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Review Article

Water and Wastewater Treatment in Africa – Current Practices and Challenges

Sustainable access to safe drinking water and basic sanitation is an important part of the millennium development goals (MDGs). For most African countries, an extensive effort is needed for the last three remaining years for the achievement of the MDGs, especially in Sub-Saharan Africa. Current practices for water and wastewater treatment in Africa are insufficient to ensure safe water and basic sanitation. To address this challenge, joint efforts are needed, including transforming to green economy, innovating technologies, improving operation and maintenance, harvesting energy, improving governance and management, promoting public participation, and establishing water quality standards.

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1 Introduction

Africa is often characterized by its clean water and abundant biodiversity [1]. It is no doubt that water quantity and quality is of vital importance for the ecosystem [2, 3]. Unfortunately, as the world's second-driest continent after Australia, Africa has only 9% of global renewable water resources to support 15% of the global population [1]. The lack of water in Africa is further aggravated by insufficient treatment of water and wastewater, particularly with rapid population growth and urbanization [2].

At present, however, the efforts to improve drinking water quality and wastewater treatment are not keeping pace with population growth and urbanization [4, 5]. The growing population and rising economy has resulted in increasing consumption of water and discharge of wastewater, which cause heavy pollution [6]. Water pollution not only reduces available freshwater, but also affects human health and ecosystem [3, 7, 8]. According to the millennium development goals (MDGs), the proportion of people without sustainable access to safe drinking water and basic sanitation should be reduced in half by 2015 [9, 10]. In fact, water and wastewater treatment is significant for the realization of the MDGs [11, 12]. For example, goal 1 (to eradicate extreme poverty and hunger) is related to water treatment because the access to safe drinking water can save the time and cost to collect daily water, thus people may have more time to work and to get food [1]. Goal 2 is to achieve universal primary education. Some kids cannot go to school due to the fact that they have to collect drinking water, or they have to quit schools due to water-borne diseases [1]. Goal 3 (to promote gender equality and empowering women) is related to water treatment because the burden of water collection in Africa falls disproportionately on girls and women [1]. Goal 4 (to reduce child mortality rates) is related to water treatment because improving water quality can reduce child mortality [1]. Goal 5 (to improve maternal health) is closely related to water treatment [13]. Goal 6 is to combat HIV/AIDS, malaria, and other diseases. It was shown that some diseases including malaria are related with water treatment [14, 15]. Goal 7 is to ensure environmental sustainability. One essential part (target 7.C) of this goal is to "halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation" (www.un.org/millenniumgoals/). Goal 8 is to develop a global partnership for development. It was noted by UN that "aid continues to rise despite the financial crisis, but Africa is short-changed". In this part, UN emphasized the importance of "technical cooperation", along with other forms of partnership, such as bilateral development projects. Thus, a close cooperation in the field of water and wastewater treatment field in Africa will contribute for the realization of this goal.

Due to the increasing population, the urban population without sanitation services in Africa increased from 88 million in 1990 to175 million in 2008, and the number of people without access to drinking water climbed from 29 million in 1990 to 57 million in 2008 [2]. Thus, an extensive effort is needed for the last three remaining years for the achievement of the MDGs [16].

2 Sources of water pollution

2.1 Domestic wastewater

Domestic wastewater is a major source of water pollution. Poor urban planning and rising population have resulted in illegal settlement and slums [17]. It is estimated that 60% of the urban population in Africa is living in slum conditions, where sanitation services are poor, inadequate, and unreliable [1]. For instance, Kibera, in Nairobi, is the

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Abbreviations: **MDG**, millennium development goal; **RWH**, rainwater harvesting; **WWTP**, wastewater treatment plant

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second largest slum in Africa [18]. Although the residents in Kibera account for 20% of the Nairobi population, this slum is traditionally looked at as an illegal settlement in Nairobi [2]. Due to lack of sewerage collection system and wastewater treatment plants (WWTPs), most residents in this area have no access to sanitation, or just limited sanitation systems such as latrines and small-bore sewers [2].

