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Articles

Classification of aquifers in the Mina field, Nuevo Leon, using geographic information systems

Tipificación de los acuíferos del campo Mina, Nuevo León, utilizando sistemas de información geográfica

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Abstract

This paper studies the availability of groundwater from the "Campo Mina" aquifer, located in the state of Nuevo Leon, Mexico for the agro-industrial planning of the Bravo-San Juan sub-basin. The methodology consists of compiling data derived from remote sensors and geographic information systems for the agroindustrial planning of the Rio Bravo-San Juan sub-basin under a climate change context. Remote sensing and GIS data were used to delineate potential groundwater zones. Several maps (such as: topographic map, geological, hydrogeomorphological, structural, relief dissection, slope map, groundwater) were processed using remote sensing data along with other existing maps. The availability of groundwater of the aquifer was classified qualitatively in different classes (ie, very good, good, regular, poor and zero) depending on their hydro-geomorphological conditions. The groundwater availability map of the Mina field, Nuevo León, was elaborated considering maximum and minimum precipitation as well as the climatic classification of Köppen modified by García (2004) and adjusted for the conditions of northeastern Mexico. The sedimentary wedges of the quaternary alluvium (free aquifer), shale limestone piedmont as well as limestone hills were successfully delineated to show groundwater potential for each formation.

Keywords: Groundwater, remote sensing, geographic information systems, municipality of Mina, GvSIG.

Resumen

El objetivo de este estudio es explorar la disponibilidad del agua subterránea del acuífero número 1908, Campo Mina, estado de Nuevo – León, México para la planificación agroindustrial de la subcuenca río Bravo-San Juan, utilizando datos derivados de sensores remotos y sistemas de información geográfica para la planificación agroindustrial de la subcuenca río Bravo-San Juan bajo contexto de cambio climático. Los datos de teledetección y sistemas de información geográfica se utilizaron para delimitar las zonas potenciales de agua subterránea en la sub-cuenca del río Bravo. Los mapas: topográfico, geológico, hidrogeomorfológico, estructural, de disección del relieve, de pendientes y de agua subterránea, se procesaron utilizando datos de teledetección junto con otros mapas existentes. La disponibilidad de agua subterránea del acuífero se clasificó cualitativamente en diferentes clases (de muy buena a nula) en función de sus condiciones hidro-geomorfológicas. El mapa de disponibilidad del agua subterránea del campo Mina, se elaboró considerando los máximos y mínimos de precipitación así como la clasificación climática de Köppen pero modificada por García (2004) y ajustada para las condiciones del noreste de México. Las cuñas sedimentarias del aluvión cuaternario (acuífero libre), los piedemonte de caliza con lutita así como las colinas de caliza fueron delineadas con éxito para mostrar la potencialidad de agua subterránea de cada formación.

Palabras clave: agua subterránea, percepción remota, sistemas de información geográfica, municipio de Mina, GvSIG.

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Introduction

Groundwater is that which occupies all the empty spaces within a geological stratum (Kasenow, 2001: 27), it is the water that is below the water table in soils and geological formations (Arizabalo and Díaz, 1991). Geological formations that contain water in the earth's crust act as communicating vessels or as reservoirs to store water. The presence of groundwater in a geological formation and the possibilities of its exploitation depend mainly on the porosity of the formation. In the presence of interconnected fractures, cracks, joints, solution cavities or crushed areas (for example, shear zones such as the Acambay graben in the State of Mexico), rainwater can easily filter through them and join the waters underground So to estimate potential groundwater areas it is necessary to conduct field studies.

However, with the advent of remote sensing and geographic information systems (GIS), the mapping of groundwater potential zones in a given geological unit has become a more precise procedure (Maidment, 2002). The groundwater conditions vary significantly depending on the slope, depth, erosion, the presence of fractures, the presence of bodies of water, irrigation channels or fields, and so on. These and other factors such as lithological substrate and halophytic contamination can be interpreted or analyzed through a GIS using remote sensing data. Fan, Li and Miguez-Macho (2013) through the use of geocoded images from satellite sensors, has created a global hydro-geomorphological map to estimate in quantitative terms the groundwater level of the areas with groundwater potential worldwide.

Minor, Carter, Chesley, Knowles, and Gustafsson (1994) developed an integrated interpretation strategy to identify and typify the places and their type of groundwater in Ghana using a GIS. Gustafsson (1993) has used GIS in the analysis of data derived from Spot images or infrared remote sensing to map the potential of groundwater based on certain geohydrological characteristics detected. To evaluate the availability of groundwater in the northwest district of Florida, Richards, Roaza, and Pratt (1996) relied on a GIS, thereby achieving a spatial analysis of the data. Krishnamurthy, Venkatesa, Jayaraman and Manivel (1996) has developed a GIS to model and delimit potential areas to extract groundwater from the Marvdaiyar basin, Tamil Nadu, India, by integrating different maps or thematic layers derived from remote sensing data. Field verification of this model confirmed the effectiveness of GIS in delimiting the potential and reserves of groundwater. The application of GIS to know the availability of groundwater has also been carried out by Teevw (1995) and Sander (1997).

A geohydrological model was developed by Das, Behera, Kar, Narendra, and Guha (1997), to logically deduce areas with a high probability of harboring groundwater near the Sali River, Bankura district, West Bengal, India. In this case, the analysis could be carried out thanks to the efficient use of thematic layers (such as: geology, geomorphology, drainage density, slope as well as maps of land use and land cover) that were processed through the application of territorial analysis tools included in free software such as: GvSIG, QuikGrid, and other patent software such as Surfer 10 and 3D Route Builder. It should be noted that through remote sensing it is possible to know the geohydrological state of the groundwater, so that artificial recharge of geological structures can be induced or planned, such as: percolation tanks, containment dikes. For example, in the case of sub-basin of the Bravo-San Juan River, it is tried to locate with precision in which areas of the upper basin, the infiltration is more efficient for the recharge of groundwater, with a view to optimizing the administration of the vital liquid, since currently while the water of the Mina field, contributes to the development of the metropolitan area of the city of Monterrey, the inhabitants of the municipality of Mina suffer from water scarcity.

Description of the study area

The aquifer number 1908, called Campo Mina, of the state of Nuevo León (N. L.), Mexico is the most important underground water supply center in the city of Monterrey. Now, considering the rapid growth of the population and the increase in urbanization, and consequently, the increase in the demand for water in the conurbated and industrial zones, it is of capital importance to know in detail its geo-hydrology.

