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The impact of urban development on aquifers in large coastal cities of West Africa: Present status and future challenges

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ABSTRACT

This paper investigates the coastal cities of Abidjan, Cotonou, Lagos and Douala in West Africa. Published data on these areas were aggregated in order to compare the urban development of some African huge cities and assess their impacts on groundwater. Those urban centers have experienced an exponential demographic expansion since the 1950s, with increased population densities and a geographical coverage expansion as well. The Continental Terminal aquifer, major groundwater resource taped in this region by the national water companies and local populations, shows a continuous downward trend in piezometric levels. Concerning water quality, the evolution up to the current state (saline intrusion, nitrate pollution) and the natural geochemical process (dilution, redox reactions) affecting the aquifer have been highlighted. The results confirm the urgent need to consider groundwater development relatively to demographic and economic growth. Some management approaches have been proposed including monitoring of contamination, protection of the resource and the use of shallow large-diameter wells, which have proved to be less saline and more sustainable than deeper small-diameter boreholes. The results and discussion of this paper have provided a considerable new insight of West African coastal cities. This will help stakeholders involved in local development to face the urban pressure.

1. Introduction

Millions of big cities inhabitants around the world depend on groundwater for drinking water supplies either as exclusive public water supply or as alternatives for the limited surface water resources. However, it is increasingly reported that aquifers in urban areas are deteriorating in water quality (Chilton, 2005; Morris et al., 2003; Lerner, 2014; Costa et al., 2016). There is no predefined strategy, set to handle the growing problem. Nowadays, more people in the world live in urban areas (54% in 2014) than in rural areas (United Nations, 2014). This percentage was 30% in 1950 and is expected to reach 66% by 2050, with nearly 90% of the increase to take place in the urban areas of Africa and Asia (Floater et al., 2014; United Nations, 2014). As the world continues to urbanize, sustainable development challenges will be increasingly concentrated in cities, particularly in the lower-middle-income countries where the pace of urbanization is the fastest (United Nations, 2014). African cities particularly constitute a good example of this evolution. However, the incomes are much lower in these cities than in other developing regions with similar urbanization levels. Also the capital investment in these cities' infrastructure, industrial, and commercial structures remains relatively low (Vinay et al., 2017) and key population facilities such as water supply, sanitation and drainage networks come later in this urbanization process. One region that combines all of these features is the Gulf of Guinea.

The Gulf of Guinea, widely considered as one of the most dynamic regions in sub-Saharan Africa in the global energy sector, is of critical importance for the economic development of much of the Atlantic Coast of Africa (Jenkins and Edwards 2006). This dynamism is demographically characterized by a growth of rare magnitude (on average 2.2–4% per year over the last three decades) expressed by a large movement of people from the countryside to the coastal cities due to economic reasons. Given their geographical position, cities of the Guinean coast ensure the transit of goods from the rest of the world to several Sahelo-Saharan countries (e.g., Burkina Faso, Mali, etc.) and fuel the growth of landlocked countries (e.g., Central African Republic, Chad, etc.).

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The coastal cities of the Gulf of Guinea region experiences a humid tropical climate characterized by high rainfall, mostly higher than other parts of Africa, responsible for large surface water masses. Braune and Xu (2009) show that in terms of the present conditions, the hydrologic function and distribution of groundwater are also highly correlated with rainfall patterns in this region. However, groundwater resources are not only influenced by the precipitation height but they also vary substantially according to the geological features of the area, which mainly comprise crystalline basement rock (40%), consolidated sedimentary rocks (32%), unconsolidated sediments (22%), and volcanic rocks (6%) (Mac Donald and Davies, 2000).

Unconsolidated and consolidated sediments found in the study area contain substantial shallow groundwater (often in unconfined conditions) that is commonly used by the local population as the primary resource for water supply. Despite the apparent abundance of water in this humid tropical region of Africa, access to potable water by the population remains difficult, paradoxically making this area looking like a damp desert. It was estimated in 2014 that more than 1/3 of Abidjan and Cotonou populations did not have access to good water quality (AFRIMAG, 2014). These statistics are even more alarming in Lagos and Douala where this proportion reaches more than half of the population (INSIGHT BDS, 2013). Hydric diseases linked to preferential uses of surface or shallow groundwater are often declared (UNICEF d'Ivoire, 2007; Odoulami, 2009; Guevart et al., 2006). Thus, deep aquifers appear to be of a major interest for their protection from surface pollution and their natural protection that make them easier for treatment processes. An example of this increasing interest on this groundwater potential, the number of boreholes in Douala, accounting for 300 in 1996, has been multiplied by ten during the last decade (Ketchemen-Tandia 2011).