2.2 Agricultural pollution

Agriculture is the main source of income for 90% of the rural population in Africa [1]. Rain-fed agriculture results in pollution such as fertilizers and pesticides [19, 20]. Large-scale commercial farming is expanding to help the exploding population in Africa survive. For example, Kenya supplies 25% of Europe's cut flowers (www.economist.com/node/10657231). Consequently, the greenhouses for rose planting have become a major source of water pollution [4]. In Lake Naivasha, Kenya, we found that the biodiversity has been shrinking in recent years. One possible reason is the deterioration of water quality in the Lake Naivasha caused by fertilizers and pesticides from commercial rose planting (www.wetlands.org/reports/dbdirectory.cfm?site_id=66).

2.3 Industrial wastewater

Typical industries in Africa include rubber plantation, mining, oil production, logging activities, etc. [1]. Stabilization ponds are widely used by industries including sugar, textile, dairy, and paper factories [21]. Due to limited capability of stabilization ponds, the pollutant concentration in the effluent of pond system is still very high [6]. For example, we found that the typical influent chemical oxygen demand of municipal WWTPs is often higher than 2000 mg/L in many pond systems in Africa, while it is approximately 400 mg/L in other countries [22].

2.4 Solid waste pollution

A huge amount of municipal solid waste, medical waste, and industrial solid waste is thrown away into open spaces, wetlands, rivers, and lakes. For example, in Addis Ababa, solid wastes are often piled on open spaces without sufficient management facilities [2]. As a result, they are washed off by runoff into rivers when it rains. Our investigation also confirms the common practice of solid waste dumping and the flying-toilet (plastic bags used for defecation and thrown away alongside the roads at night) in Africa [4]. Illegal dumping, including municipal dumping of industrial hazardous waste and medical waste, is a common practice in Africa [21].

3 Current practices for water and wastewater treatment

3.1 Wastewater treatment

3.1.1 On-site treatment

On-site sanitation systems such as pit latrines and septic tanks are widely used in rural and semi-urban areas in Africa. However, the maintenance and management of these pit latrines is very poor. This deteriorates the groundwater quality [1]. Many pit latrines are full and the wastewater is flowing. This is a source for waterborne diseases. Natural wetlands are used for wastewater treatment or disposal in some countries such as Uganda; however, due to increasing pollutant loads, more and more natural wetlands are weakened or diminished [23].

3.1.2 Off-site treatment

In urban areas, off-site wastewater treatment systems are a common practice [24]. Wastewater is collected and transported to WWTPs for treatment. In Zambia, available technologies for WWTPs include activated sludge treatment in some selected towns, combined trickling filter plants in most of the cities and towns, and stabilization ponds, which are most popular. In Kenya, out of 39 publicly operated systems, there are 27 waste stabilization ponds because they are robust in operation under harsh conditions, six conventional processes such as trickling filters, three oxidation ditches, and three aerated lagoons.

3.1.3 Conventional treatment

Conventional treatment processes such as activated sludge and biofilms are used seldom in Africa due to lack of energy and financial resources. For instance, in Uganda, the National Water and Sewerage Corporation employs Conventional Sewage Treatment Works only at Bugolobi Sewage Treatment Works for Kampala City and one plant in Masaka Sewage Treatment Works (www.nwsc.co.ug/about04.php), while it applies stabilization ponds for the other sewerage treatment plants. The Bugolobi Sewage Treatment Works only covers 55% of the sewage produced within the Nakivubo catchment area, while the rest of the sewage goes into natural wetlands around Kampala without any treatment (www.afdb.org/en/projects-and-operations/project-portfolio/project/p-ug-e00-008). Figure 1 is the Sirte City Wastewater Treatment Plant in Libya, where secondary treatment and tertiary treatment are adopted before the effluent goes into the Mediterranean Sea.

