Groundwater pollution and the safe water supply challenge in Cotonou town, Benin (West Africa)

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Abstract Environmental change has impacted water systems inducing groundwater pollution in the town of Cotonou, in Benin, West Africa. Accordingly, it is important to improve the understanding of the drinking water supply problem, focusing on key aspects of the pollution problem and alternative approaches to the provision of safe water for human consumption. This study was based on the integration of existing literature, physicochemical and bacteriological analyses, assessment of drinking water quantity and the returns from participative investigations. Water quality standards in Benin reflect those set by the World Health Organization (WHO). The results of the study suggest that the shallow aquifer (depth less than 2 m) is more polluted by wastes and often by septic tanks situated less than 5 m from water sources. Groundwater mineralization depends on human activities, induced recharge and saltwater intrusion. Bacteria counts frequently exceed drinking water guidelines and standards (0 coliform counting units (CFU)/100 ml). Given these pollution problems, the shallow Quaternary aquifer is excluded for drinking water supply which is restricted to the Continental Terminal aquifers on the Plateau of Allada. Sustainable safe water supply is dependent on groundwater quality protection using an ecosystems approach, deep aquifer water extraction and rational water use by multiple consumers.

Key words Cotonou, Benin; groundwater quality; ecosystems approach; safe water; sustainable potable water supply

INTRODUCTION

Urbanization and rapid population growth (320 332 inhabitants in 1979 compared to approx. one million inhabitants in 2012) with an annual rate of 2.07% in the town of Cotonou (79 km^2) have induced increasing water demand (about 66 m^3/day by 2012).

Groundwater is the preferred source for piped water supplies in many urban areas across Sub-Saharan Africa and its development is forecast to increase dramatically in an attempt to improve urban water supply coverage (Adelana *et al.*, 2008). But, natural factors such as geological controls, topographic variation and hydroclimatic variability, combined with various human factors (demographic pressure, uncontrolled land use, etc.) influence environmental health and water supply systems. Kouadio *et al.* (1998), Jourda (2003) and Soro (2003) reported that, like other coastal cities of Western Africa, the recent increased population of Abidjan has resulted in environmental problems such as the deterioration of drinking water quality and quantity.

In Cotonou, shallow groundwater is the most detrimentally impacted by uncontrolled land occupation due to the higher density (10 431 people/km^2) of population. This population growth has seriously compromised access to safe water (Odoulami, 2009) on account of groundwater physicochemical and bacteriological pollution (Boukari, 1998; Adékambi & Adamou, 2000; Ahoussinou, 2003; Boukari *et al.*, 2008; Totin, 2010a).

Cotonou town is located in the lowest coastal sandy plain of Benin, between 6°20' and 6°23' N. It is established on a site that is between 4 and 6 km long, formed by a succession of offshore bars, lagoons and marsh, between the Atlantic Ocean and Lake Nokoue (Fig. 1). Its relatively flat topography has an altitude varying between 0.4 and 6.5 m (Fig. 2). Soils are generally sandy with 80% being coarse sand and having a porosity exceeding 40% and a water storage coefficient of 20% (Maliki, 1993). These characteristics facilitate water infiltration and the fast transfer of pollutants towards the main aquifers.

