Urban impact in Groundwater Levels in Dakar Shallow Aquifer (SENEGAL)

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ABSTRACT
The Quaternary Sandy sediments which cover most part of the Cap Vert peninsula bear considerable groundwater resources. The aquifer laying beneath a densely populated suburb zone is encountered major issues such as induced recharge from anthropogenic surface derived pollution and rising water table to groundsurface. This groundwater level rising contributes in part to recurrent urban flooding events in recent years, causing environmental and health problems. In this context, the present study aims at characterizing urban and rainfall impact on the groundwater level of Dakar quaternary sandy aquifer using long term groundwater monitoring levels and rainfall data. Monthly rainfall analysis in Dakar-yoff meteorological station indicate rainfall deficit since 1970. Seasonal fluctuations of groundwater levels in response to precipitation are monitored during time period (2010-2012) using "Thalimede Orpheus mini" recorders in two piezometers located in the suburban area (P3-1 and PSQ1) in order to determine groundwater fluctuations in response to rainfall events. In addition to that, long term water level records in few piezometers, located in the inhabited area (PS10, PS11, P2-10, P2-9 and P2-7) and in the urban area (P2-6, P2-2 and P2-5) were investigated to infer urban and rainfall impact in the groundwater levels. Results indicated a groundwater levels rising in the peri-urban area due to waste water infiltration and a water levels decline in the inhabited areas related to rainfall deficit since the 70s.

Keywords: Rainfall, piezometric levels, groundwater, Quaternary sandy aquifer, Dakar.

INTRODUCTION
The Quaternary sandy aquifer located in the region of Dakar plays a major role in supplying drinking and irrigation water in rural areas. Use of this resource began in the 50s with periods of higher and lower exploitation ranging from 15 000 m$^3$/d to 1 300 m$^3$/d. This present paper aims at understanding urban and climate change impact in the Thiaroye groundwater levels using long term piezometrics levels and rainfall data. Previous studies in the Thiaroye aquifer [1-6] reported high nitrate levels which deteriorate water quality. Recently, the effects of suburban development have been characterized [1,7,4,6,8,12] and the increased nitrate levels and frequent floods in the area were reported during the last two decades. Degradation of this water quality deriving from improper sanitation system in the urbanized region, cause a significantly reduce of this groundwater pumping for water supply to Dakar city. In this paper, we propose to investigate spatio-temporal variation of Thiaroye groundwater level depending on rainfall and urbanization.

Description of the study area
The peninsula of Cap-Vert extends over 550 km$^2$ between longitudes 16°55' and 17°30' west and latitudes 14°55' and 14°35' north (fig 1). Dakar city is a fast growing metropolitan area, it population increased from 583,000 inhabitants in 1971 to 2.5 million in 2006 with an emergency of suburban zone where the population is estimated at 1 154 316 with a density of 9335 inhabitants/km$^2$.
Evidence of the fast urban expansion was investigated using time series aerial photos and satellite images interpretation (1966, 1978, 1989, 2000 and 2006). Results show that urban occupation increase from 36 km\(^2\) in 1966 to 150 km\(^2\) in 2006. This region is characterized by a semi arid climate with a short rainy season, which lasts from June to October. Annual rainfall has varied between 150 mm (1983) and 664 mm (2005) over recent decades and has become slightly above the mean of 410 mm (1961-1990). The maximum temperature recorded in this area between 1980 and 2010 has averaged 29.5 °C. It occurs from May to June and October-November corresponding to the beginning and the end of the rainy season respectively; minimum temperatures are observed during the period from December to February (18.5 °C). Evaporation estimated by Turc Formula ranged between 200 mm/yr and 500 mm/yr between 2000 and 2008. From the geological standpoint, the region of Dakar belongs to the Senegalese-Mauritanian basin, the largest coastal basin of northwest Africa [13]. Most of the geological formations encountered correspond to thickness reaching several thousand meters. At the outcrop appear almost exclusively Quaternary sediments sandy and sandy clay, especially alluvial and wind deposit [14]. This Quaternary sandy formation constitute the reservoir in the Dakar region; it overlay the impermeable marly of Eocene age. The aquifer extends from the Dakar peninsula to Saint Louis in the north. It is confined beneath a basaltic layer at the peninsula head then unconfined in the region extended from Patte d’Oie toward the East. This system consists of medium to fine sands with intercalations of sandy clay in places. Its thickness varies between 5 m (southeast) to 40 m (West) and 75 m (northwest) (fig. 2). The permeability values of the Thiaroye aquifer are variable and range from \(10^{-4}\) m/s at Thiaroye to \(5.10^{-4}\) m/s around the Retba lac. Transmissivity values varies as a function of the thickness of the sands and are between \(1.10^{-2}\) m\(^2\)/s and \(1.10^{-3}\) m\(^2\)/s.