Although there is a growing awareness of the need to take care of water resources in order to maintain the required environmental balance, the high interdependence between water users and the availability of this liquid in the subsoil is still unknown, because only water is known. schematic level the movement of groundwater within the hydrological cycle of NL

At the southeastern end of the Rio Bravo basin, there is the Rio Bravo-San Juan sub-basin, in the northern part of this sub-basin the micro-basin of the El Potrero river is located, which is the extraction area of the Mina field. Topographically it is located about 36 km northwest of the city of Monterrey, N. L., Mexico. The upper part of the El Potrero river basin was considered for the study of the Mina field (Figure 1).

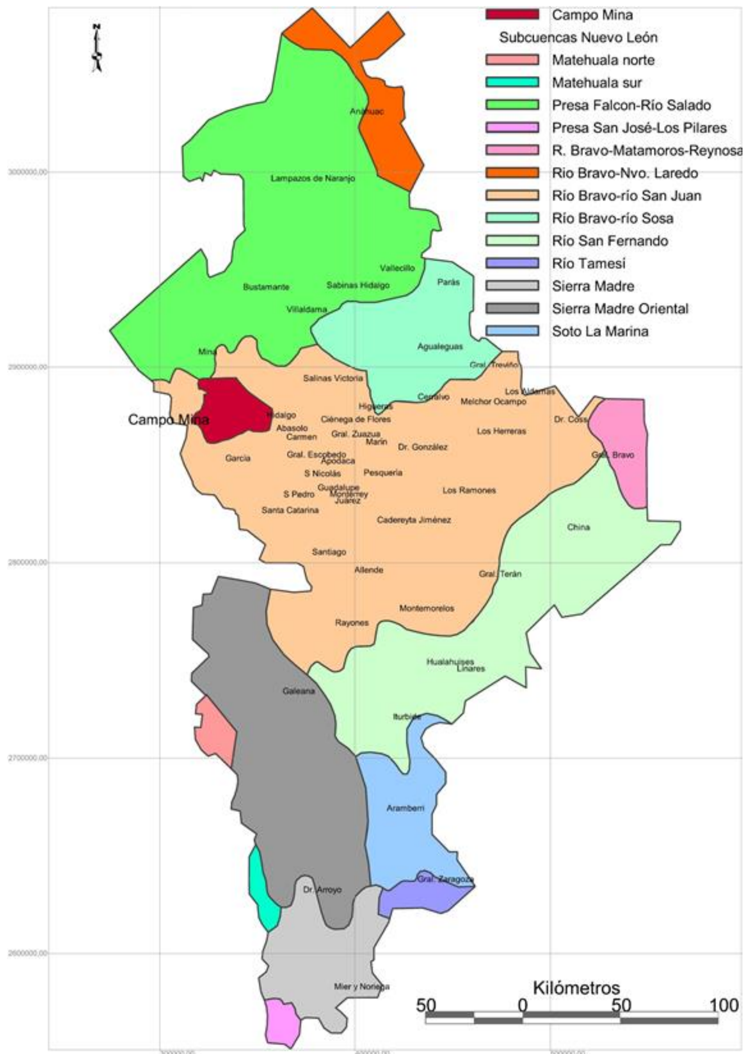

Figure 1. Location map: Field Mina, Nuevo Leon, Mexico. Source: own elaboration based on INEGI, 2001.

The study area is between the lengths of 100 ° 24'W to 100 ° 48'W and between the latitudes of 25 ° 50'N to 26 ° 08'N. The polygon that includes the Mina field has an approximate surface of 835 km2. This sub-basin does not have reservoirs. The sub-basin of the Bravo-San Juan River, at the height of the municipality of Mina, has an average altitude of 600 msnm, this gradually decreases eastward to 90 msnm upon its exit from the State by the municipality of Los Aldamas. The upper part of the micro-basin of the El Potrero River has six types of

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semi-arid climates, all with slight rainfall during the rainy season, from June to October, with a total average of 680 mm per year.

The fluvial network of the Rio Bravo-San Juan sub-basin, in its western portion, has a drainage density of 6 km / km2, while in its eastern portion the density of the dissection decreases to 4 km / km2. Its three main rivers are the Salinas River, the Pesquería River and the San Juan River. The Salinas River originates southwest of the El Jaralito ejido, municipality of General Cepeda, State of Coahuila, and joins the Pesquería River on the western border of the municipality of Marín, NL The Pesquería River originates in the eastern hills of the Chupaderos village del Indio, municipality of García, NL, and joins the San Juan river near the town of Dr. Coss, downstream of the El Cuchillo dam. The San Juan River is born near the town of Laguna de Sánchez, municipality of Santiago, N.L. In the Bravo-San Juan sub-basin, irrigation is still carried out with run-off water, however, due to the expansion of the agricultural frontier, little by little this activity makes use of groundwater, especially during the dry season.

The sub-basin of the San Juan River is composed mainly of conglomerates, sandstone with conglomerate and sandstones of Tertiary age (43%). In the southwestern part of the sub-basin (Lower Cretaceous) there are a series of limestone and limestone rocks with shales (25%). The rest of the sub-basin is occupied by the Quaternary alluvium, whose thickness ranges from 300 to 600 meters in depth (Figure 8).