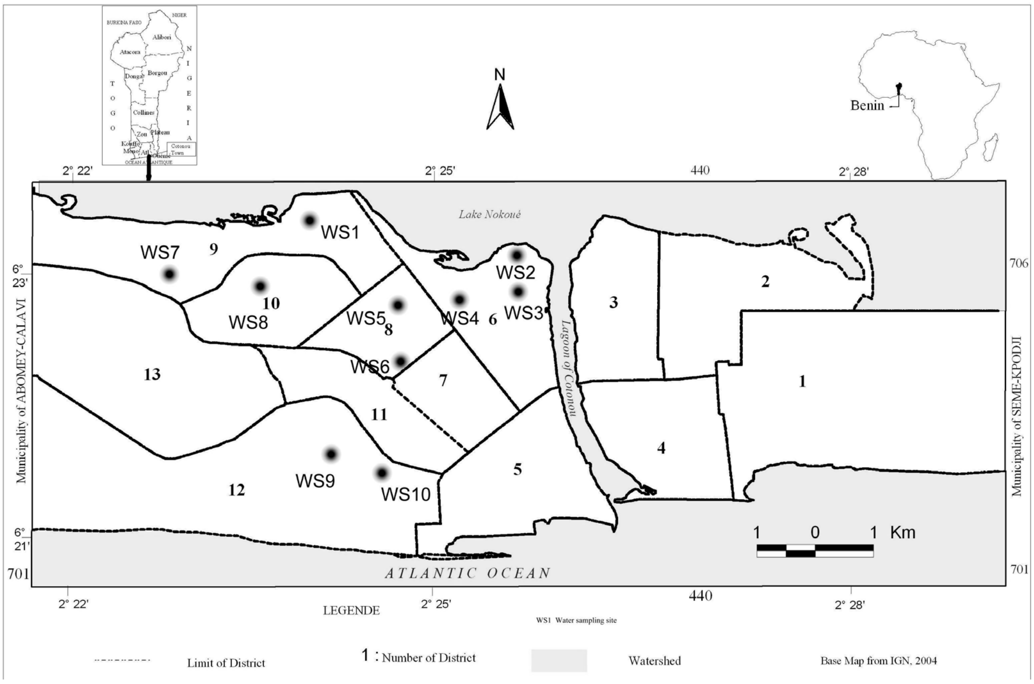

Fig. 1 The geographical location of Cotonou town and the study sites.

Cotonou town is in the hot and wet subequatorial climatic zone, characterized by two annual rainy seasons (March to July and September to October) and two dry seasons (November to March and August). Monthly average rainfall was 109.6 mm over the period 1951–2010 (Totin, 2010a) while potential evapotranspiration reaches 136 mm. Monthly average temperatures vary from 30.6°C in March to 24.3°C in August (Totin, 2010a). In this hydroclimatic context, rapid decomposition of waste occurs, enhancing the risk of pollutant transfer towards the key aquifers.

