GROUNDWATER SALINIZATION IN THE CENTRAL REGION OF RECIFE (BRAZIL) DUE TO BRACKISH WATER IN CAPIBARIBE RIVER AT HIGH TIDE

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Abstract

Recife is a commercial and tourist city, with about 3 millions inhabitants, at the coastal zone in northeastern Brazil. Recife central region is a low flat plain where Capibaribe river meanders. Groundwater has been excessively exploited and some spots of salinization problems have occurred. A list of 1,640 wells has been recorded; some of them pump groundwater from the Boa Viagem unconfined aquifer (shallow) and some from the Beberibe semi-confined aquifer (deep). Electrical conductivity in 270 wells of the Beberibe aquifer has been measured and 36 of them present high values, characterizing brackish water. One possible reason for this problem is the poor construction of the wells, but in other points, high pumping rates may induce recharge from saline sources. On plotting electrical conductivity values in a map, it was observed that a large number of wells with brackish water appeared next to Capibaribe river. At high tide in dry season, the last 8 kilometers of the Capibaribe river present high salinity. Excessive groundwater pumping from wells located near the river may induce recharge from saline river water and thus the aquifer begins to develop salinization problems. This work presents the preliminary results of the investigation on groundwater salinization and its relation to the Capibaribe river estuary.

Keywords: Layered aquifers, overexploitation, river estuary, brackish recharge from rivers

Introduction

Recife, the capital city of Pernambuco State, is one of the largest cities in the northeast coast of Brazil (Figure 1). Recife lays over a sedimentary low plain located about 2.0 m, on average, above the mean sea level, surrounded by small hills. Recife Metropolitan Region (RMR) comprises fourteen cities, and has about 3 millions inhabitants.

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Figure 1. Geographical position of study area in Recife (Brazil).

Recife was built on the estuarine area of the Capibaribe river and other small rivers that share the same estuary. Recife has been developed through the last five centuries, with many bridges over the rivers that run through the town. These rivers provide beautiful landscapes but also facilitate the saline penetration from the sea into the aquifers.

Water demand in Recife is approximately 14.0 m^3/s, with 60 % supplied by surface systems. Groundwater use in the area has been growing for the past 25 years, with some deep wells drilled on the north of RMR and controlled by the State Water Supply Company (COMPESA), which add 1.6 m^3/s to public supply, and an increasing number of private deep and shallow wells in south and central area of Recife, which add 4.0 m^3/s for supplying hotels, industries and residential houses and buildings (Costa, 2002).

The over-exploitation of groundwater and recharge difficulties to aquifers in the highly urbanized area has produced a severe depletion of the piezometric levels. In addition, the coastal aquifers in the area increase their vulnerability to seawater intrusion as a consequence of over-exploitation. Many wells have been abandoned due to high groundwater salinity. A monitoring program has been developed to assess groundwater salinity in the most extensively exploited area in the Recife coastal plain (Montenegro et al., 2002).

Several studies have been carried out to get a better understanding of the salinization processes that take place in the region (França et al., 1987; Cabral and Cirilo, 1987; Cabral et al., 1992; Cabral et al., 2000; Costa et al., 1991; Costa el al., 1998; Montenegro et al., 2001; Montenegro et al., 2002; Montenegro et al., 2003). The main causes pointed out for groundwater salinization are the downward leakage from upper saline layers through the open space between the borehole and the well casing, and the landward motion of the salt water wedge.

Excessive groundwater pumping from wells close to estuaries may induce recharge with brackish river water and thus the aquifer begins to develop salinization problems. This work presents the preliminary results on the investigation on groundwater salinization in the central area of Recife and its relation to Capibaribe river estuary.

Groundwater exploitation

The Recife Coastal plain occupies an area of 112 km^2 where three main aquifers occur: Beberibe, Cabo, and Boa Viagem. The Cabo aquifer occurs in the south of Recife, and comprises sandstones, siltstones and mudstones, with an average thickness of 90 m. The Beberibe aquifer occurs in the north and central area of Recife, with an average thickness of 100 m of sandstones with mudstone intercalations. Both Beberibe and Cabo aquifers are semi-confined formations. The Boa Viagem aquifer, an unconfined formation, overlies both the Beberibe and Cabo aquifers and comprises sand, silt and clay, with an average thickness of 40 m (Costa et al., 1998).