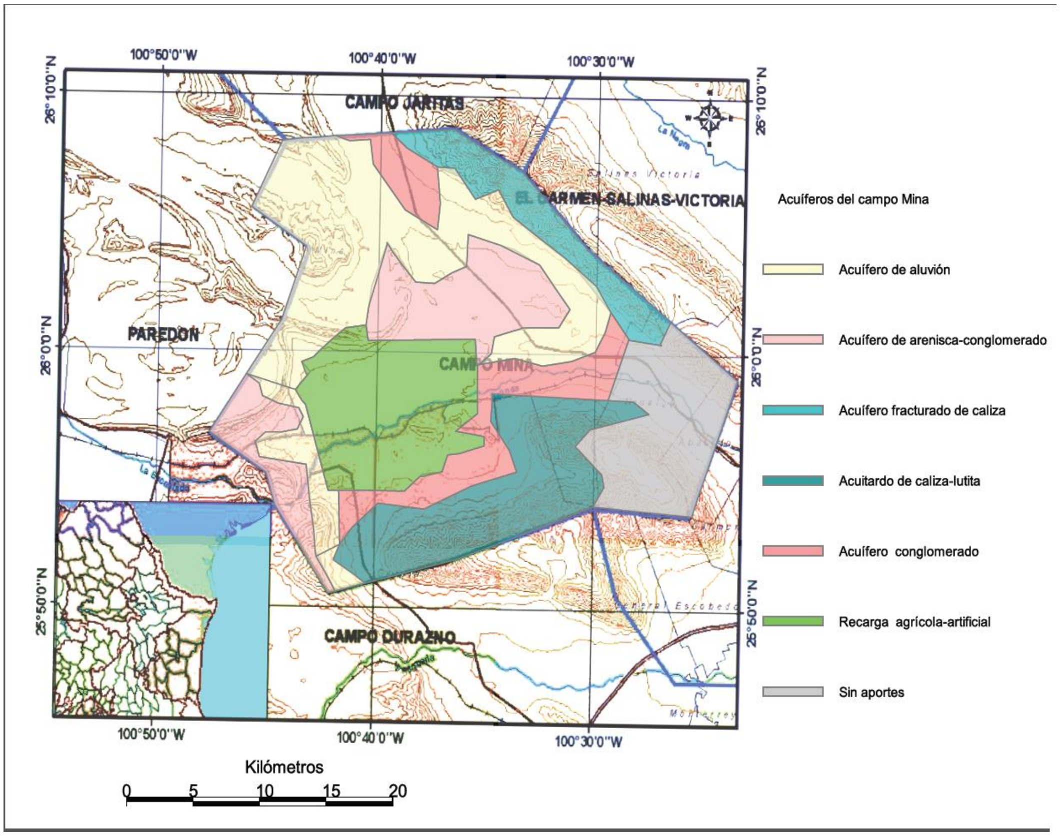

Figure 8. Types of Aquifers in the Mina field, Nuevo Leon, Mexico. Source: self made.

In agricultural terms, in the northwestern part of the sub-basin of the San Juan River, the main crops, in order of priority are: corn, beans, barley, wheat, sugar cane, sorghum and oats. In the northeastern part, corn, sorghum, wheat, beans, oats, melons, oranges and walnuts are grown. While in the southern portion of said sub-basin, sugarcane, peach, bean, walnut, potato, wheat and oranges are produced. Of which beans, corn and peach use rain water; wheat and oats require both rainwater and groundwater; while barley, sorghum and walnuts are the main commercial crops that are irrigated using well water despite the fact that their water footprint is the highest.

The Bravo-San Juan sub-basin, according to García's climate classification (2004) has four tropical climates, two temperate climates and 11 arid climates. The climate (A) C (w0) x 'covers approximately

4,000 km2 (most) of the center of said sub-basin. However, given that its precipitation falls on land that is 370 meters below the Mina field, such precipitation, however abundant, does not contribute to the recharge of the aquifer under study (the same case exists between the dry climates of the east of the sub-basin: BS1 (h ') w; BS1 (h') (x ') and BS0 (h') (x ')). On the other hand, the climate (A) C (w1) covers approximately 1,100 km2, most of its precipitation (1020 mm / year) drains towards the east of the basin, however the infiltration water flows in a north-northwest direction towards the area where the Mina field is located. This is due to the preferential direction of the geological fault of the Monterrey Curvature. This same situation can experience the infiltration water of the climate C (w1) and (A) C (w2) whose maximum average rainfall reaches 880 and 1360 mm per year respectively.

For what strictly in climatological terms, the effective recharge of the Mina field, within the territory of NL, only comes from three dry climates, namely: BWhw whose extension within the sub-basin is 2,100 km2 and whose maximum precipitation is 200 mm /year; BS1hw whose extension is of 2,700 km2 and a maximum precipitation of 760 mm / year; and BS0hw with an extension of 1,400 km2 and a precipitation of 400 mm / year (Figure 2).

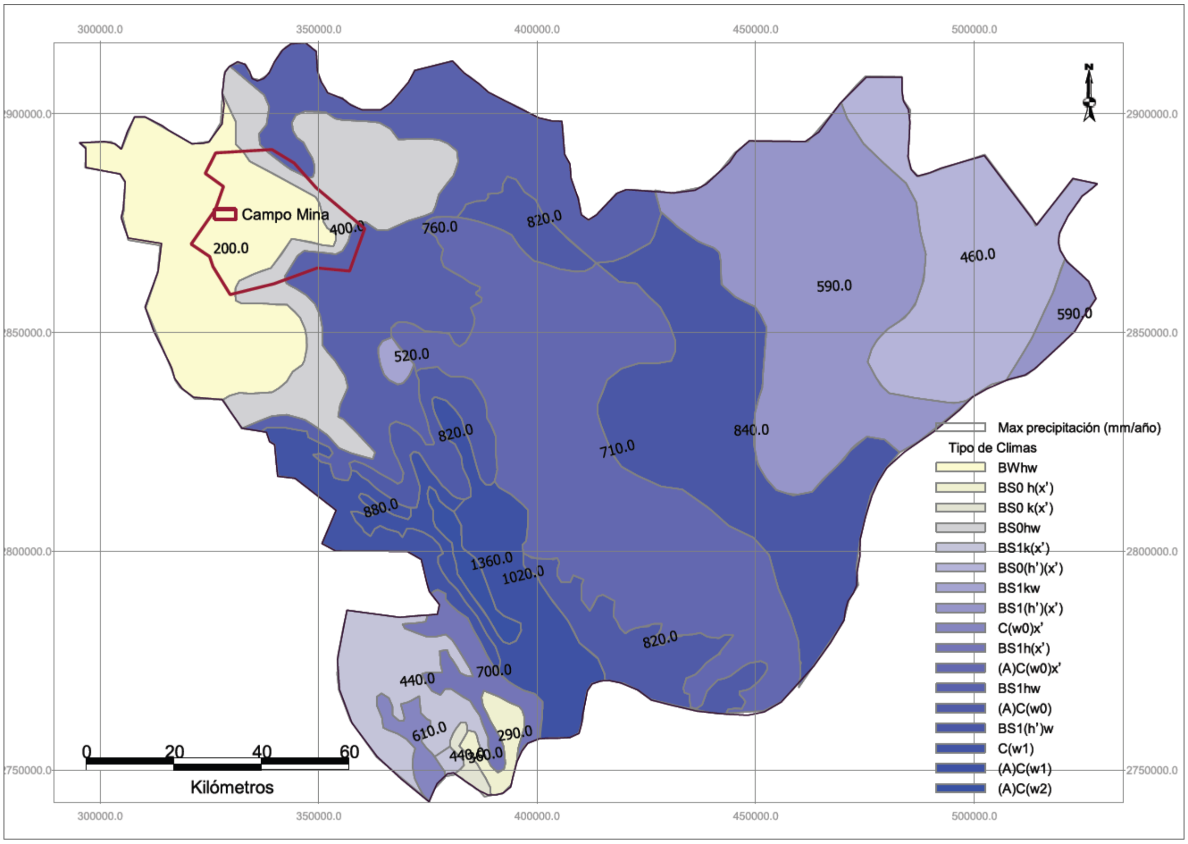

Figure 2. Climatology of the Bravo-San Juan sub-basin. Source: own elaboration based on García, 2004.