3.1.3.1 Stabilization pond systems

In the stabilization ponds, waste water is treated through two processes: physical treatment and biological treatment. The Dandora Oxygenation Pond is a wastewater stabilization pond system with a capacity of over 80 000 m^3/day [25]. It is Nairobi's main sewage treatment system, which receives about 80% of wastewater generated from Nairobi city (www.nairobiwater.co.ke/water_quality/?ContentID=7). The main process includes anaerobic ponds, facultative ponds, and maturation ponds (Fig. 2).

3.2 Drinking water sources

3.2.1 Groundwater as drinking water

Approximately 75% of Africans rely on groundwater for drinking [2]. In recent years, extracting groundwater in many areas has become

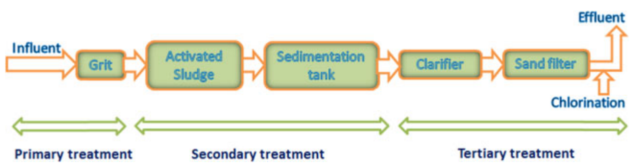

Figure 1. Flow chart of Sirte wastewater treatment plant (Sirte, Libya).

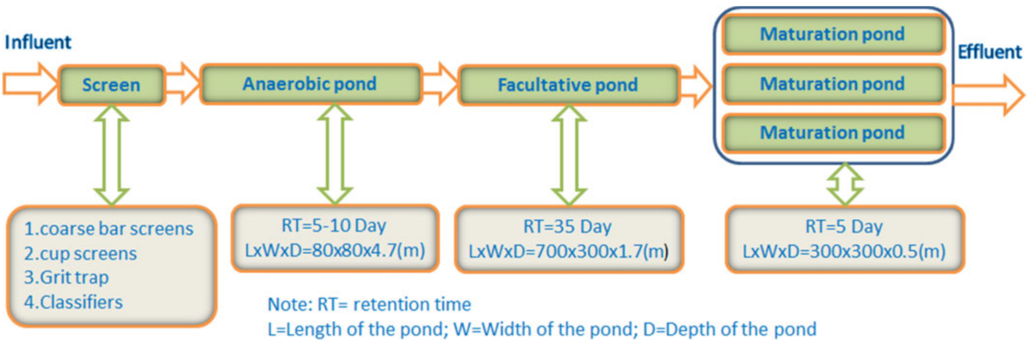

Figure 2. Flowchart of Dandora wastewater treatment plant (Nairobi, Kenya).

more difficult because of overexploitation. In addition, the water quality of groundwater is becoming a major concern [2, 26]. Fluoride, iron, and manganese are widely detected in groundwater [21]. Typical problems of groundwater pollution are listed in Tab. 1.

3.2.2 Rainwater as drinking water

Rainwater harvesting (RWH) is usually a system of collecting rainwater from rooftops and yards and to storing it in a tank for later use (Fig. 3). RWH is a common practice in Africa and it improves water supply [32]. RWH is encouraged as a step toward achieving MDGs [16]. For example, in Rhodes University, South Africa, a project is promoted to collect and utilize rainwater for agricultural irrigation, cooking, and drinking [21]. A recent research indicated that rainwater is safer than water from unimproved water supplies [16]. However, it should be noted that the quality of rainwater might be doubtful [16, 33]. The consumption of rainwater may result in risk of illness [33, 34]. For example, *Salmonella* and *Campylobacter* can cause bacterial diarrheas, *Legionella* result in bacterial pneumonia, *Giardia* and *Cryptosporidium* lead to protozoal diarrheas [35]. It is highly recommended that rainwater should be treated prior to drinking [33].

3.3 Centralized and decentralized drinking water treatment

Basically, there are two systems for drinking water supply in Africa: centralized and decentralized [36]. For centralized waterworks, the raw water is collected, treated, and distributed by pipeline network. Generally, there are treatment processes such as coagulation, filtration, and disinfection in the public waterworks [37]. For decentralized systems, it might be a borehole where underground water is abstracted, or a mobile truck, or a water vendor who sells water house by house. However, for the decentralized water system, most of the water is not well treated. In many African areas where there are no pipelines, people have to buy water from vendors. This "commercial water" is very expensive and the water quality might not be ensured. For example, the price of public water from waterworks is 0.21 US$/m^{3}in Nairobi, Kenya, while it is 1.7 US$/m^3 from KIOSKS [21]. However, some decentralized treatment systems

