ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 7 No. 1 March 2021*

Water Appropriations and Groundwater Pollution in Less-Developed Regions

Ahmed Fate Ali
Department of Environmental Management,
Bayero University,
Kano, Nigeria

Email: ahmadpate@yahoo.co.uk

Abstract
This article presents a review of the fundamental principles of freshwater distribution and appropriation within the hydrologic cycle, and the significance of groundwater in potable water supplies and sanitation, especially in urban areas of less-developed regions, like Kano in Nigeria. It also discusses the general aspects of groundwater pollution and vulnerabilities, which are critical to ensuring sustainable groundwater resource management. The review also highlights the significant reliance on untreated groundwater resources for drinking in many parts of the less developed regions. Many of the regions' poor are reliant on unprotected, often, contaminated groundwater sources to meet their potable needs. This underscores the need for protecting the quality of groundwater aquifers if public health is not to be compromised, especially in the most vulnerable communities.

Keywords: freshwater, hydrologic cycle, water supply, sanitation, groundwater pollution

Introduction
Water is an essential element for sustenance of life, supporting healthy environment, maintaining ecosystems and socio-economic development (Ali & Young, 2013). In recent years, however, there has been growing concern over a global water crisis resulting from increasing demand and competition between the various water users, contamination of water resources and degradation of ecosystems due to poor management (Gleick & Palaniappan, 2010).

Underlying those factors are continuing population growth, urbanization, industrialization and intensification of agriculture. As the world population increases rapidly, more densely populated urban areas evolve that need to be catered for in terms of food and livelihood, thus, increasing industrialisation and agriculture (UN-DESA, 2011). Noteworthy, however, most of this growth is concentrated in the less-developed regions, with sub-Saharan Africa (SSA) having the highest rate of urban population growth of 4.1% per annum, compared to the global rate of 2.0% (Santos *et al.*, 2017) and 3.5% for the entire less-developed countries (Fotso *et al.*, 2007). While around 40% of SSA's total population lived in urban areas by 2010, it is expected that, by 2030, about half of its total population would be in urban areas (AfDB, 2012). A great challenge, therefore, is to make these urban centres habitable by providing every citizen with the required basic services of acceptable quality.

These growths are accompanied by an unprecedented increase in water consumption and emission of high levels of wastes that often result is the deterioration of environmental quality (UNEP, 2010; Ali & Young, 2014). The resultant pressure is pushing the earth closer

*Author for Correspondence

to the limit of its carrying capacity. These challenges have been studied extensively across many countries by several researchers (such as, Shiklomanov & Rodda, 2003; Gleick, 2003; Gleick & Palaniappan, 2010; Nandalal, 2010). In sub-Saharan Africa where population growth is staggering (Hove *et al*., 2013), the per capita water demand is increasing primarily as a result of rapid industrialization and urbanization whereas, the per capita water availability is decreasing not only by the population growth, but also due to misuse and poor management (Gleick & Palaniappan, 2010).

To address these global challenges, individual countries must look inward to their situations and devise local solutions. Also, these issues should be approached holistically in order to protect the quality of freshwater resources and encourage their sustainable utilisations. This is the basis upon which this article was based. It presents a review of the fundamental principles of freshwater distribution and appropriation, significance of groundwater in potable water supplies, aspects of groundwater contamination in addition to some key challenges affecting sustainable water supplies especially in urban areas of less-developed countries.

Global Freshwater Distribution

The occurrence, distribution, movement and properties of water on earth are the fundamental principles of hydrology. As a concept, hydrology is centred on the hydrologic cycle, which is a solar-powered system that supplies and removes water from the earth's surface. By that means, freshwater reaches the land through precipitation and is then recycled continuously as a result of evaporation powered by solar energy (Shiklomanov& Rodda, 2003). Figure 1 illustrates the various components in the hydrologic cycle.