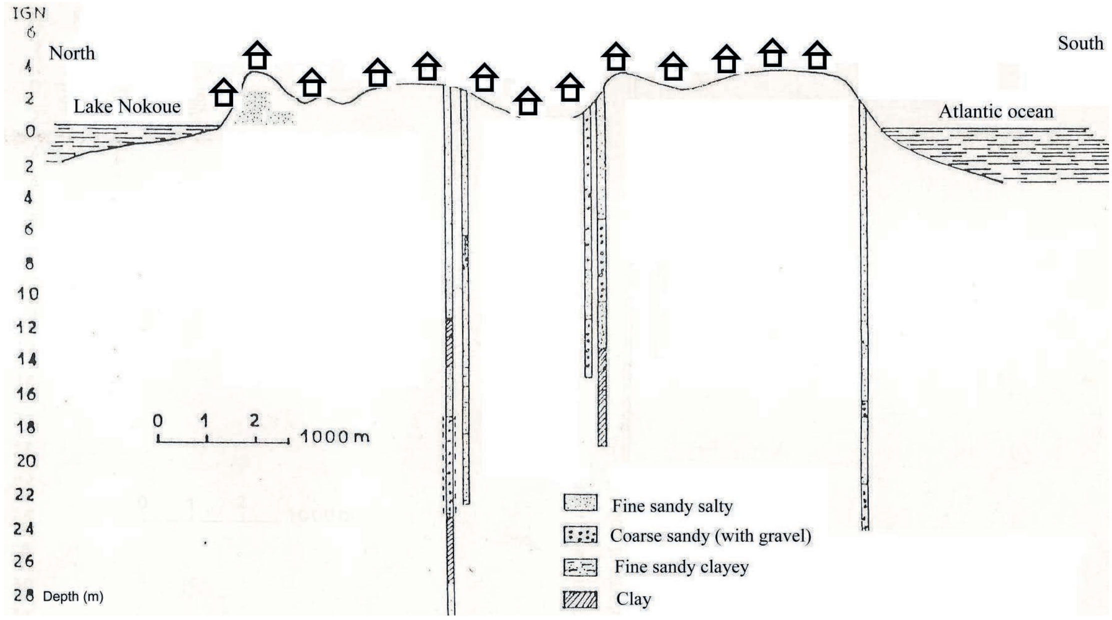

Fig. 2 Cross-section of the offshore bar in Western Cotonou.

Given the vulnerability of groundwater supplies to pollution, it is important to strengthen the management of drinking water supply in Cotonou, using alternative approaches to safe water provision for its increasing population.

DATA AND METHODS

Data

Existing literature (Boukari, 1998; Adékambi & Adamou, 2000; Boko, 2001; Guendehou, 2002; Ahoussinou, 2003; Konmy, 2005; Odoulami, 2009; Totin 2010a,b) was used to help to assemble data related to the problems of environmental change and water pollution in the town of Cotonou. In addition, data were available from groundwater samples collected through the town at various sites (Fig. 1) selected on the basis of various criteria for environment health and the existence of a rubbish tip, proximity of the water supply point to waste or excreta disposal or latrine pits, human pressure on urban land, etc. These indicators of the risk of environmental pressure on groundwater supplies support identification of sites prone to groundwater contamination and help identify potential sources of the pollution problem.

The data used by this study also included the compliance of water quality in Cotonou town with the WHO (2008) drinking water guidelines and standards, as well as information on the number of urban inhabitants and water demand.

Methods

To assess water quality, a number of physicochemical and bacteriological properties of the groundwater samples were analysed. These analyses generated data for nitrogen, sodium and chloride, as well as bacteria content such as total coliforms, *Escherichia coli* and faecal streptococcus.

The key physicochemical parameters were analysed using an Ionic Chromatograph DIONEX ICS 1000 in the Laboratory of Applied Hydrology (LHA) at the University of Abomey-Calavi in Benin. The Laboratory of the National Company of Safe Water Supply for urban areas (SONEB) in Benin contributed to the identification of bacterial pollutants in the water samples using the membrane filter technique with specific culture media: Mac Conkey agar (for coliforms), Slanetz and Bartley agar (for streptococcus) and Eosin methylene blue agar (EMB) (for enterobacteria such as *Escherichia coli*). Water quality compliance was assessed *versus* the drinking water standards of the WHO (2008) referred to as the Maximal Allowable Concentration (MAC) for the chemical parameters and Maximum Allowable Value (MAV) for the bacteria content.

Water pollution sources were identified by participative investigations in the urban area of Cotonou deploying a Rapid Assessment Methodology (MAP). Accordingly, direct observations were used to identify environmental impacts and to evaluate the population behaviours which contribute to aquifer deterioration. Moreover, focus group (5–10 persons) discussions helped to assess popular perceptions of the groundwater pollution problem and the potential strategies for providing safe water for supporting future population growth (1 088 699 in 2025 and 1 860 113 in 2050) in Cotonou.

RESULTS AND DISCUSSION

Groundwater quality and pollution sources in Cotonou

In Cotonou town, groundwater is currently extracted from the shallow aquifer (1 to 2 m depth). It is extracted through various wells which are often unprotected (Fig. 3). The increasing vulnerability of the shallow aquifer to contamination and pollution is a product of the geological context (sandy layer), local topography, the location of the town in the complex hydrological context formed by its juxtaposition to the sea (Atlantic Ocean), lake (Nokoue) and lagoon (of Cotonou), as well as land use or cover change due to demographic pressure and uncontrolled land occupation.