To complement it, it is known that small manual water pumps (faucets) and traditional waterwheels in the last 40 years have been replaced by windmills or electric pumps to extract groundwater from the mine field. Nowadays the windmills have an average height of 10 m, an average yield of 20 to 30 m3 / day and extraction wells that have a depth of 40 to 80 m. The 15 HP electric pumps operate at a limit depth of 50 m, and have a performance of 100 to 300 m3 / day. The management of this flow of extraction water is supplied through tanks of 10 m3, dikes and agricultural channels. For this reason, in the last decade, the extraction of groundwater from the mine field must have increased five hundred percent (case of unregulated or clandestine wells).

Methodology

The data used in the study were worked with remote perception and several geographic information systems. For example, the topography of the National Institute of Statistics and Geography (INEGI, 2015), was completed with data from Google Earth with the intention of creating a digital elevation model (MDE). The thematic cartography was compiled from different national and international sources, whose scales ranged from 1: 2 000 000 (climatology maps) to 1: 250 000 (geology maps), etcetera.

To develop the digital elevation model and merge it with the three-dimensional model of groundwater potential (Figure 3), we proceeded as follows: first, the different sets of topographic vector data of the 95 letters were collected, scale to 1: 50,000 (INEGI, 2015), which are required to cover the state of NL, then such data was mapped in GvSIG in a single layer or layer, after which the format was changed, from .shp to .dbf for its modeling in the Surfer software 10.

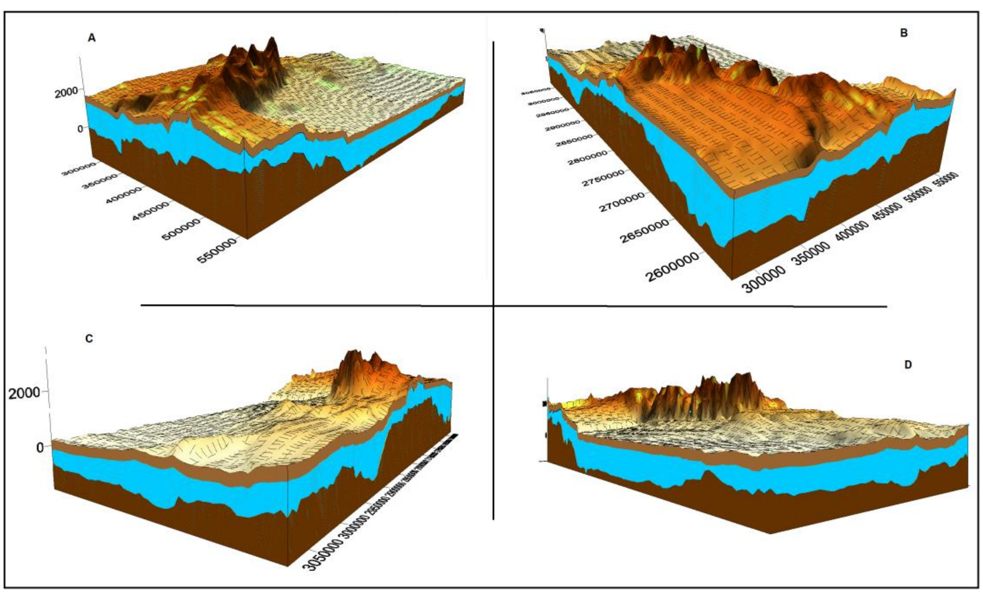

Figure 3. Digital model of the land and the potential of groundwater of the State of Nuevo León. a) seen from the SE; b) seen from the OS; c)

seen from the NO; d) seen from the NE. Source: own elaboration based on Montalvo, Ramos, Navarro, et al., 2011; INEGI, 2011; Fan, Li, and Miguez-Macho, 2013.

To model the upper limit (phreatic level) of the area with the greatest potential to house groundwater, the map of Fan, et al. (2013), said water table map was passed from raster format to vector format to later emulate it in .dbf format; To model the lower limit of the area with the greatest potential to house groundwater, we resorted to the distribution map of the S waves of Montalvo, Ramos, Navarro and Ramírez (2011), this map was also changed from raster format to vectorial format to later convert it to .dbf format. The horizontal and vertical precision of the conjugate data is 50 meters on average.

The increasing availability of geophysical and geological data linked to hydrogeology, derived from different techniques, such as: interferometer, georadar, lidar, echo sounder, resonance, orthophotodron, gamma ray spectroscopy, satellite imagery, etc., offers new possibilities to the Earth sciences to deepen the analysis of the quantitative and qualitative characteristics of the Earth's interior. In this sense, an MDE provides an agile and basic spatial representation of different geological and hydrological phenomena linked in this case with the availability of groundwater in a particular sub-basin.

Analysis and results

In order to delimit the areas with the greatest potential for groundwater from the Mina field, different thematic maps were prepared from remote sensing data, topographic and geological maps, as mentioned above. The resulting map or synthesis map was derived from the conjugation of several pre-existing maps. The maps prior to the preparation of the groundwater potential map of the Bravo-San Juan sub-basin were the following.

Topographic map

The base map was made with the free software GvSIG (Figure 4), which contains the following details represented with the appropriate symbols: rivers, bodies of water (both perennial and ephemeral), roads, railway lines, urban spots, as well as territorial limits.