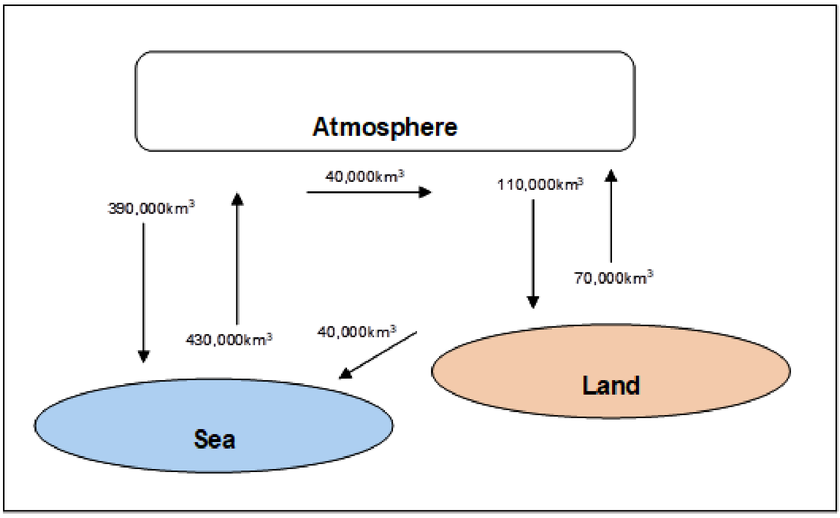

Figure 1: Simplified hydrologic cycle

Energy from the solar system and atmospheric moisture are the primary ingredients for precipitation that falls over oceans and land. On land, precipitation can infiltrate the soil, percolate downward to the underlying groundwater aquifer, evapo-transpire from confined areas and vegetation back to the atmosphere, or flow to the surface water. Because of the hydraulic interconnectivity between surface water and groundwater aquifers, the latter can be recharged by the flowing rivers and can act as discharge points for aquifer outflows. Eventually, the surface and groundwater from surrounding land areas reaches the ocean, which is the main source of water for evaporation back to the atmosphere (Shiklomanov & Rodda, 2003; Gleick, 2003; Gleick & Palaniappan, 2010; Nandalal, 2010). Therefore, there is a continuous transfer of fresh water from the oceans to the land in terms of precipitation, and vice versa in terms of runoff.

In terms of total volume, Earth has abundant water resources; an estimated 1.4 billion km^3 of water in numerous forms and qualities, in various stocks and flows in the hydrologic cycle. However, about 97% occurs as saline found in the oceans and seas. Of the remaining 3% that is low in dissolved salts, nearly 70% exists in the form of permanent ice or snow in the polar ice caps, and about 30% in deep groundwater aquifers (Gleick, 2004). The principal sources of usable freshwater are lakes, rivers, wetland and shallow aquifers, which comprise less than 1% of the total freshwater, and are estimated by Sandhyavitri (2002) to be around 14,000km^3.

Conversely, uneven spatial and temporal variations in the distribution of rainfall, evaporation, groundwater resources and storage sites significantly affect the amount of freshwater readily available for human appropriation. For instance, about 20% of the global surface runoff comes from the Amazon River alone, while the whole of Europe accounts for only about 7% of the global runoff. In Africa, about 30% of the total continental runoff comes from a single Congo/Zaire river basin (Gleick, 2003), while the large sedimentary aquifers in the North African region holding a large proportion of the continent's groundwater reserves. Aquifers of Libya, Algeria, Egypt, Sudan and Chad stores as much as 75×10^6 m^3 $km^{-2}$of groundwater resources (MacDonald *et al.,* 2012).

Furthermore, a significant amount of freshwater is required to sustain natural ecosystems for efficient functioning and environmental sustainability. This requirement is increasingly recognised by many authors (for example: Gleick, 2004; Gleick & Palaniappan, 2010; Dudgeon, 2010). According to Sandhyavitri (2002) as high as 70% of the total accessible freshwater may be needed to sustain the natural ecosystems. Based on this assumption, only about 4200km^3 of freshwater may remain for human consumption.

Indeed, these estimates highlight that, despite the limited availability of freshwater, not all of it is readily accessible for unrestricted human uses. Of growing concern is the rapid growth of the human population, which increases demand pressure and reduces the availability of freshwater per capita. The situation is exacerbated further by the associated human polluting activities such as discharge of untreated sewage and industrial effluents (Rodda, 1995; UNEP, 2010).

It should be noted that in spite of these limitations (in freshwater availability), which are being recognised increasingly, the quantity of freshwater withdrawn and consumed by human activities has been increasing steadily over the last century, and is expected to grow continuously in line with the rapid growth of human population, urbanisation and changing living standards. Many authors, such as Shiklomanov & Rodda (2003) and Gleick & Palaniappan (2010) have estimated that about 5000 km^3/year of freshwater is withdrawn globally for a wide range of human activities. It is, therefore, important to emphasise the significance of more efficient and sustainable utilisation of freshwater resources.