Assessment of the groundwater quality generated data for the concentrations of pollutants: nitrogen (5.05–68.6 mg L^{-1}), sodium (74–78.3 mg L^{-1}) and chloride (1.82–319.5 mg L^{-1}).The changing chemical composition of groundwater in various climatic contexts is related to ion exchange, rock dissolution or weathering, seawater intrusion and contamination from human pollution, etc.

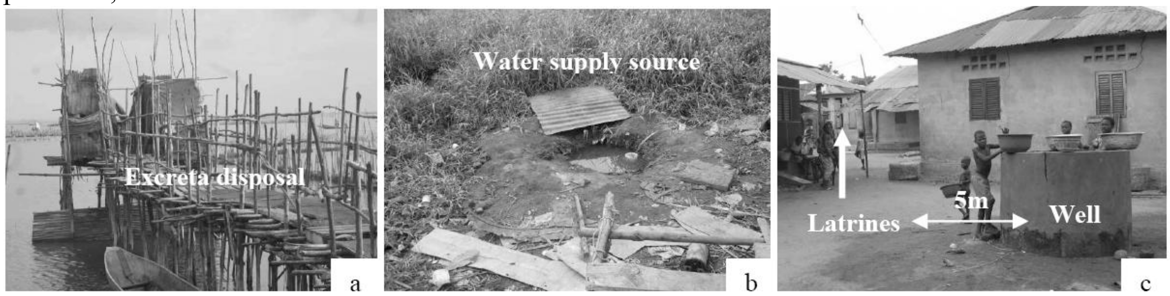

Fig. 3 Water supply sources in the context of environmental pressures in Cotonou: (a) inadequate excreta disposal on Lake Nokoue; (b) contamination around the water supply source; and (c) lack of distance between pit latrine and well in the context of current WHO standards (15 m).

So, the main sources of nitrate in local drinking water were identified as agricultural contamination during the wet season followed by the transfer of this contamination by recharge (by wastewater) during the dry period (Totin, 2010b). Kortatsi *et al.* (2007) suggested that NO_3^-, Cl^- and SO_4^{2-} loadings in groundwater supplies were positively correlated with anthropogenic sources, including pollution from human-induced activities such as inorganic fertilizer or animal manure applications to land and the construction of pit latrines. In Cotonou, these environmental factors undoubtedly help to degrade groundwater (Boukari, 1998; Boukari *et al.*, 2008; Odoulami, 2009; Totin, 2010b; Totin *et al.*, 2012) so that water supply is compromised because of its degraded quality.

Bacteriological analysis has helped to highlight bacterial pollutants like total coliforms, *Escherichia coli* and faecal streptococcus which consistently exceeded drinking water guidelines and standards (0 CFU/100 ml) set by the WHO (2008). The main sources of bacterial pollution of groundwater in Cotonou, as shown in Fig. 3, include waste deposits, inadequate toilets and pit latrines (situated less than 5 m from the water source), septic tanks which are prone to leakage and hydraulic failure, land-use change and wastewater induced recharge of local aquifers.

During the groundwater recharge period (June to August), organic pollutants (bacteria) are transferred towards aquifers by higher rain and subsequent infiltration, while in the dry season, evaporation increases their concentrations. As a result, the concentrations of total coliforms, *Escherichia coli* and faecal streptococcus are commonly too high to count (cf. Gandaho, 1994; Totin, 2010a, Totin *et al.*, 2012). According to Khan & Khan (1985) and Narayani (1990), the strong presence of bacteria during the dry season reflects temperature rise, which increases microbial activities, thus causing an excessive production of CO_2. Unprotected wells are generally flooded in the rainy season (April–July and September–October) and are frequently polluted by waste and excreta coming from inadequate latrines. So to reduce groundwater vulnerability in the rapidly changing environment of Cotonou, adequate strategies are needed to provide safe water in the context of the increasing population and the pressures that inevitably come with such growth.

