildings.

The importance of this analysis is also based on diverse backgrounds and ground observations of the city of Piura, which come to the same conclusion: the city has very favourable conditions for the development of the phenomenon of soil liquefaction. [13, Pinto Zegarra]

On the south-eastern part of the expansion zone 6 groundwater levels are close to the deep foundation; this being a risk in case of an earthquake as the sands there present could originate liquefaction of the ground. In north-western case in the expansion zone 6 and 7 groundwater levels are 4 - 6 meters below the foundations.

4.3 Quality parameters of groundwater

The risk of contamination of groundwater is relative; it depends on the effectiveness of the hydrogeological media to mitigate pollution, types of pollutants, the process of contamination and the use to which these waters are intended. [14, Banco Mundial]

That is why in order to analyse the quality of groundwater in the study area over time, we will focus on the following physical parameters: turbidity, pH, hardness, electrical conductivity (EC) and with respect to chemical parameters we will focus on Chlorides and sulphates.
The turbidity of the water is difficult to transmit light, this property is responsible for measuring the content of colloidal matter and matter very thin and difficult to settle and filter out suspended. And according to the environmental quality standards for water in Peru a maximum allowable limit of 5 NTU (Nephelometric Turbidity Unit) is supported. [15, Decreto Supremo N° 002-2008-NINAM]

By comparing different years (1993,2011.2012 and 2013) can see that has been an increase in water turbidity especially in the north around the river and in the north-west of the city. While the values of turbidity not exceed the maximum allowable limit, they have increased considerably from 0.799 to 4.24 NTU.

The hydrogen ion concentration $[H^+]$ is a very important figure but to avoid using very small numbers using pH defined as pH = -log <H +>. The pH value increased by 8% / ° C as the temperature increases, that why it must be refer to a given temperature. Usually the range of values in which it varies from 6.5 to 8, where the seawater has a pH 8.

Comparing the years 1993, 2011, 2012 and 2013, the pH values are within the average range and minimum and maximum values vary due to variations in temperature experienced in those years. Hardness measures the ability of water to consume or produce soap deposits and is identified with the alkaline ion content, essentially Ca and Mg. According to the environmental quality standards for water in Peru a maximum permissible limit of 500 mg / L for drinking water is allowed.

Comparing the years 1993, 1998, 2011, 2012 and 2013, can be seen that despite the decrease in the water hardness areas still exist where the maximum allowable limit is exceeded. It is important to reach his maximum allowable value, because hard water produce large consumption of soap and difficult of cooking food. However, also keep in mind that the very soft waters are aggressive and may not be very suitable for human consumption.

Electrical conductivity is the ability of water to conduct electricity, and this increases as a function of temperature 2% / ° C so it is necessary to take a reference temperature. It is also a function of the dissolved ion concentration and type of ions found. According to the environmental quality standards for water in Peru a maximum permissible limit of 1500 mS / cm is supported.

Comparing the years 1993, 2004, 2011, 2012 and 2013 respectively; we realize that there are still several wells that do not comply with the maximum allowable limit.

The chlorides are very soluble, very stable in solution and hardly to precipitate. The maximum permissible limit in Peru, according to the environmental quality standards for water is 250 mg / Comparing the yeas 1993, 2011, 2012 and 2013, can see that few wells within the city of Piura which meet the quality standard, and although the chloride content is not harmful to a few thousand mg / l brackish taste not provide consumption.

Sulphates are moderately to highly soluble, and are difficult to be precipitated chemically. The waters with high sulphate content, does not quench thirst and have unpleasant and bitter taste. The maximum permissible limit is 250 mg / l according to the environmental quality standards for water is 250 mg / l.

Comparing the years 1993, 2011, 2012 and 2013, can observed that it has decreased the number of wells which are not met to the maximum allowable value but should be made to comply with this value as high sulphate concentrations are harmful to health.

5. Conclusions

It is clear the importance of the relationship: groundwater with urban area and the need it to study to achieve an adequate future water management plans for the City of Piura.

In the expansion areas dominated in different way the strata of sand, clay, silt and fill areas; this knowledge remains important to project a proper urban planning analysis area. The sand layer is the layer which is closer to the surface; so that for the construction of buildings areas where the groundwater level rises because of the phenomenon El Niño or in areas where the groundwater level is always close to the surface must be considered.

Until today, not have data on the level of subsidence in the area, which would be cause for further study.

Monitoring water quality, especially in the human consumption, is important because high contents of sulphates or chlorides can be harmful to health. Also, we must not forget that physical characteristics with a good indicator of water quality we have.

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