Access to Water Supply and Sanitation in Less Developed Regions
Adequate access to safe water and good sanitation is crucial to maintaining good quality public health. However, despite their importance and the efforts made at various levels of authority around the world, access to these vital utilities remain difficult for many people, especially, in the less-developed regions. A joint monitoring programme for water supply, sanitation and hygiene (WHO/UNICEF, 2019) reported that about 71% of the global population use improved water supply sources, there are yet, over 2.2 billion people living without access to readily available and uncontaminated drinking water sources. These include around 785 million people that lack access to even the most basic unimproved sources. All these people live in less developed regions, with over half of which are in sub-

Saharan Africa, as shown in Figure 2. The lack of access to clean and adequate water supply to many people has led to the widespread use of self-supply options that are often unprotected and contaminated (Smits and Sutton, 2015).

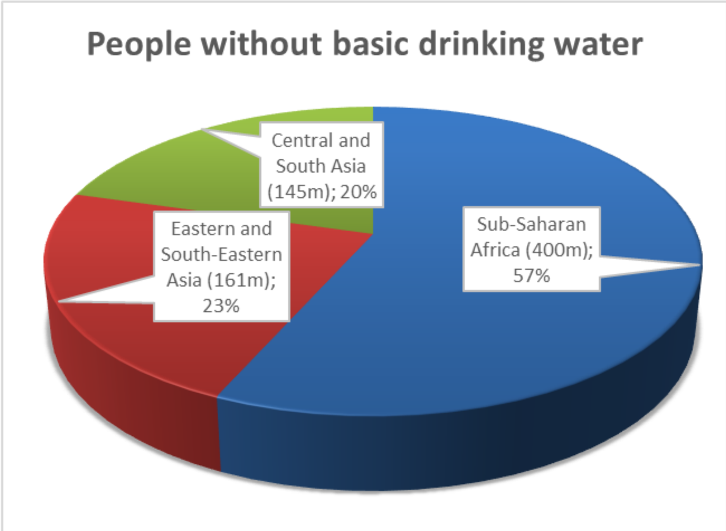

Figure 2: Population without access to unimproved sources of drinking water

Globally, an estimated 2 billion people lack access to the basic sanitation facilities, nearly half of which defecate in the open. Majority of the unserved population live in the less-developed regions, with over 90% of which are in the three regions without access to even the basic drinking water sources, as can be seen in Figure 3. Even among the less-developed regions, the situation in sub-Saharan Africa (SSA) stands alone as only region where the number of people practising open defecation has remained largely unchanged (around 200 million) between 2000 and 2017(WHO/UNICEF, 2019).