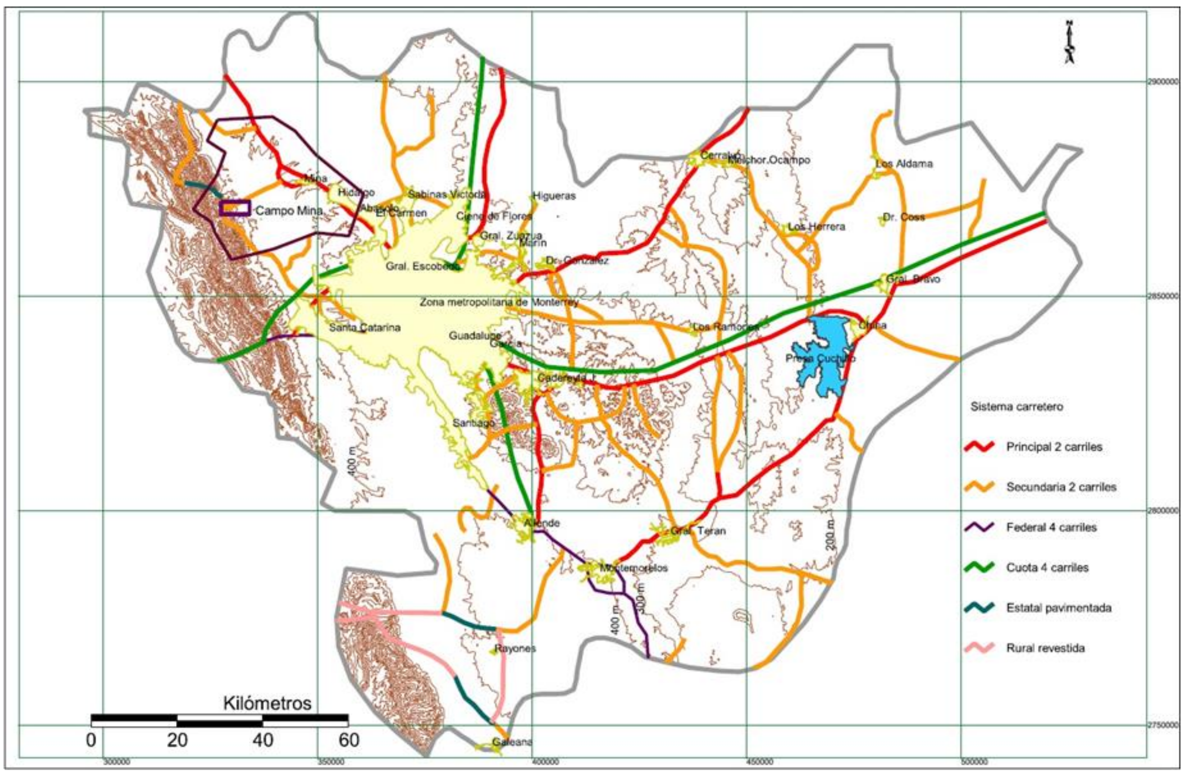

Figure 4. Topographic map of the Bravo-San Juan sub-basin. Source: own elaboration based on INEGI, 2011.

It is important to bear in mind that the availability of drinking water is a big problem for all the towns of the sub-basin of the Rio Grande - San Juan, but this circumstance is becoming more acute in the metropolitan area of Monterrey, since its drinking water has to be transported from hundreds of kilometers. The pattern and connectivity of roads and railways (inheritance of the economy for more than a century) makes planning difficult on a regional scale, as places arranged under aquifers or within the area of influence of some body of water (dams) , live with levels of development close to the poverty line, while the vital liquid is transferred to the big capital. To have more elements for the analysis of the groundwater potential of the sub-basin of the Rio Grande - San Juan, it was decided to include the details of the pattern of the communication lines.

Map of pending

The drainage map shows an extract from the slope map of Lugo-Hubp, Aceves, and Córdova (1991). The resulting grid (classified into three categories) indicates the direction of surface water flow. A plot of the direction of the flow is shown in (Figure 5), this pattern indicates the direction of the flow of water through the sub-basin of the Rio Bravo - San Juan.

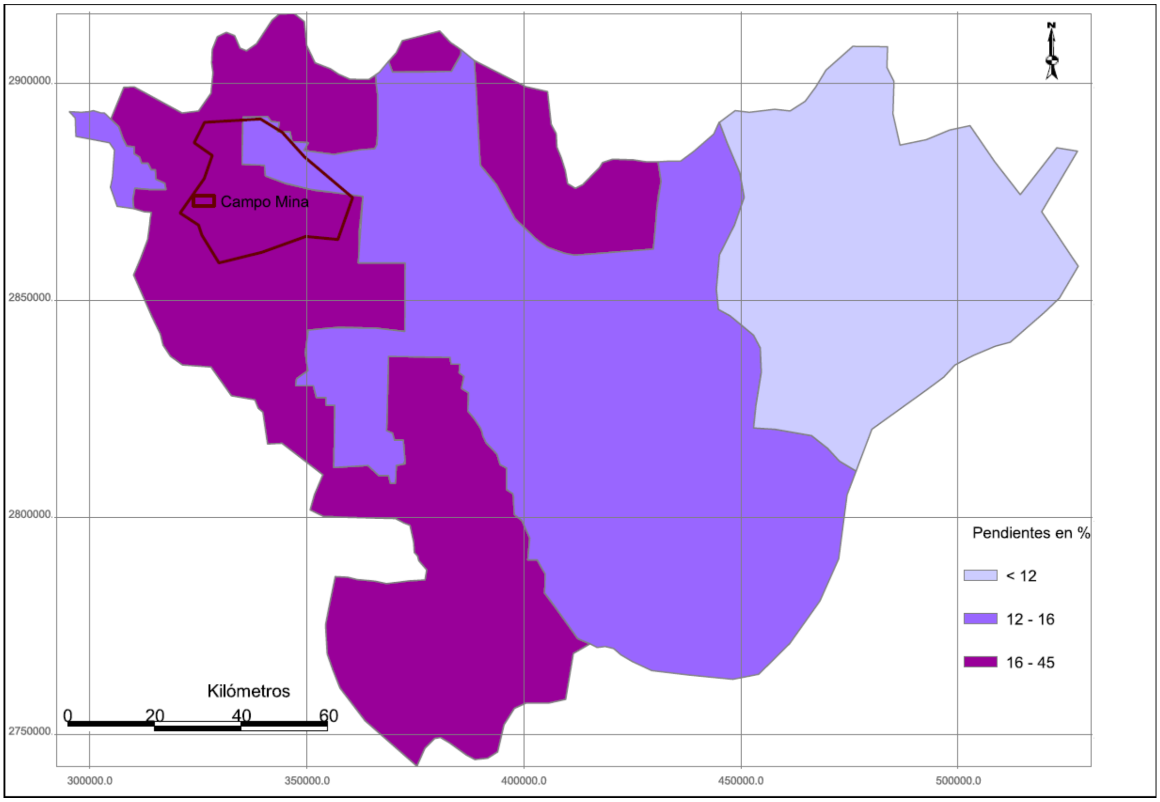

Figure 5. Pending map of the Bravo-San Juan sub-basin. Source: own elaboration based on Lugo-Hubp, Aceves and Córdova, 1991.