This study focuses on the Beberibe and Boa Viagem aquifers on the central area of Recife. The Beberibe aquifer is the most important formation in terms of water storage, and the Boa Viagem system is the most vulnerable aquifer in terms of water quality degradation because of the impact of the leakage of sewage septic tanks, and due to the connection to the mangroves and river estuaries. Table 1 shows the average hydrogeological characteristics of both aquifers. Below the Beberibe aquifer, the Precambrian crystalline basement crops out on the west side, approximately 25 km from the sea, and presents a slope of 28 m/km to the east side (Batista, 1984).

Table 1. Hydrogeological characteristics and hydraulic parameters of the Boa Viagem and Beberibe aquifers.

Characteristics and parameters	Beberibe aquifer	Boa Viagem aquifer
Age	Upper Cretaceous	Quaternary
Geology	Sandstone with mudstone intercalations	Sand, silty and clay
Transmissivity	2.2×10^{-3} m^2/s	7.0×10^{-3} m^2/s
Hydraulic conductivity	2.2×10^{-5} m /s	1.7×10^{-4} m /s
Effective porosity	1.0×10^{-1}	1.0×10^{-1}
Storage coefficient	2.0×10^{-4}	–

The Beberibe aquifer, in the central area of Recife coastal plain, has been intensively exploited through private wells, mainly during the past 25 years. The population growth, and deficiencies in the water supply systems, due to water losses, droughts and lack of investment, have put pressure on the exploitation of groundwater without control. The number of production wells has increased dramatically with the urbanization process. The majority of the wells are private. This over-exploitation has changed the potentiometric gradients between the upper and the lower aquifers, and between the sea and the lower aquifer. Now, in some places, hydraulic gradients produce flow from the sea to the continent, with high risk of seawater intrusion.

The number of wells has been continuously increasing and there was a drilling peak in 1998/1999 due to a severe water supply shortage caused by a drought, which occurred in northeastern Brazil. For both years, the annual rainfall volume was lower than 65 % of the long-term average annual volume. As a consequence, an excessive and disorganized exploitation of coastal aquifers has occurred, aiming to overcome surface water supply shortage problems. It has been estimated that the number of operating

private deep wells almost doubled during this period, while the total extraction rate increased from 1.6 to 4.0 m^3/s (Costa, 2000).

A study funded by IDRC (Canada) (Costa et al., 1998) has found that the massive exploitation of the aquifers in the last 20 years at Recife plain has deteriorated the system both in terms of groundwater quality and quantity.

A management information system has been developed and implemented, compiling all the available information on the wells (Cabral et al., 2000). This software is aimed as a tool for supporting groundwater management.

In spite of the yet scarce information on the operating wells, it has been possible to built a cross-sectional conceptual model describing the lithology and geometry. One of the studied sections is depicted in Figure 2, and presents the conceptual model for the aquifers in the central area of Recife.