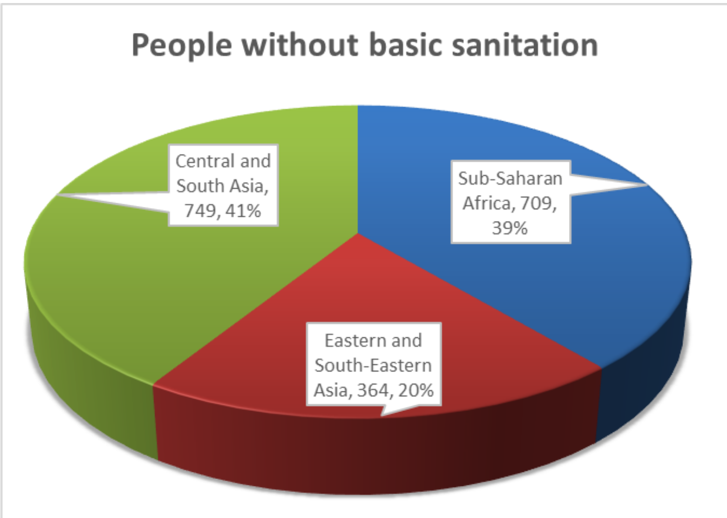

Figure 3: Population without access to basic sanitation facilities

The linkages between provisions of water supply and sanitation (WSS) on one hand, and a cluster of other issues like health, education, agriculture, and environment on the other, have been well documented previously (Gleick, 2003; Shiklomanov & Rodda, 2003; UNICEF/WHO, 2006; Hunter *et al.* 2010; UNICEF/WHO, 2012; Ayyam *et al.*, 2019). Significant linear correlations were reported between poor WSS standards and a decline in indicators in health, education and productivity (Henley, 2000; Pruss-Ustun *et al.*, 2014; World Bank, 2017). According to WHO (2014) and Pruss-Ustun *et al.* (2014), up to 842,000 deaths occurred in the year 2012 due to inadequate WSS and hygiene worldwide. This represents 58% of total diarrhoeal deaths. Diarrhoea remains a major killer but is largely preventable. These underscore the need for a paradigm shift in the region, from the traditionally fragmented approach, to a more holistic, adaptive and sustainable solutions that can address the challenges faced by the less developed regions relating to WSS and the pursuit of sustainable development.

Groundwater Utilisation in Water Supplies

As an important natural resource, groundwater is used widely by humankind for potable uses, agricultural and various industrial activities across many parts of the world. In fact, about half of the global portable water supplies are sourced from groundwater (Smith *et al*., 2016; UNEP, 2010). This includes water supplies in most of the highly populated urban centres in less-developed regions, such as, Jakarta in Indonesia, Lagos, Maiduguri and Kano in Nigeria, Addis Ababa and Mekele in Ethiopia, and Mexico City in Mexico (Mautner *et al*., 2020). For most of these places, groundwater is considered primarily an affordable alternative to the piped water systems that are often difficult for the local authorities to provide (Ali & Young, 2014). It is also favoured because of its wide distribution, dependability and inexpensiveness. Additionally, groundwater tends to have better chemical and microbial quality, in natural state, than surface water. As such, it often requires little or no treatment before use (Morris *et al.*, 2003; Gleick & Palaniappan, 2010; UNEP, 2010).

Across continental Africa, over 75% of the total population are estimated to be reliant, almost exclusively, on groundwater for potable supplies (Lapworth *et al*., 2017). For countries that receive very little precipitation in the region such as Libya, Tunisia, Namibia and Botswana, groundwater represents the single most important source that accounts for nearly all their potable water needs (MacDonald *et al.,* 2012; WWAP, 2012). Given the poor access to access to readily available and uncontaminated drinking water sources in many parts of the less developed regions, many people resort to the use of self-supply options, that include shallow wells and boreholes, for drinking and other domestic purposes without any form of treatment (Smits & Sutton, 2015; Silva *et al.,* 2020). Therefore, development of groundwater resources represents a critical path to increasing water supply coverage in continental Africa (MacDonald *et al.,* 2012). While poorly developed and unsustainable in most cases, these options are, often, the only economically viable water supply option for many people, especially in the rural, peri-urban and urban slums across the regions (Gronwall *et al.,* 2010; Smits & Sutton, 2015; Silva *et al.,* 2020).

Groundwater Pollution

Pollution of groundwater results from a number of naturally occurring and anthropogenic sources of widely varied origin, manifestation and chemistry (Foster *et al.,* 2002). Although, the natural sources are often difficult to control, they are mostly less damaging compared to anthropogenic sources. Most groundwater contamination incidences occur because of various anthropogenic activities subject to the degree of vulnerability of the aquifer to such activity (Dimitriou *et al*., 2008). A range of point and non-point sources of pollution originating from varied land use practices infiltrates the aquifer system and contaminate the groundwater resources. These sources include fertiliser and chemical applications in agricultural processes, increasing urbanization, infiltration of sewage, solid waste leachates, discharge of industrial effluents and many others (Rodríguez *et al*., 2018). Pollution of groundwater resources has been reported in many parts of the world (for example:

Adhikary *et al.,* 2010; Vinod *et al.,* 2015; Ali & Young, 2014). It is established that once groundwater is contaminated, restoration of its quality is technically difficult and economically expensive (Ali & Young, 2014). In fact, full restoration of groundwater quality is even impossible in some cases (UNEP, 2010). Determining the extent of the pollution requires a multitude of physical, chemical and sometimes biological parameters for both the porous medium and the concerned contaminant (Sililo *et al.,* 2001). Because of the complexity of factors surrounding the assessment processes in terms of pollutant loading, mobility and the peculiarity of each situation, groundwater pollution assessments involve a range of activities are conducted under a variety of conditions. These could range from a simple setting that is easy to identify, such as high density of poorly-sealed latrines on a shallow unconfined aquifer, to a highly complicated urban and industrial activities that are very difficult to evaluate.