Strategies to cope with the safe water supply challenge

In the above context of water system vulnerability and increasing groundwater pollution, the shallow Quaternary aquifer is currently excluded from drinking water supplies (Boukari, 1998), which are reliant on the Continental Terminal aquifer of the Plateau of Allada far from Cotonou (Fig. 4). The extraction of water from deep aquifers on the plateau of Allada is therefore expected to offset the contamination problem for the shallow groundwater supplies and the growing demand for potable water.

Groundwater pollution is insidious and expensive to treat; insidious because it takes many years to show its full effect in the quality of water pumped from deep wells, and expensive, because, by the time it is detected, the cost of remediation of polluted aquifers is often extremely high (Mehta, 2006). The sustainable safe water supply for Cotonou town will therefore rely on improved and targeted groundwater quality protection using an ecosystems approach.

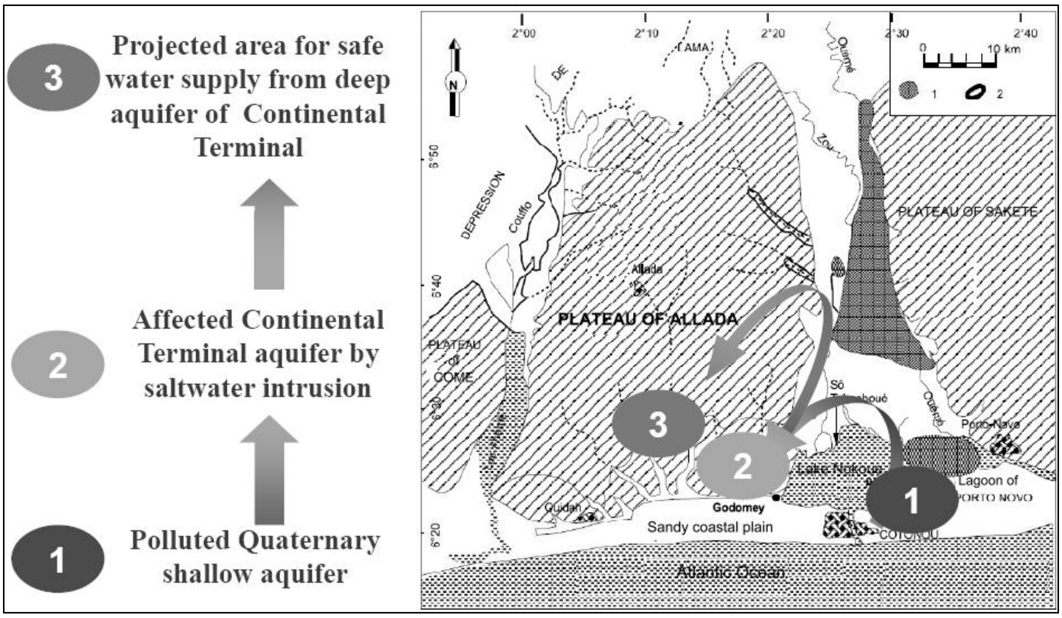

Fig. 4 Moving trajectory of the potable water supply managed by the National Company of Safe Water Supply for the urban area (SONEB) in Benin.

A report by the WHO (2004) suggested that the improvement of water quality control strategies, in conjunction with improvements in excreta disposal and personal hygiene, can be expected to deliver substantial health gains for those clusters of population dependent on specific water supply sources.

Groundwater protection will be improved by appropriate excreta, solid waste and wastewater treatment and disposal. An improved excreta management strategy will require the installation of individual or public latrines in order to avoid indiscriminate defecation. But, in the disadvantaged areas of Cotonou, the WHO standards for latrine installation (the bottoms of latrines to be at least 1.5 m from the top of the groundwater aquifer; a distance of 6 m between water sources and pit latrines; a distance of 15 m between water source and latrines) cannot be respected at all times. A part of Cotonou town with private occupation land (20 m × 20 m plots) does currently allow the construction of improved latrines with waterproof tanks. These systems use the excreta disposal specifications of the ECOSAN latrine which consists of semi-buried or raised tanks with provision for the separation of faeces and urine (Konmy, 2005). This type of latrine system consistently helps to avoid the contamination of groundwater by human faecal waste.