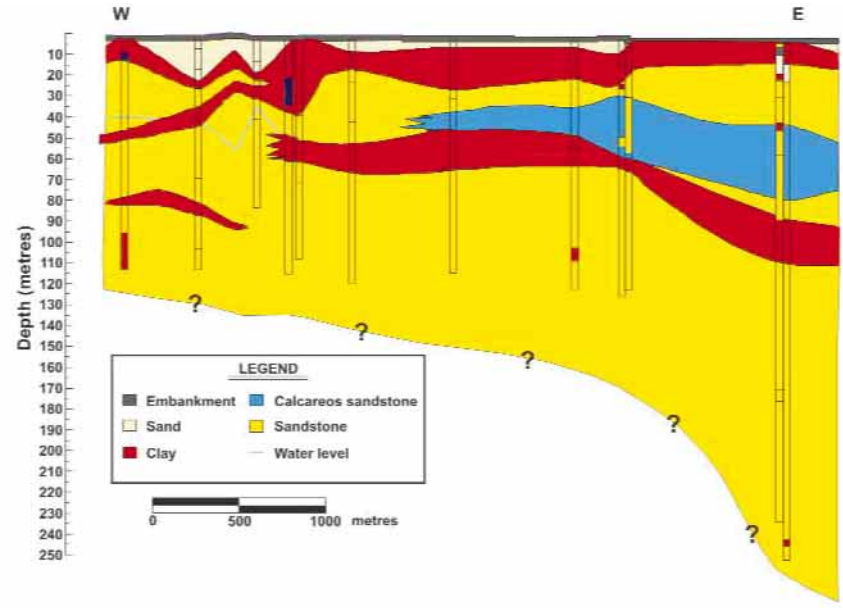

Figure 2. West / East cross–section, with the Boa Viagem (upper) and Beberibe (lower) aquifers.

Legislation for groundwater management has been approved, after some years of discussion, and now government agencies started controlling the drilling and exploitation rate of private wells. For drilling a new well, the owner or responsible must apply for a license and the new drilled wells should encompass devices for allowing groundwater level and discharge rate evaluation. For old wells, the owners have an extended period of time for getting the license.

There is also a management plan established by the Pernambuco State Environmental and the Water Resources Agency (CPRH), which set up control zones, each of them with a maximum extraction rate per

single well. In one of these zones, drilling would no longer be permitted, and any new well should not start operating.

In the central area of Recife, where this study has been carried out, the Beberibe aquifer piezometric levels have been decreasing for several years. Several residential buildings with large number of apartments have been built, and in each building the entrepreneurs have drilled a new well. In this heavily pumping condition, the piezometric level has lowered from 40 to 70 m in the last 15 years (Costa , 2002). In special, the neighborhoods of Aflitos, Espinheiro and Graças (Figure 3) present a huge depression cone. Also, in the studied area, there are 161 health services (varying from clinics to big hospitals), which generally pump large amounts of groundwater (Farias, 2003).