Table 1. Typical problems of groundwater pollution

City/country	Problems of groundwater pollution
Port Harcourt, Nigeria	>80% of drinking water is reliant on groundwater, but the shallow water table makes it prone to pollution such as untreated wastewater. This increases the risks of water-borne diseases [2].
Nairobi, Kenya	1. Nairobi's upper aquifer is particularly vulnerable to pollution from human activities such as landfills and dumpsites, leakage from underground storage of petroleum and chemicals, and infiltration from polluted streams [21]. 2. Industrial wastewater and pesticides lead to pollution of groundwater.
Kisumu, Kenya	Although groundwater is easily available (ground water levels are 2–5 m from the soil surface), basically the water supply in this area is still dependent on surface water, mainly because groundwater is susceptible to contamination by inadequate drainage and overflowing pit latrines [27].
Thiaroye, Darker, Senegal	The concentration of NO_3^- in groundwater can be >50 mg/L, which is due to the overuse of agricultural fertilizers [2].
Ghana	Chemicals in borehole water from 38% of samples exceed the WHO guidelines; typical contaminants are nitrate (NO_3^-), manganese (Mn) and fluoride (F^-) [28].
Bolama Island, Guinea-Bissau, West Africa	~79% of the wells showed moderate to heavy fecal contamination [29].
Addis Ababa, Ethiopia	The toxicant leachate from dumped solid waste is a major factor for the contamination of groundwater [2].
Northern Mali and Zambia	As a global challenge, arsenic pollution is a common contamination in groundwater, either geogenic or anthropogenic [30].
Kampala, Uganda	1. Pit-latrine deteriorates the groundwater quality; 2. Dilapidated pipelines result in the contamination of groundwater [2].
Sirte, Libya	Groundwater is becoming salted because of Mediterranean Sea water intrusion. The salted water results in higher cost for desalination [31].

Figure 3. Rainwater collection tank in a private house in Nairobi, Kenya.

are necessary. For example, household water treatment methods, such as boiling or chlorination, were found to be effective, especially in the acute emergency context [38]. Other useful point-of-use water treatment technologies include dilute hypochlorite solution, porous ceramic filtration, and combined flocculant-disinfectant powdered mixtures [39]. In the areas where disinfection is too expensive to be employed, solar disinfection might be an effective method for point-of-use water treatment [40]. Solar disinfection is a good practice for the prevention of dysentery in Kenya and South African children aged under five [41, 42]. However, the safety issue of solar disinfection needs to be addressed further [40].

4 Challenges for water and wastewater treatment

4.1 Insufficient infrastructure

Limited sewer collection is a bottleneck for wastewater treatment. For example, in Addis Ababa, the capital of Ethiopia, the Kaliti treatment plant was designed to serve 50 000 people in 1982 (www.sswm.info/category/implementation-tools/water-distribution/hardware/non-piped-distribution/human-powered-distr). However, after almost 30 years of development, the population served was only 13 000 people. One of the reasons is its insufficient connection from the houses to municipal sewerage pipelines. The rate of connections is very low and has not improved since 1993 (http://www2.gtz.de/Dokumente/oe44/ecosan/en-wastewater-masterplan-2002.pdf). In Addis Ababa, <3% wastewater joins the wastewater treatment facilities [43]. Another case is the Kisumu district in Kenya, where all three of the existing pump stations (Sunset Hotel, Kendu Bay, and Mumias road) are broken down and result in the overflow of sewage at manholes upstream of the pump stations, as well as the direct discharge of sewage to Lake Victoria [27].

Water quality monitoring is often poor in African countries [44]. In most of the labs for water quality monitoring in waterworks and WWTPs, only few parameters such as turbidity, pH, and alkalinity are monitored. For example, in Nairobi, Kenya, although the significance of organic pollutants in drinking water is realized, there are few waterworks monitoring total organic carbon due to lack of instruments. In Kampala, although the environmental management agency is aware of the illegal discharge, it is hard to monitor and manage these industries partly due to lack of an effective monitoring system.