In addition, urbanization has hydrological impacts including increases in peak runoffs (caused by increased urban fringe impermeability), deterioration in the quality of both surface and groundwater resources, and changes in frequency and volume of groundwater recharge (Foster, 1999). Added to these features, the increase in the number of inhabitants leads to an over-exploitation that in turn enhances the vulnerability of groundwater. Inadequately controlled groundwater exploitation is well known to result in an increase in the scarcity of water resources, which may largely contribute to the escalation of water supplies costs (Morris et al., 1997) and lead to potential conflicts (Foster et al., 2003). Moreover, over-exploitation can generate quality problems due to the contamination of good quality groundwater masses by seawater in coastal cities, or by superficial aquifers and/or surface waters suffering from an anthropogenic pollution.

This paper focuses on the impacts of urban development on aquifers in coastal large cities of West Africa located around the Gulf of Guinea: Abidjan, Cotonou Lagos and Douala (Fig. 1). All of these cities are economic capitals occupying a strategic position in the sub-regions of western and central Africa, concentrating more than 2/3 of national industrial production and the greatest part of the population of Côte d'Ivoire, Benin, Nigeria and Cameroon, respectively (Kouakou Yao et al., 2010; Mairie de Cotonou, 2008; Opoko and Oluwatayo, INS, 2011). These cities have been selected in this work according to their fast urbanization and wide range of available data (environmental, societal and hydrogeochemical).

The objective of this paper is to describe the importance of groundwater in the water supply of these four major cities in sub-Saharan Africa and to examine the impact of urbanization on quality and quantity of groundwater. The history of urban development, current groundwater management practices, policy implications and future challenges are also discussed as well as the evolution of climatic parameters and their possible impact on the resource.

2. Studies areas – overview

2.1. Location, climatology and hydrography

The Gulf of Guinea is the north easternmost part of the tropical Atlantic between Cape Lopez in Gabon and Cape Palmas in Liberia. The location of the four studied sites with mean monthly precipitation is illustrated in Fig. 1.

Although some differences in environment resources and economy, those four cities present some similarities. Indeed, the mean annual temperatures are the same with a value of about 27 °C. The moisture inputs in the region originate directly from the Atlantic Ocean. Recordings of rainfall amounts over more than five decades vary from 1 330 mm in Cotonou to ~ 4000 mm in Douala, with intermediate values of 1 920 mm in Abidjan and 1 515 mm in Lagos. The precipitation decreases in the west-northwest direction from the Cameroon coast to Accra (semi-arid coast) then increases to Liberia, where rainfall reach 5000 m/year in Free Town.

The regional hydrography is shaped by many rivers flowing to the

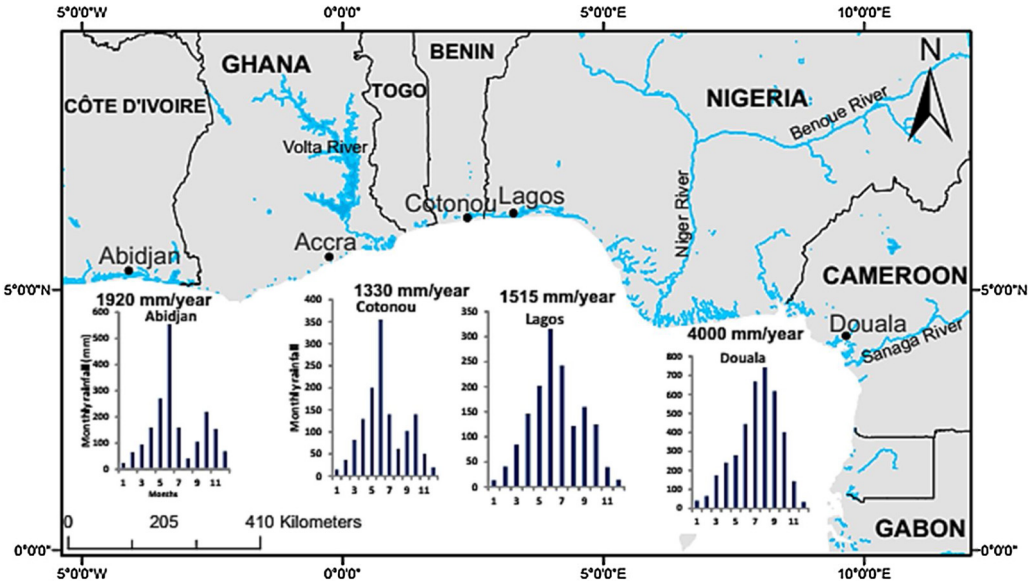

Fig. 1. Location of the four study sites (Abidjan, Cotonou, Lagos, and Douala) in the Guinean coastal area. The monthly rainfall distribution of each site is also presented.