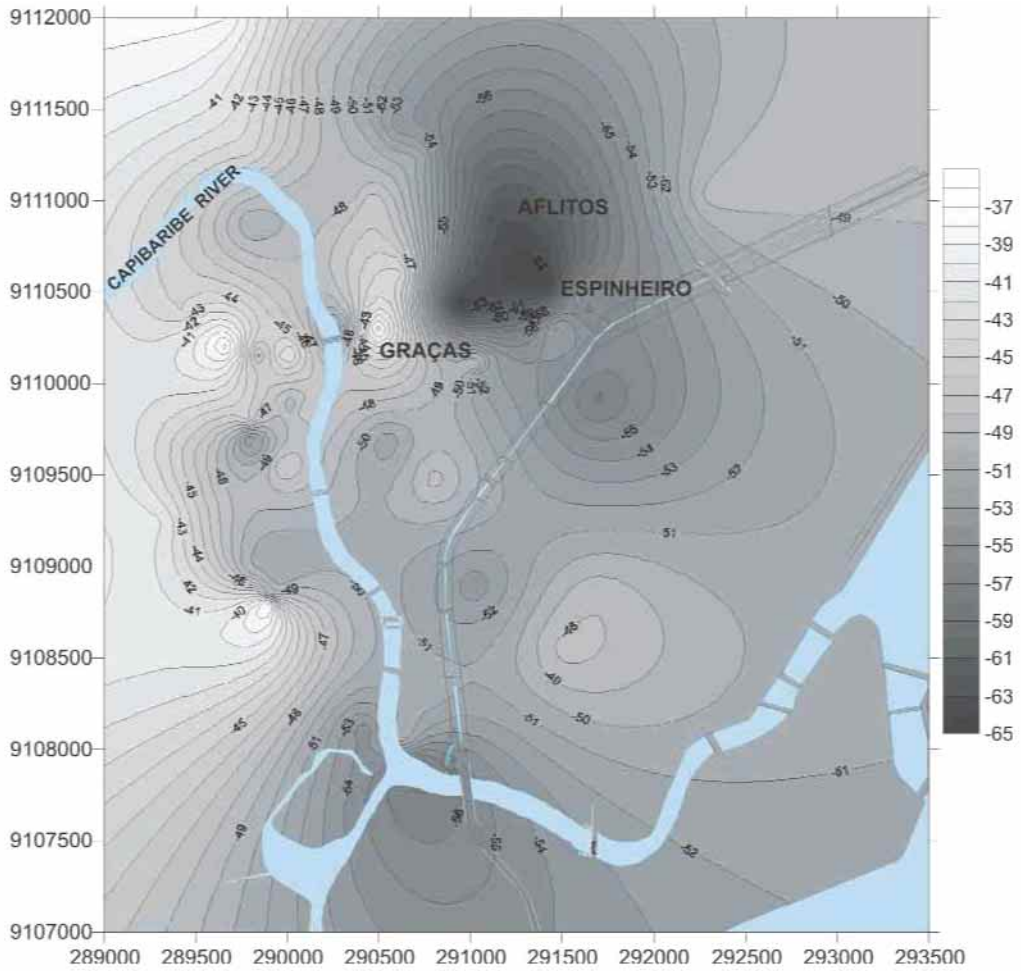

Figure 3. Potentiometric map of the Beberibe aquifer (years 2000/2001).

Salinization problems

The present study was carried out in Recife plain, with coordinates ranging from UTM 9107000 to 9112000 North and from 289000 to 293500 East (Figure 1). This area includes 28 neighborhoods., iIt is quite low and flat, with altitudes ranging from 1.0 m to 10.0 m above sea level, and is highly meandered by Capibaribe river and a few canalized tributaries.

In this area (4.5 x 5.0 km) a total of 1640 wells have been catalogued; roughly other 60 wells were left out, 20 of them because they were saline and have been cemented to avoid salinization spreading and, 40 of them are old wells and the owners didn't know anything about them (Costa, 2002).

The well depths in the Boa Viagem aquifer ranges from 3 m to 40 m (Table 2), and its average pumping rate ranges from 2 m^3/h to 24 m^3/h. Higher flow rates can be obtained from the Beberibe aquifer, (Table 2). The thickness of thise Beberibe aquifer increases in the northward direction, and to the north, some wells pump as much as 120 m^3/h (Paiva et al., 2003).

Piezometric levels in the Beberibe aquifer have been lowering in the last decades. Figure 3 shows the potentiometric surface obtained with information of years 2000 and 2001. It can be highlighted the significative drawdown in the area, which reaches 65 meters below sea level, and gives indications that withdrawals far exceeded recharge rates.

Table 2. Well depths and pumping rates from the Boa Viagem and Beberibe aquifers.

		Well depth	**Pumping rate**
Boa Viagem aquifer	Total number of wells	576	576
	Number of wells with information	562	13
	Average	12.80 m	12.94 m^3/h
	Standard deviation	7.33 m	7.64 m^3/h
	Median	11.9 m	14.7 m^3/h
	Maximum	40.0 m	24.0 m^3/h
	Minimum	3.0 m	1.64 m^3/h
Beberibe aquifer	Total number of wells	784	784
	Number of wells with information	773	481
	Average	123.85 m	49.24 m^3/h
	Standard deviation	27.76 m	16.28 m^3/h
	Median	120.0 m	49.5 m^3/h
	Maximum	270.0 m	120.0 m^3/h
	Minimum	42.0 m	3.5 m^3/h

Several wells in the Recife central area present high electrical conductivity. Many of these saline wells had initially good water quality, but after some months of pumping, the salinization process has been triggered.

This study is focused on the Beberibe aquifer because it has better water quality and it provides more water volumes for supplying residential buildings, high schools, hospitals and a few other uses in the Recife

central area. To estimate the salinization conditions, electrical conductivity measurements were obtained at 270 wells in the Beberibe aquifer (Table 3).