In this case the preferential direction of the flow runs from the steepest slopes to the milder ones in the west to east direction, for this reason the Salinas River joins the Pesquería River near the western border of the municipality of Marín, NL, from there river runs 60 km to reach the Marte R. Gómez Dam, passing the state border. Depending on the relief, the eastern portion of the Bravo San Juan sub-basin presents the best conditions for water recharge from aquifers: Agualeguas-Ramones; China-General Bravo; and Campo Papagayos.

Map of geological units

The geological map was prepared by digitizing each lithological unit or type of rock in the GvSIG software package. The geology map of the study area is a compilation of the different geological studies carried out during the 20th century in N. L., mainly from Mullerried (1946) to Montalvo (Op. Cit.). In such a way that each lithological unit was classified based on a general geological legend (Figure 6).

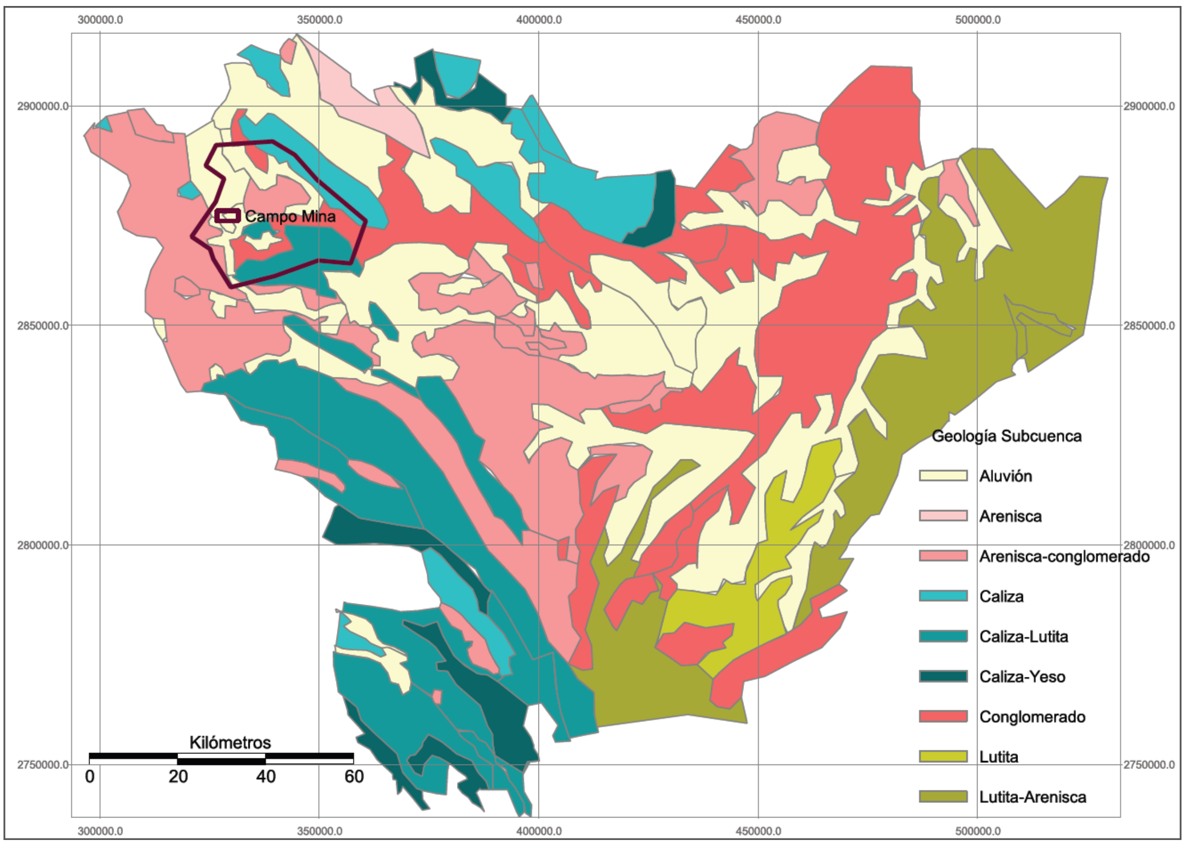

Figure 6. Map of geological units of the Bravo-San Juan sub-basin. Source: own elaboration based on Müllerried, 1946; Montalvo, Ramos, Navarro, et al., 2011.

The importance of the lithological map is that depending on the bedrock, the granulometry of the soil type can be inferred, ergo, also the horizontal and vertical infiltration velocities can be inferred by Breddin's granulometric curve. In that sense the ability to infiltration, during the rainy season, given the materials of the Bravo sub-basin San Juan presents an average of 18 meters per day.

Map of pending

The different geomorphological units were assigned on the basis of the characteristics of the relief, extension, depth of the dissection, thickness of the deposition, and so on. The genesis of the relief forms, the nature of the rocks or sediments associated with geological structures were used for the identification of the different forms of geomorphological units. Initially, the entire sub-basin was classified into three main zones; plateaus, hills, and foothills of the plains, taking into account physiography and alluvium as the main criterion; each zone was analyzed in different geomorphological units according to the main features of the relief, as explained above. Subsequently, these characteristics were regrouped and represented by a slope map (Figure 5). It is worth mentioning that the geomorphological units and other interpreted geographical features were verified with field work, from which additional information was obtained regarding the nature of the different deposition materials and thickness of the same.

Geo-hydrological map

As noted, satellite images provide excellent information on hydrological aspects, such as: rivers, canals, reservoirs, major lakes, tanks, infiltrations, areas irrigated with groundwater, and so on. With all the information compiled in the GIS, the interpretation can be done by superimposing simple or combined layers for later classification through appropriate symbols. For the preparation of the geo-hydrological map of the San Juan Bravo sub-basin, the superposition required the following sources of information: (i) interpretation of satellite images, (ii) field visits and interviews, (iii) meteorological data, (iv) topographic digitization, (v) modeling of groundwater zones, etcetera. As has been said, the precipitation data source was obtained from García's work (Op. Cit.). Later, during the field studies, the necessary information on irrigated land (traditional systems such as melgas and backyard orchards), groundwater, cultivation patterns, environmental management areas, existing wells, etc. was corroborated. These data were also collected and incorporated into the GIS for the superposition of the geo-hydrological map.