The continued success of these types of groundwater pollution control strategies in the town of Cotonou requires: (1) the development of an Environmental and Sanitary Information System (ESIS) for supporting decision making; (2) taking account of the WHO directives for latrine and water sources installation (a big challenge in the urban areas of Cotonou); (3) incentives for maintaining safe drinking water supply from the National Company of Safe Water Supply for the urban area (SONEB), or for using individual water treatment techniques; (4) proper delimitation of the aquifer recharge area and the banning of human occupation therein; and (5) rational water use by the growing population.

CONCLUSION

In Cotonou town, the most urbanized and densely populated part of Benin, the shallow aquifer (Quaternary aquifer) is polluted due to the natural conditions and human pressures arising from population growth. This coastal town is therefore confronted with the serious problem of water scarcity on account of declining groundwater quality.

To face the safe water supply challenge for increased demand due to demographic pressures, groundwater pumping areas are moving from the coastal sandy plain (Quaternary shallow aquifer) towards the plateau of Allada (Continental Terminal deep aquifer). An ecosystems approach could be adopted to help improve the protection of groundwater quality and to provide sustainable safe drinking water to the growing population of the coastal region of West Africa.

Acknowledgements The authors acknowledge funding from the Global Change System for Analysis, Research and Training (START) within the Global Environmental Change (GEC) Research Project.

REFERENCES

Adékambi, E.C. & Adamou, B.Z. (2000) Contribution à la gestion des excréta, à l'approvisionnement en eau dans la ville de Cotonou en temps normal et en période d'inondation. Mémoire de Master, Université Nationale du Bénin, Cotonou, Bénin.

Adelana, A.M.S., Abiye, A.T., Nkhuwa W.C.D., Tindimugaya, C. & Oga, S. M. (2008) Urban groundwater management and protection in Sub-Saharan Africa. In: *Applied Groundwater Studies in Africa* (ed. by S. Adelana & A. MacDonald), 13, 231–260. CRC Press/Balkema.

Ahoussinou, A.S. (2003) Pollution fécale de la nappe phréatique et comportement des populations à Cotonou. Mémoire de Master, Université d'Abomey-Calavi, Cotonou, Bénin.

Boko, M. (2001) Recherche en écologie urbaine à Cotonou : Cas des quartier périphériques du lac Nokoué entre Mènontin et le chenal. *Rapport du Conseil Scientifique de l'Université d'Abomey*-Calavi, Cotonou, Bénin.

Boukari, M. (1998) Fonctionnement du système aquifère exploité pour l'approvisionnement en eau de la ville de Cotonou sur le littoral béninois. Impact du développement urbain sur la qualité des ressources. Thèse Doctorat ès-Science. Université Cheick Anta Diop de Dakar, Sénégal.

Boukari, M., Viaene, P. & Azonsi, F. (2008) Three-dimensional modelling of a coastal sedimentary basin of southern Benin (West Africa). In: *Applied Groundwater Studies in Africa* (ed. by Segun Adelana, Alan MacDonald), 13, 437–456. CRC Press/Balkema.

Comlanvi, F.M. (1995) Amélioration de la qualité des eaux de puits dans la ville de Cotonou : Cas de quelques quartiers. Mémoire de Master, Université Nationale du Bénin, Cotonou, Bénin.

Gandaho, P.S. (1994) Problème de pollution de la nappe phréatique de Cotonou: Etude comparative et perspectives d'aménagement. Mémoire de Master, Université Nationale du Bénin, Cotonou, Bénin.