Table 3. Electrical conductivity of the Beberibe aquifer.

Wells with information	309
Average electrical conductivity	631 μS/cm
Standard deviation	1695 μS/cm
Minimum	107 μS/cm
Maximum	15360 μS/cm
Number of wells (< 700 μS/cm)	270
Number of wells (700 to 1500 μS/cm)	16
Number of wells (1500 to 2300 μS/cm)	7
Number of wells (> 2300 μS/cm)	16

In Table 3, electrical conductivity values were sorted in four groups: wells with less than 700 μS/cm were considered having good water quality; wells with electrical conductivity between 700 μS/cm and 1,500 μS/cm were considered in the early stages of the salinization process; for wells with values ranging from 1,500 μS/cm to 2,300 μS/cm it was assumed that salinization has occurred and for wells with values higher than 2,300 μS/cm, it was assumed to have suffered strong salinization (Farias et al., 2003). Figure 4 presents the distribution of the wells with the measured electrical conductivity.

Figure 4 shows some important features:

1) There are several saline wells on the east side, but there are also non- saline wells on the very east of the area, on the sea side. So, one cannot say that there is a thorough landward motion of the salt wedge caused by the seawater intrusion process.
2) Some wells are saline among several other wells with good water quality. Although it could be a case of upconing, it is possible that in this case there is a downward leakage of saline water from upper layer either through aquitard discontinuities, or through discarded wells, or through lack of isolation between aquifers in the drilling operation and well completion.
3) Along the sides of Capibaribe river there are several saline wells, which may indicate that the river also propagates the salinization. River water in its final kilometers close to the sea presents high salinity due to the hydrodynamics of the estuarine region. This brackish water can percolate into the aquifer, mainly in locations in which excessive pumping induces higher infiltration recharge from the river.

Capibaribe river: one of the salinization pathways

Groundwater salinization in Recife is a quite complex issue, and Capibaribe river plays a role in it as one way of landward salinization propagation. Capibaribe river in Recife plain presents a bed gradient close to zero and it meanders slowly through the low flat estuarine area. Tidal effects go backward in the Capibaribe river as far as 12 km from the sea, and saline tidal effects reach almost 10 km from the sea.