Land Use Map

The land use map of the Bravo - San Juan sub - basin was prepared under the ten Anderson classification criteria (1976), with the respective adaptations of INEGI (2015). The input data of the LANDSAT spectral bands that were used had a spatial resolution of 50 m, from them average values were determined for the different output data of the different classes. The resulting map was corroborated by a random sampling applied in areas close to the network of roads and dirt roads in the sub-basin (Figure 7).

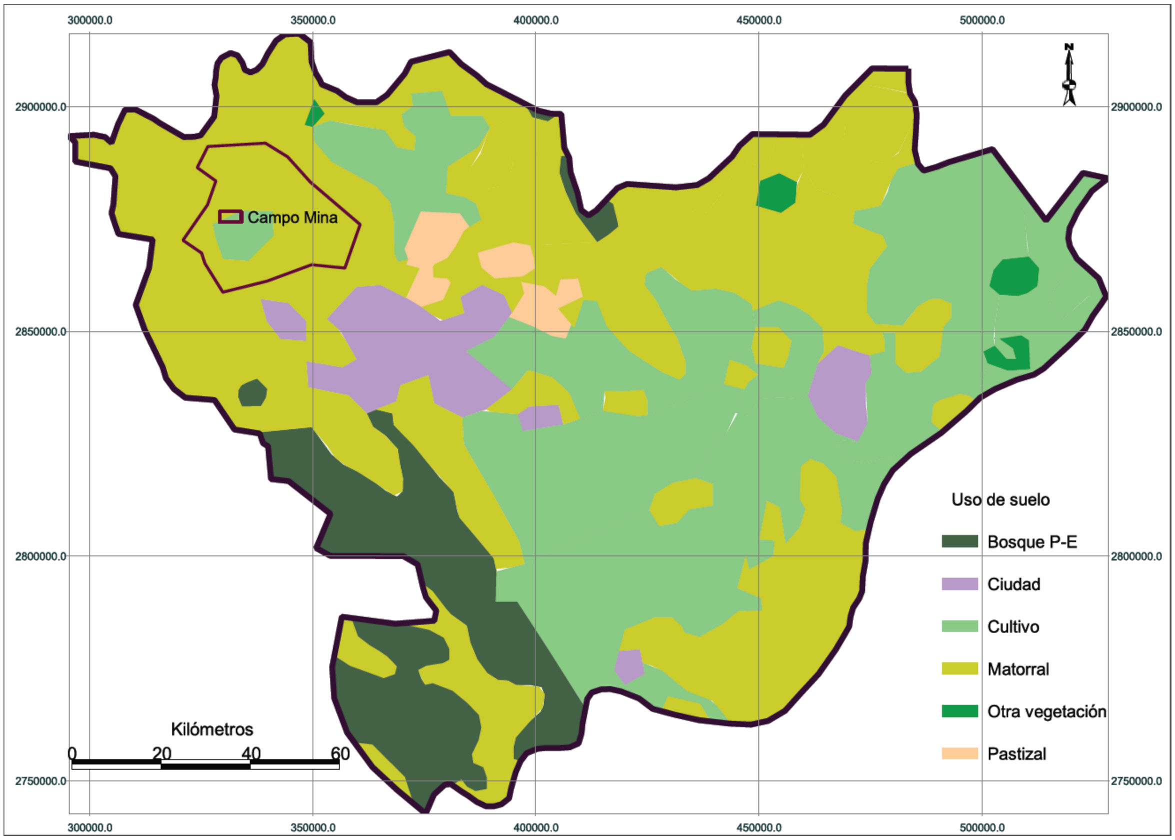

Figure 7. Land use of the Bravo-San Juan sub-basin. Source: own elaboration based on INEGI, 2015.

Classes have the flexibility to merge or group a different class into another based on the percentages of spatial representation of each land cover. The precise locations of the samples were compiled in the DEC system through the use of a global positioning system, Garmin-GPS software, then they were emulated to the universal Mercator system (UTM), with NAT27 datum. About 50 samples were obtained for each class.

From each place the following data was determined:

a) Urban sprawl at the level of blocks, streets and lots.

b) Main types of crops (seasonal and perennial).

c) Encino pine forest.

d) Soils with a large percentage of grassland.

e) Soils with a large percentage of shrubs, grasses, fallow lands, weeds and wild crops; all of them were grouped as scrub.

f) Other types of vegetation, such as hydrophilic.

g) Bodies of water.

In total there were four types of vegetation cover (b, c, d and e) and two land uses (a and g) for the sub-basin of the Rio Grande - San Juan (Figure 7). Therefore, it is estimated that the extension of the total agricultural area irrigated with groundwater from the Mina field, mainly in the municipalities of Mina and García, is of the order of 12,456 hectares. While 26.1 million cubic meters is pumped for the city of Monterrey.

Preparation of the groundwater potential map of the Mina field

After integrating into a geographic information system the data concerning climatic, topographic, lithological, geomorphological (slope map), hydrogeological (3d model of groundwater availability) and land use of the Rio Grande sub-basin San Juan, was proceeded to map the typing of groundwater from the field of Mina, NL (Figure 8) by the following procedure.

Step 1: A new layer was created in the GvSIG software, to which were transferred the layers (maps) of climatology, topography, geology (lithology and tectonics), slope of the terrain, estimated availability of groundwater and land use. All this with the intention of making several overlays, for example between the maps of lithology and climatology, between water availability and topography, and so on. This exercise allowed us to identify units of potential availability of groundwater, which, depending on the different crosses, were assigned an alphanumeric code (for example, CL1-L1, to designate an area of high precipitation rate with optimum lithology for the infiltration, etc.), that is, such an alphabetic code, finally represents a proxy data of the underground water potential of the Mina, N. L.

Geo-hydrological interpretation of the Mina field

Currently the Mina field (a polygon composed of twenty aquifers) has an annual geohydrological potential of 9.33hm3 (cubic hectometres or millions of cubic meters). Whose hydrogeological modeling, conceptually, can be classified by means of seven main aquifer points (Figure 8), which serve as a reference to know the characteristics of the groundwater potential of each aquifer in said field, as well as its water balance, the dynamics of the areas of recharge, among other characteristics of hydrological importance for the agroindustrial planning of the western part of the Bravo-San Juan sub-basin in the context of climate change.