In existing waterworks, lack of financial support restricts the upgrade of treatment facilities or monitoring instruments. For example, in Nairobi, a jar tester made in 1938 is still in use. In peri-urban and slums areas, the residents believe that it is the government or landlord's responsibility to construct sanitation systems. In addition, it takes money and space to establish sanitation facilities, and this is beyond what the poor residents can afford, but the landlords and governments are not willing or cannot afford to invest in on-site treatment systems.

The lack of power supply also hinders water and wastewater treatment to a great extent in Africa [4]. We found that many treatment plants cannot operate properly due to unreliable power supply system.

4.2 Poor operation and maintenance

Poor operation and maintenance is a challenge for WWTPs and waterworks. For some manufacturers in Africa, they cannot get applicable technologies to remove pollutants from their industrial wastewater due to limited available information and experiences. Some waterworks are facing challenges for the dosage of coagulants when the turbidity is too high or too low [4]. For example, the turbidity of raw water in Nairobi can reach 5000 nephelometric turbidity units in rainy season due to soil erosion in the upper stream, while it is <10 nephelometric turbidity units during dry season [4]. The variation of coagulant dosage is complicated for the operators in these waterworks. Coagulants imported from France, USA, and China, are used in African countries, and the selection of cost-effective coagulant is difficult in some cases. Another challenge for drinking water treatment in Africa is algae. Algae may consume more chemicals, clog filters, result in bad smell, and cause microcystin, which is toxic and hazardous to human health [45].

Disinfection should be a necessary step for drinking water treatment [41, 42]. Unfortunately, this is often not the case in Africa [40]. Disinfection is also important for wastewater treatment. Generally, the effluent is discharged from WWTPs to rivers or lakes without disinfection. In the Dandora WWTP, effluent from stabilization ponds is flowing into the Nairobi River through an open channel, where livestock drink the river water (Fig. 4). It should be noted that this might cause harm to the livestock and human health in the long run. In Bugolobi Sewerage Treatment Works in Uganda, it was found that *Escherichia coli* in the effluent is much higher than the discharge standard (www.mwe.go.ug).

A serious challenge for stabilization ponds and lagoons is the heavy load of influent. The influent concentration is high due to insufficient pretreatment of industrial wastewater. One case in point is the Dandora WWTP, Nairobi, Kenya [21]. We collected samples and found that the influent chemical oxygen demand and biochemical oxygen demand in the Dandora WWTP is 2030 and 1500 mg/L, respectively, while the average removal of organic pollutants is 70%. According to our investigation, the average removal efficiency of NH_3-N, TN, and TP in Dandora WWTP is only 46, 36, and 16%, respectively. The effluent from the system is heavily colored due to algae.

5 Recommendations

Based on the current practices and challenges, here we propose the following recommendations for the improvement of water and wastewater treatment in Africa.

a)

b)

Figure 4. (a) Cattles drinking water in the wastewater stabilization ponds. (b) Birds drinking water in the wastewater stabilization ponds. Wastewater without disinfection might be harmful to animals and birds.

5.1 Transforming to green economy

It is imperative to move from the end-of-pipe water pollution control mode to more proactive pollution prevention. A green economy and cleaner production should be employed to reduce wastewater discharge and to recycle resources from wastewater (www.grida.no/publications/green-economy/). Green economy can also minimize the impact of human activities on the ecosystem, and the protection of ecosystem can conserve and preserve water quality [4].

5.2 Innovating technologies

Typical applicable technologies for water and wastewater treatment in Africa include cost-effective measures to control algae, low energy consumption treatment, affordable on-site sanitation construction, combination of pond system with biological treatment, and constructed wetland system, proper disinfection for wastewater, groundwater purification, water reuse and desalination, and rainwater treatment. For example, metals and sulfates can be recovered from acid mine drainage [46]. Struvite (magnesium ammonium phosphate hexahydrate, $MgNH_4PO_4 \cdot 6\ H_2O$), which contains phosphorus and nitrogen can also be recovered from domestic wastewater [47]. The constructed wetlands, which are useful systems for wastewater treatment [48, 49], have been proposed for tertiary wastewater treatment in order to prevent eutrophication and protect ecosystem [50]. These suggested technologies are listed in Tab. 2.