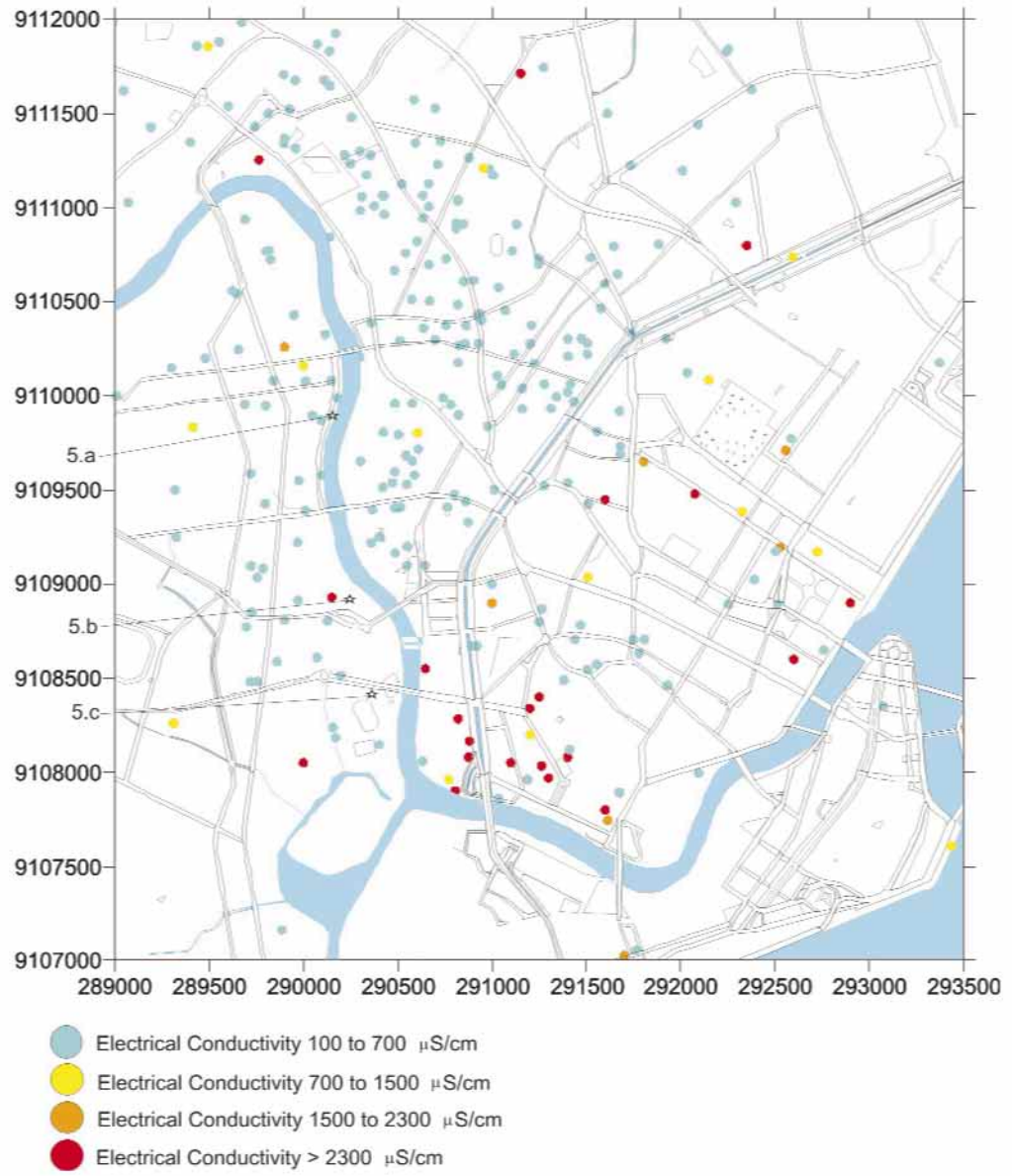

Figure 4. Variation of electrical conductivity of Beberibe aquifer on the study area.

Table 4 shows the salinity of Capibaribe river at four sampling stations. At high tide on dry months the salinity at station 1 is similar to that of seawater, and gradually decreases upstream the river. But, even at station 4, which is 8 km far from the sea, the saline concentration peak reaches 25 g/L, only a little below the sea water concentration (Travassos, 1991).

Table 4. Salinity (g/L) in Capibaribe river at high tide on a dry month (February, on the summer) at four sampling points.

Sampling Point	Sample distance from the sea	Salinity at the river water surface	Salinity on the river water bottom
1	1.0 km	34 g/L	36 g/L
2	3.5 km	33 g/L	36 g/L
3	4.5 km	32 g/L	34 g/L
4	8.0 km	25 g/L	26 g/L

This salt water in the river can infiltrate into the aquifers, especially at locations with excessive pumping. Unfortunately, during the dry summer months in which the salinity is higher, people pump more water to compensate surface water shortage and this may increase recharge from the river.

Recharge from the river into the shallow Boa Viagem aquifer is straightforward, but probably there is also recharge into the Beberibe aquifer because the clay intercalation layer that acts as an aquitard between both aquifers is not continuous (Figure 2). Figure 5 shows the lithological description of some wells in Recife plain, next to the river bank. For example, the well in Figure 5b presents clay layers with low permeability and large thickness; then the Beberibe aquifer is protected against downward leakage in this area. But there are some places with discontinuities, and for example, figures 5a and 5c show profiles where the impervious layer that isolates the Beberibe aquifer from the Boa Viagem aquifer is absent. The river bottom near well W1 (Figure 5a) is around 8 m deep; then water from the river goes to the upper sandy layer and the clay layer below is not thick enough to protect the lower aquifer. The borehole description for well W3 shows that there is no impervious layer to protect the lower aquifer; and the whole layer is silty or sandy, with medium to high permeability.