Groundwater Vulnerability to Pollution

While the significance of groundwater resource utilisation in sustenance of humankind and ecosystems cannot be overemphasised, unsustainable practices could lead to degradation of its quality, often, with overwhelming negative consequences. Naturally, all groundwater aquifers are connected hydraulically to the overlying land surface through complexly interwoven pore fringes. Thus, as the groundwater moves along flow lines from recharge to discharge areas, its chemistry is altered by the effect of a variety of geochemical processes (Suresh & Kottureshwara, 2009)**.** However, a certain combination of geological and hydrological characteristics of an area give rise to situations where a groundwater system is more at risk from any form of pollution than other combinations. This natural inherent phenomenon implies the vulnerability of the groundwater to pollution (Klinck, 1994; Dimitriou *et al.*, 2008).

The degree of vulnerability of an aquifer to contamination therefore depends to a large extent on the effectiveness of this connection. Consequently, groundwater that readily and quickly receives water and contamination from land surface is thus considered more vulnerable than groundwater that receives water and contaminants more slowly and in lower quantities. In line with this, the WHO has classified groundwater vulnerability into four broad categories, as defined in Table 1 (WHO, 2006).

Table 1: Classes of groundwater vulnerability to pollution (WHO, 2006)

Vulnerability class	Definition
Extreme	Vulnerable to most water pollutants with a relatively rapid impact on many pollution scenarios
High	Vulnerable to many pollutants, except those highly absorbed and/or readily transformed, in many pollution scenarios
Moderate	Vulnerable to some pollutants, but only when continuously discharged or leached
Low	Only vulnerable to most persistent pollutants in the very long-term, when continuously and widely discharged or leached
Negligible	Confining beds present and prevent any significant groundwater flow

Generally, groundwater quality depends largely on the relative quantity of contaminants that can reach the aquifer, the travel time of groundwater and contaminants, and the contaminant-attenuation capacity of the geological system. Also, the degree to which attenuation occurs depends on the type of soil and rock, the type of contaminant and the associated activity (Klinck, 1994; WHO, 2006).

Conclusion and Recommendations

The significance of freshwater resources to the survival and efficient functioning of ecosystem cannot be over emphasised. Furthermore, groundwater represents an important component of the available freshwater resources. It is also central to water supply systems in many parts of the world. However, groundwater pollution in urban areas is a growing environmental problem worldwide, especially as many urban areas in the less-developed regions depend on groundwater for drinking purposes. The rapid growth of urbanisation experienced in these regions, especially in SSA, can have a profound effect on the groundwater resources, both quantitatively and qualitatively. Inadequate protection of groundwater resources from anthropogenic contamination represents one of the greatest challenges facing the present generation, especially the populations in cities of less-developed countries. Unlike the situation in most parts of the more-developed regions, where public perception of groundwater protection is geared towards a more preventive approach, groundwater protection measures in less-developed regions are often non-existent or are initiated at a stage where severe contamination has already occurred. It is, therefore, recommended for the communities in less-developed countries to experience a paradigm shift from the existing curative 'fire brigade' approach to preventative and more sustainable solutions. To achieve that, there need to be an effective precautionary plan for the various forms of land use and human activities, which can be used as a guide in the regulation and supervision of groundwater operations. These require a range of information, such as the hydrogeological conditions and possible pollution sources that can be gathered through strategic activities that include: identification and mapping of sources of pollution; establishment of a database and information management system; development of groundwater vulnerability map; assessing groundwater protection needs and priorities; initiation of a monitoring network; integration of groundwater protection in the urban planning process, legislation and institutional coordination; establishment of protection zones; and promotion of public awareness and participation.

References

Adhikary, P. P., Chandrasekharan, H., Chakraborty, D. and Kamble, K. (2010). Assessment of groundwater pollution in West Delhi, India using geostatistical approach. Environ Monit Assess 167: 599–615.

AfDB, (2012). Briefing Note 4: Africa's Demographic Trends. Briefing Notes for AfDB's Long-Term Strategy. African Development Bank Group.

Ali, A. F., and Young, R. J. (2014). An assessment of groundwater contamination around a solid waste disposal site in Kano, Nigeria. Waste Management and the Environment VII, 180: 317-323.