5.3 Improving operation and maintenance

It is important to provide training and to enhance the expertise for the operation and maintenance of the facilities for water and wastewater treatment. Otherwise the facilities in waterworks and wastewater treatment plants cannot work effectively. Capacity building is needed to improve the knowledge of the workers in this sector. Only qualified and efficient operators and managers can ensure the smooth operation of these treatment facilities. In addition, those who construct the water and wastewater treatment facilities should establish necessary maintenance mechanisms so that these facilities can run sustainably.

5.4 Harvesting energy

Energy is of vital importance for the water and wastewater treatment systems. However, many African countries are lack of reliable energy supply systems. One possible solution is the utilization of solar energy. The other possibility is to recover energy from wastewater or waste sludge. For example, upflow anaerobic sludge blanket reactor makes it feasible to harvest biogas from wastewater, and a microbial fuel cell pit latrine is supposed to be used in Ghana to harvest electricity and to prevent groundwater pollution (http://cee.umass.edu/news/green-latrine-purifies-human-waste-and-turns-it-in-to-electricity).

5.5 Improving governance and management

The low priority accorded to water sector leads to poor water quality. The governments usually do not have political will to emphasize

Table 2. Innovative technologies to be used in Africa for better water supply and improved sanitation

	Drinking water treatment	Wastewater treatment
Cost-effective measures to control algae	√	√
Low energy consumption treatment/solar energy	√	√
Affordable on-site sanitation	×	√
Pond system + biological treatment + constructed wetland	×	√
Proper disinfection	√	√
Groundwater purification	√	√
Water reuse and desalination	√	√
Rainwater treatment	√	×
Harvesting resources and energy from wastewater	×	√

Note: √, applicable; ×, not applicable.

water and wastewater treatment because this is not considered as "vote winning". It was suggested that local planning processes need to be reformed so that local politicians commit more strongly to improving water supply [51]. To establish good governance with a better mechanism and institutional framework is a key to avoiding the lack of political will and commitment for water and wastewater treatment. The management of drinking water quality, wastewater discharge, and solid waste disposal should be enhanced. The regulatory authorities should put up legislations and rules to require industries to establish on-site pre-treatment facilities.

6 Promoting public participation

The improvement of water and wastewater treatment needs joint efforts from different stakeholders, including the public [52]. Currently, many decisions for water and wastewater treatment are taken without public involvement, and most people are not aware of the significance and methods to protect water quality. In fact, public participation may enhance the political will if politicians seek public support. Training and education is necessary to promote public awareness on the nexus between water and energy, water and health, as well as water conservation.

6.1 Establishing water quality standards

Most of the African countries adopt the WHO guidelines for drinking-water quality; yet due to lack of monitoring instruments and qualified labs, the water quality control is poor. In consideration of different situations and conditions, it is important to establish their own standards system for monitoring water quality without compromising key health issues in Africa (www.unwater.org/downloads/waterquality_policybrief.pdf).

7 Concluding remarks

The water quality in Africa is facing severe challenges. Improvement of water and wastewater treatment is of vital importance to achieve the MDGs. Currently available treatment methods of water and wastewater are often chemically, energetically, and operationally intensive, which might not be used in many places in Africa due to the lack of appropriate infrastructure [53]. Thus, it is important to develop applicable water and wastewater technologies for African countries. Comprehensive efforts are needed. It requires contributions from all stakeholders: governments, non-government organizations, and private sectors. In consideration of the unique characteristics of Africa, it is of vital importance for the Africans to find their own way to protect water quality. Although it is important for African countries to get financial aid and technical support from the outside nations, it should be noted that the internal efforts are far more important than any external aids and assistance for safe water and healthy ecosystem in Africa.

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