Guendéhou, F.J.C. (2002) La gestion des excréta en milieux marécageux : cas de la ville de Cotonou : Conséquences sur la santé publique et perspectives. Mémoire de Master, Université Nationale du Bénin, Cotonou, Bénin.

Jourdan, J.R.P. (2003) Evaluation de la pollution et de la vulnérabilité des aquifères des grandes cités urbaines d'Afrique: La Côte d'Ivoire. *Rapport du Projet UNEP/UNESCO/UN-HABITAT/ECA*, Abidjan, Côte d'Ivoire.

Khan, I.A. & Khan, A.A. (1985) Physico-chemical conditions in SeikhaJheel at Aligarh. *Journal of Environment Ecology* 3, 269–274.

Konmy, R.D. (2005) Les latrines écologiques, une nouvelle approche de gestion des excréta : Cas de Communes de Cotonou et d'Abomey-Calavi. Mémoire de Master de Géographie, Université d'Abomey-Calavi. Cotonou, Bénin.

Kortatsi, K.B., Anku, A.S.Y. & Anornu, K.G. (2007) Characterization and appraisal of facets influencing geochemistry of groundwater in the Kulpawn sub-basin of the White Volta Basin, Ghana. *Environ. Geol.* 1638-9, doi:10.1007/s00254-008.

Kouadio, L.P., Abdoulaye, S., Jourda, P., Loba, M. & Rambaud, A. (1998) Conséquences de la pollution urbaine sur la distribution d'eau d'alimentation publique à Abidjan. *Cahier de l'Association Scientifique Européenne pour l'Eau et la Santé* 3, 61–75.

Maliki, R. (1993) Etude hydrologique du littoral béninois dans la région de Cotonou (Afrique de l'Ouest). Thèse de Doctorat de 3ème cycle, Université Cheick Anta Diop, Dakar, Sénégal.

Mehta, M. (2006) Status of groundwater and policy issues for its sustainable development in India. *Groundwater Research and Management: Integrating Science into Management Decisions*. (ed. by B. R. Sharma, K. G. Villhoth& K. D. Sharma), 62–76. Malhotra Publishing House.

Narayani, N. (1990) Seasonal changes in abiotic parameters of eutrophic wetlands (lower lake, Bhopal). *Advances in Environmental Biopollution*. (ed. by A.C. Shula, A. Vandana, P.S. Trivedi & N.S. Pandey), 155–163. A.P.H. Publishing Corporation.

Odoulami, L. (2009) La problématique de l'eau potable et la santé humaine dans la ville de Cotonou (République du Bénin). Thèse de Doctorat, Université d'Abomey-Calavi, Cotonou, Bénin.

Soro, N. (2003) Gestion des eaux pour les villes africaines : évaluation rapide des ressources en eau souterraine/occupation des sols. *Rapport final de UN-HABITAT*, Nairobi, Kenya.

Totin, V.S.H. (2010a) Sensibilité des eaux souterraines du bassin sédimentaire côtier du Bénin à l'évolution du climat et aux modes d'exploitation : Stratégies de gestion durable. Thèse de Doctorat, Université d'Abomey-Calavi, Cotonou, Bénin.

Totin, V.S.H. (2010b) Assessment of global change impacts on groundwater in the coastal sedimentary basin of Benin (West Africa). *Global Change SysTem for Analysis, Research and Training (START) Report*.

Totin,V.S.H., Boukari, M., Odoulami, L. & Edorh, A.P. (2012) Qualité bactériologique des eaux souterraines et sources de pollution dans le bassin sédimentaire côtier du Bénin. *Climat et Développement*, 13, 16–27.

WHO (2004) *Guidelines for Drinking-Water Quality*, third edition, vol. 1 *Recommendations*. Geneva.

WHO (2008) *Guidelines for Drinking-Water Quality: Incorporating 1st and 2nd addenda*, vol.1, *Recommendations*, 3rd edn. Geneva.