According to the map of Figure 8, the alluvial deposits of the Mina field represent the largest territorial extension, some 23 thousand ha., Which, given its rainfall regime and infiltration rate, contribute to the aquifer just over 1.5 million of cubic meters of water (16.15% of the total). Which, taking into account a Breddin curve of 9.5m / day, and an average distance of 13km between the recharge areas and the extraction points, the recharge rate of the natural groundwater cycle, for this case, is approximately 3.5 years.

Depending on the territorial extension, the area of crops is at the same time the maximum artificial recharge area of the Mina field, which provides an estimated 3,928,007m3 (42% of the total). This polygon, is constituted mostly by a flood, followed by a conglomerate and a small portion of limestone-shale. Taking into account that the horizontal displacement of groundwater, on average is greater than 45m / day, its geo-hydrological cycle is annual.

In the southern portion of the Mina field, there is a geological substrate composed of limestone with shale, which, given its low Breddin curve

(2m / day), is geo-hydrologically located as an aquitard. Well, despite the fact that this geological substrate, in combination with its rainfall regime, is the one with the highest annual water infiltration (1.64 hm3 / year), corresponding to 18% of the relative recharge of the Mina field, its recharge cycle is very slow (greater than 6 and a half years), in addition to its groundwater, given a topographic analysis of the Mina field watershed, it is inferred that they are absorbed by the Salinas River. So it is necessary to deepen the studies in this part of the Mina field, to specify the dynamics of said aquitard.

To the southeast of the Mina field there is an area consisting mainly of three geological units: one of limestone, another of limestone with conglomerate, and one more made of conglomerates, which, due to a topographic barrier, do not contribute to the recharge of the Mina field; besides that the area where the wells are located is upstream of such geological substrates. Here it is advisable to evaluate the possibility of opening new extraction wells for the planning of the local agro-industry.

In the northern center of the Mina field is a portion of sandstone with conglomerate, which contributes with half a million cubic meters of water (0.51 hm3) of annual infiltration (5% of the total). Which according to its Breddin curve corresponds to a horizontal movement of 43m / day, in that sense its recharge cycle is practically annual, as long as an average distance of 6 km is taken into account, between the recharge areas and the extraction zones.

Finally, to the north-northeast of the Mina field there is a hill of 9 million ha., Consisting basically of pure limestone, which contributes with around 800 thousand cubic meters of annual infiltration water to the Mina field (equivalent to 8%). Of which its geo-hydrological cycle, estimated from a horizontal rate of 600m / day, is the most dynamic of the whole, because theoretically there, the rainwater takes 15 days to get from the recharge area to the zones of extraction (located this last one to a depth of water table of 80m). Now, due to the topographic configuration and the rain regime that the geological body experiences, if we consider the dew and the mist water, this substrate annually contributes an additional 700 thousand m3 of water to the aquifer under study. So this little hill of limestone is one of the most important points of recharge.

Conclusion

Regarding the mapping of groundwater resources, it is seen that this has been gradually implemented in recent years due to the greater demand for water. The most commonly available data for the study of groundwater are geological, geomorphological and hydrological information. In this study the groundwater potential of the different zones that make up the Mina field was characterized using remote sensing techniques and information systems geographic in the sub-basin of the Rio Bravo San Juan. To delimit the availability of groundwater in the Bravo San Juan sub-basin, several thematic maps were digitized, such as: lithological map, geological, slope map, among other maps such as location, climatology, topography. For this, it was required to make use of several software, such as: GvSIG, Google Earth, Qgrid, Surfer, 3D Route Builder; among others. All the resulting maps were integrated for the preparation of the groundwater availability map of the Mina field, belonging to the Bravo-San Juan sub-basin.

According to the analysis, the Mina field is composed of five geomorphological units that act as unconfined aquifers, namely: Quaternary alluvium; limestone hills, conglomerates; sandstones; and limestone piedmont with shale, as well as an artificial recharge zone and a geomorphological formation to the east not yet exploited. Where, from the geomorphological point of view, the limestone hills, in effect, turned out to be areas of high potential for water extraction, however from the agroindustrial point of view, the center of the Mina field (crop area), Having a higher optimum artificial recharge, can be considered as the area of maximum potential for water extraction. Quaternary alluviums, as well as conglomerates and sandstones, can be considered as medium potential areas for extracting groundwater, while the southern aquitard of the Mina field, composed of limestone with shale, turns out to be a low potential area to extract water. . Finally, it should not be forgotten that in the eastern portion of the Mina field, there are still water reserves with a medium potential that have not yet been explored or exploited.

On the other hand, if you compare the volume of annual recharge of the aquifers of the Mina field (9.33 hm3) with the volume of extraction of the same (35 hm3) it is noted that the policy of water supply Mainly for the metropolitan area of the city of Monterrey, it relies on the extraction of water from an aquifer confined to the Mina field. Such a deep aquifer is independent of the current recharge cycles, whose average is 4 years.

This is the reason why despite the deficit of extraction greater than 25 hm3 per year, the Mina field, still does not give our de-abatement, since its cones of abatement are not pronounced, and the jumps in the piezometric levels of the different aquifers that make up, for decades oscillate 15 meters on average.

Now, if we consider the drainage network (rivers, streams and large bodies of water), the basin in its western portion has a lower capacity to capture water than its eastern portion. Therefore, extracting geological water from the Mina field to supply the metropolitan area of Monterrey is not related to the extraction of groundwater that is carried out locally in the municipality of Mina, NL. However, the lack of differentiation between the hydro- geologic, of the limestone aquifer of the Mina field, of the hydro-annual cycle of the sandstone with conglomerate, to mention an example, has been the cause of the increase of the water vulnerability of the inhabitants of the municipality of Mina. Therefore it is necessary to specify that this availability of water does not depend on the current climatology, but on the water accumulated in geological time.

Finally, to deepen in the hydraulic behavior of the commented formations, it is necessary to elaborate a continuous geohydrological mapping at a scale of 1: 5 000 of the study area, paying special attention to the cartographic definition of the lithostratigraphic units of greater hydrogeological interest, at the same time to expand the piezometric observation network with a view to improving the planning of the geological water supply of the Mina field.

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