Concluding remarks

Although there are several saline wells, one cannot say that there is a thorough landward motion of the salt wedge, because there are also non-saline wells on the very east of the area, on the seaside.

Downward leakage from the upper saline layers that have been reported on South Recife, also occurs in the central area. Plotting groundwater salinity on a map has shown some saline wells located among several other wells with good water quality. Although it could be a case of upconing, it is possible that in this case, there is a downward leakage of salt water from the upper layers, either through aquitard discontinuities, through abandoned wells or through poorly isolated wells between aquifers during the drilling operation and well completion.

The Capibaribe river plays a role in Recife aquifer salinization, as it represents one way of landward salt propagation. The Capibaribe river on Recife plain presents a slope close to zero in the flat low estuarine area and the saline tidal effect reaches almost 10 km from the sea. This brackish water can percolate into the aquifer, mainly in locations in which excessive pumping induces higher infiltration recharge from the river.

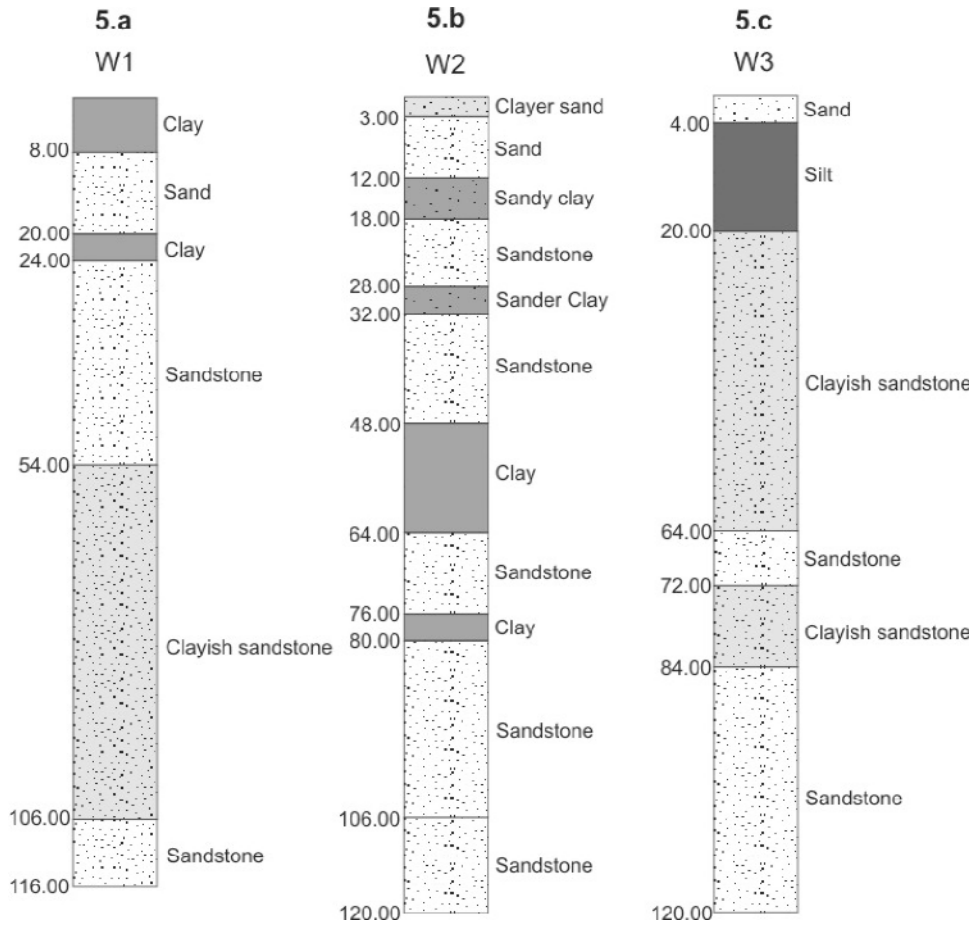

Figure 5. Lithological description of some boreholes in the study area.

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