Figure 1: Localization of the study area

Figure 2: Geological cross-section in the study area (Chaoui, 1996 modified)
Water table depth map was established from values carried out in October 2008 (high water level). It shows that quaternary sandy aquifer is shallow with depths ranged from 1 to 3 m in the basin of Thiaroye and less than 2 m in the «Niayes». Instead, water table depth varies between 5 and 10 m at Golam and Bambilor. Maximum depths are observed in the confined part and ranged between 10 and 35 m (fig. 3).

**Figure 3: Water table depth (October 2008)**

Groundwater nitrate evolution shows relatively low values between 5-34 mg/l between 1966 and 1972; these values are lower than the WHO standard (50 mg/l). Nitrates values increase rapidly and reach 285 mg/l and 300 mg/l respectively at 1987 and 1995 in pumping well F19. Higher values ranged between 388 mg/l and 500 mg/l are observed between 2000 and 2008 F21 (fig. 3). Pumping rate decrease (fig. 4) between 15 000 m³/d and 1300 m³/d is due to this nitrate pollution.

**Figure 4: Urban area and nitrate evolution**
MATERIALS AND METHODS
The methodology used in this study consists in different points:

- Rainfall analysis in Dakar-Yoff meteorological station was used to characterize climate variability during time period 1900-2008;
- Dealy monitoring groundwater levels were obtained using «Thalimede Orpheus mini» recorders. This operation was carried out in two piezometers (PSQ1 and P3-1) located in the suburban area during time period 2010–2012; in order to determine groundwater fluctuation levels in response to rainfall events. In addition to that, long term water table records in few piezometers, located in the inhabited area (PS10, PS11, P2-10, P2-9 and P2-7) and in the urban area (P2-6, P2-2 and P2-5) in correlation with daily rainfall were investigated to infer the change patterns in relation to geographical area and for understanding urban and rainfall impact in the groundwater level (cf. fig.1).

RESULTS AND DISCUSSIONS
Rainfall evolution in Dakar-Yoff meteorological station
Rainfall analysis from 1900 to 2008 shows a high interannual variability (Fig. 4). This irregularity of rainfall during this period is especially marked by a succession of wet and dry years and is characterized by a downward trend in rainfall observed from the 70’s and related to rainfall deficit. The interannual average rose from 550 mm before 1970 to 350 mm down to about (15%) compared to the mean reference (1961-1990) who is 410 mm. These different years correspond to periods of drought (fig.6).

Figure 6: annual average rainfalls compared to the 1961-1990 mean (1900-2008) Groundwater level evolution
Groundwater levels records show rising water table from July to October and a water level decline in the rest of the year. This recovery depends on the amount of rainfall during the year and varies respectively
between 1.2 m to 0.5 m in 2010 and 2011 when collected rainfall was respectively 595 mm and 330 mm (P3-1). Piezometer located at Diamaguene (PSQ1) show a rising water level about 1 m (Fig. 7).

**Figure 7: Water level fluctuation in two piezometers (P3-1 and PSQ1)**

Long term groundwater level records shows a water level decrease in piezometers P2-9, P2-10, PS8, PS10 and PS11 located in inhabited area. This decrease varies between 1 and 3 m and can be related to rainfall deficit since the 70s. However, in urban areas groundwater levels rose about 4 m at piezometer P2-6 (Boune) since the 90s. This water level rising exhibit the groundwater pumping decrease and domestic wastewater infiltration due to the improper sanitation system (Figs. 7; 8 and 9). Piezometer P2-7 (Tivaouane Peuhl) located in area recently urbanised (cf.fig.1) support these two groundwater levels evolution.

**Figure 8: Long term groundwater levels records in the urban area**

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CONCLUSION

Climate and urban impact analysis in Thiaroye aquifer located in the western part of Senegal indicate the following information:

- Climate analysis exhibits high rainfall variability and suggests rainfall deficit since the 70s.
- Groundwater monitoring levels showed a rising water table in the densely populated urban area and a water levels decline in the inhabited areas. This water levels rising in the urban area can be related to pumping decrease but also to "permanent infiltration" of domestic wastewater due to the sanitation drainage deficit.
REFERENCES


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