Ali, A. F. and R.J. Young (2013). Effects of waste disposal sites on groundwater quality in Urban Kano, Nigeria. Proceedings Sardinia 2013, Fourteenth International Waste Management and Landfill Symposium. S. Margherita di Pula, Cagliari, Italy. CISA Publisher, Italy

Ayyam V., Palanivel S. and Chandrakasan S. (2019). Water Resources and the Changing Needs. In: Coastal Ecosystems of the Tropics - Adaptive Management. Springer, Singapore.

Dimitriou, E., Karaouzas, I., Sarantakos, K., Zacharias, I., Bogdanos, K. and Diapoulis, A. (2008). Groundwater risk assessment at a heavily industrialised catchment and the associated impacts on a peri-urban wetland. Journal of Environmental Management, 88 (3): 526–538.

Dudgeon, D. (2010). Prospects for sustaining freshwater biodiversity in the 21st century: linking ecosystem structure and function. Current Opinion in Environmental Sustainability, 2(5-6): 422-430.

Foster, S., Hirata, R., Gomes, D., D'Elia, M. and Paris, M. (2002). Groundwater quality protection: a guide for water utilities, municipal authorities and environment agencies. World Bank, Washington DC.

Fotso J., Ezeh A. C., Madise N. J. and Ciera1 J. (2007). Progress Towards the Child Mortality Millennium Development Goal in Urban sub-Saharan Africa: the Dynamics of Population Growth, Immunization, and Access to Clean Water. BMC Public Health 7:218. Available at: http://www.biomedcentral.com/1471-2458/7/218

Gleick, P. H. and Palaniappan, M. (2010). Peak Water: Conceptual and Practical Limits to Freshwater Withdrawal and Use. Proceedings of the National Academy of Sciences (PNAS), Washington, D.C.

Gleick, P. H. (2003). Global Freshwater Resources: Soft-Path Solutions for the 21st Century. Science of the Total Environment, 302: 1524-1528.

Gleick, P. H. (2004). The world's water: 2004-2005: the biennial reports on freshwater resources. Washington, D.C, Harper Perennial.

Gronwall, J. T., Mulenga, M. and McGrananhan, G. (2010) Groundwater Self-Supply and Poor Dwellers – A Review with Case Studies of Bangalore and Lusaka. IIED – Human Settlements Programme Publication. IIED, London, UK.

Henley, D. (2000). Nigeria Water Supply and Sanitation Strategy; Nigeria Water Sector available at: www.nws.org/henley/Nwss/strategy.pdf

Hove, M. (2013) The Urban Crisis in Sub-Saharan Africa: A Threat to Human Security and Sustainable Development. Stability, 2(1): 1-14.

Hunter, P. R., MacDonald, A. M., and Carter, R. C. (2010). Water supply and health. *PLoS medicine*. *7*(11): 1-9

Klinck, B. A. (1994). A Review of Hazard Ranking Schemes for Waste Disposal. British Geological Survey Technical Report WC/94/76.

Lapworth, D. J., Nkhuwa, D. C. W., Okotto-Okotto, J, Pedley, S., Stuart, M.E., Tijani, M.N. and Wright, J. (2017). Urban groundwater quality in sub-Saharan Africa: current status and implications for water security and public health. Hydrogeol J. 25:1093–1116

MacDonald A.M, Bonsor, H. C., Dochartaigh, B. E. O. and Taylor, R. G. (2012). Quantitative maps of groundwater resources in Africa. Environ. Res. Lett., 7: 1-7.

Mautner, M., Foglia, F., Herrera, G., Galán, R. and Herman, J. (2020). Urban growth and groundwater sustainability: Evaluating spatially distributed recharge alternatives in the Mexico City Metropolitan Area. Journal of Hydrology. 586 (2020): 12490920

Morris, B. L., Lawrence, A R L, Chilton, P J C, Adams, B, Calow R C and Klinck, B A. (2003). Groundwater and its susceptibility to degradation: a global assessment of the problem and options for management. Early warning and assessment report series, RS. 03-3. Kenya, UNEP.

Nandalal, K.D.W. (2010). Groundwater Resources. In Proceedings of the National Forum on Water Research Identification of Gaps and Priorities. Colombo, Sri Lanka.

Prüss-Ustün, A., Bartram, J., Clasen, T., Colford, J. M., Cumming, O., Curtis, V., Bonjour, S., Dangour, A. D., France, J. D., Fewtrell, L., Freeman, M. C., Gordon, B., Hunter, P. R., Johnston, R. B., Mathers, C., Mausezahl, D., Medlicott, K., Neira, M., Stocks, M., Wolf, J. and Cairncross S. (2014). Burden of diarrhoeal disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries. Tropical Medicine & International Health. 19(8):894–905.

Rodda, J. C. (1995). Guessing or assessing the world's water resources? J. Chartered lnstn Wat. Environ. Managers. 9: 360-368.

Rodríguez, A., López, M., Casillas, A., León, J. and Banik, S. (2018). Impact of pesticides in karst groundwater. Review of recent trends in Yucatan, Mexico. Groundwater for Sustainable Development, 7: 20-29.

Sandhyavitri, A. (2002). Fundamental Elements of Sustainability in Urban Water Supply: Case Studies in Indonesia. Unpublished PhD Thesis submitted to Manchester Centre for Civil and Construction Engineering, University of Manchester Institute of Science and Technology (UMIST), UK.

Santos, S. D., Adams, E. A., Neville, G., Wada, Y., Sherbinin, A., Bernhardt, E. M. and Adamo, S. B. (2017). Urban growth and water access in sub-Saharan Africa: Progress, challenges, and emerging research directions. Science of The Total Environment. 607–608: 497-508

Shiklomanov, I. A. and Rodda, J.C. (2003). World water resources at the beginning of the 21st century. Cambridge, Cambridge University Press.

Sililo, O. N. and Saayma, C. (2001). Groundwater vulnerability to pollution in urban catchments. Cape Town, Water Research Commission.

Silva, R., Grönwall, J., Kwast, J., Danert, K. and Foppen, J. (2020). Estimating domestic self-supply groundwater use in urban continental Africa. Environmental Research Letters. 15(10): 1-10

Smith, M., Cross, K., Paden, M. and Laban, P. (2016). Spring – Managing groundwater sustainably. International Union for Conservation of Nature and Natural Resources (IUCN), Gland, Switzerland.

Smits, S. and Sutton, S., (2015). Self-supply: the case for leveraging greater household investment in water supply. Briefing note. Building blocks for sustainability series. IRC, The Hague, The Netherlands.

Suresh, T. and Kottureshwara, N.M. (2009). Assessment of groundwater quality of borewells water of hospet taluka region, karnataka, India. Rasayan J. Chem, 2(1): 221-233.

United Nations, Department of Economic and Social Affairs [UN-DESA]. (2011). Population Distribution, Urbanisation, Internal Migration and Development: An International Perspective. New York City, NY

UNEP (2010). Africa Water Atlas. Division of Early Warning and Assessment (DEWA). United Nations Environment Programme (UNEP). Nairobi, Kenya.

UNICEF/WHO (2006). Joint Monitoring Programme (JMP) for Water Supply and Sanitation. Meeting the MDG drinking water and sanitation target: the urban and rural challenge of the decade. WHO Press. Printed in Switzerland.

UNICEF/WHO (2012). Joint Monitoring Programme (JMP) for Water Supply and Sanitation. WHO Press. Printed in the United States of America

Vinod, P.N., Chandramouli, P.N. and Koch, M. (2015). Estimation of nitrate leaching in groundwater in an agriculturally used area in the state Karnataka, India, using existing Model and GIS Aquatic Procedia, 4 :1047-1053

WHO (2014). Preventing diarrhoea through better water, sanitation and hygiene: exposures and impacts in low- and middle-income countries. WHO Press, World Health Organization. Geneva, Switzerland.

WHO (2006). Protecting Groundwater for Health: Managing the Quality of Drinking-water Sources. Edited by Schmoll, O., Howard, G., Chilton, J. and Chorus, I. Published by IWA Publishing, London, UK.

UNICEF and WHO (2019). Progress on household drinking water, sanitation and hygiene 2000-2017. Special focus on inequalities. New York: United Nations Children's Fund (UNICEF) and World Health Organization (WHO). Edited by Richard Steele. Design, layout and production by Cecilia Silva Venturini. Printed in New York, USA.

World Bank, (2017). Improving Service Levels and Impact on the Poor: A Diagnostic of Water Supply, Sanitation, Hygiene, and Poverty in Indonesia. World Bank, Washington, DC. USA.

WWAP (World Water Assessment Programme) (2012). The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.