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Review

Wastewater as a Source of Productive Water, Biomass, and Energy at Low Cost Against the Respective Scarcities in the Present and the Future in African Countries

Bilassé Zongo[1]*, Saka A. Balogun[2, 4], Taofeek Shittu[3]

[1]Department of Biological Sciences, Université Nazi Boni, Bobo-Dioulasso, Burkina Faso
[2]Department of Microbiology, Federal University of Agriculture, Abeokuta, Nigeria
[3]Department of Food Science and Technology. Federal University of Agriculture, Abeokuta, Nigeria
[4]Summit University, Offa, Kwara State, Nigeria

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Abstract

With the increasing population and urbanization in the world, generated wastewater is an alternative to water scarcity. Treated wastewater has environmental, human health and socio-economic benefits. However, in Africa, 95% of raw-wastewater is released into the environment. Therefore, this paper emphasizes wastewater reuse meeting the standard criteria, particularly in Africa.

Data were collected based on peer review literature on wastewater reuse systems, and handling systems in general and specifically in Africa. In addition, online publications and onsite visits in Burkina Faso and Nigeria allow apprehending wastewater reuse systems in the world including Africa. Then, analysis was done and challenging prospects were identified.

Results show that from ancient to the present, wastewater is disposed of or reused for different purposes. Because of increasing waterborne diseases, advanced water reclamation technologies were developed for water reuse. In Africa, raw wastewater is still disposed of and reused while cost-effective technologies and facilities are now developed for wastewater reclamation. Consequently, populations are suffering from waterborne diseases. Produced effluent meeting the standards for reuse is the appropriate treatment. To make it possible in Africa, leaders must pay attention to population wellbeing as a priority, to infrastructures and their maintenance, to integrated technologies for cost-effective treatment, and to consider the removal of antimicrobial resistances.

Keywords: wastewater, productive source, water reuse, treatment technologies, Africa

*e-mail: azongo@hotmail.fr
bzongo@univ-bobo.gov.bf

Introduction

Worldwide, water scarcity has become an immense problem with increasing population, climate change, urbanization, and overexploitation [1]. Water is always used all time for human activities and needs thereby frequently wasted as wastewater all over the world. Wastewater (WW) is mainly generated from industrial, agricultural, domestic, and hospital activities [2]. There is an increase in the use of water resources and the production of wastewater both in urban and rural environments due to growing populations. With the rapid growth of cities and water demand observed since the mid-nineteenth century [3], irrigation and fertilization of agricultural lands using sewages were viewed favorably as an appropriate solution for the disposal of large volumes of wastewater. In ancient times, important water was however used and discharged to the environment without any treatment. During this period, wastewater at a relatively acceptable quantity and less contaminated was naturally recycled with limited disposal problems. Nowadays, untreated wastewater typically contains a variety of biological and chemical constituents that may be hazardous to human health and the environment. That is why the United Nations (UN) at its Target 6.3 plans "By 2030, to improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally". Modern treatment technologies which were developed to remove a variety of pollutants from wastewater can help reach this target. Wastewater treatment has environmental, human health, social and economic benefits. Treated wastewater is promoted for many reuse purposes (agricultural or landscape irrigation, industrial recycling and reuse, recreational uses, non-potable urban reuses, potable reuses, and groundwater recharge). Reuse criteria and regulations dictate the feasibility and acceptability of water reuse applications [3] conducting the elaboration of different reuse standards [4-6]. Wastewater with high organic loading is used to obtain biogas by applying aerobic and/or anaerobic digestion. Furthermore, during a biological treatment stage, important biomass can be obtained and recovered for biofuel/biogas production, production of fertilizers, and other uses.

However, over 95% in some under-developing countries wastewater is still released into the environment without treatment [3]. Despite the non-treatment of wastewater in the countries, it is used by populations for many activities especially market gardening thereby exposing their persons and all populations consuming farming products. Untreated wastes especially wastewater causes major damage to the environment and human health [7]. Due to the unclean water supply in low-income countries, populations are indeed exposed to numerous waterborne diseases such as diarrhea, malaria, trypanosomiasis, bilharziasis, typhoid, and cholera. Often the reason for the lack of wastewater treatment is financial, but it is also due to an ignorance of low-cost wastewater treatment processes and the economic benefits of treated wastewater reuse [7].

In a world where over 80% of wastewater is released to the environment without treatment [3] with its multiple consequences on the environment and human health, each country must develop the required infrastructures and systems for the entire wastewater collection and treatment. Treating WW will help deal with the problems related to its disposal without treatment and provide multiple advantages to humans and the environment.

Therefore, to emphasize the importance of wastewater reuse meeting the standard criteria in countries all over the world and mostly in developing countries of Africa, this study aims to give relevant information on:

1. a brief story of water reuse systems,
2. the situation of wastewater handling in African countries,
3. the modern technologies used for effective recycling of wastewater treatment,
4. the required infrastructures and systems for wastewater collection,
5. the concepts of the modern wastewater reuse systems
6. some challenging perspectives.

Methods

Collection of Information

A systematic literature review that was focused on peer review literature was done on wastewater reuse systems from the future to the present in general and on wastewater handling systems in African countries nowadays. A review was also done on different wastewater treatment technologies and facilities existing and applied around the world and on the concept of wastewater reuse systems in modern times. Data from the literature review related to the previous points were collected and gathered.

In addition to the systematic literature review, online pictures related to wastewater treatment technologies and facilities were visited for a better understanding of existing wastewater treatment and reuse systems in African countries and around the world.

Visits were also conducted to stations of wastewater treatment systems existing in Burkina Faso and Nigeria to apprehend the technologies used in the stations of these countries.

Analysis of Information

The main information related to wastewater treatment and reuse systems in the world and specifically in some African countries that are reported in peer review literature were selected and synthesized. Pictures and photographs in peer review papers and/or simply published online were directly used or modified by indicating the source. The literature and pictures allow realizing now pictures. Furthermore, based on collected data and information related to the major points previously listed in the first part, some challenging prospects have been identified for sustainable wastewater treatment and reuse in the present and the future.

Results and Discussion

A Brief Story of Water Reuse Systems

This story will mainly be based on the work of Angelakis et al. [3] who provided interesting information on water reuse from the ancient to the future. Indeed, humans use clean water for their needs and produce wastewater as a product. The use of produced wastewater for any other purpose (activity) is qualified as water/wastewater reuse. Until the Medieval times, in addition to disposal, wastewater was used for both irrigation and fertilization of crops. During this period, water technology and sanitation were not a priority until waterborne diseases become a real issue because of decimating populations in Europe for example. Such pandemics become a reality in several regions of the world during mid-modern times. That obliged authorities to recognize the need for sanitation and this led to the development of effluent disposal and reuse practices. Therefore, the applications of wastewater to the lands for agricultural use called ''sewage farms'' were developed to protect populations in rapidly growing cities in Europe, USA, and Australia. In some cities (Mexico City for example), wastewater was drained by canals to irrigate agricultural lands, while cities in Germany implemented sewers discharging wastewater into a system of the pond to recycle water for agriculture and aquaculture. At the end of the mid-modern times, modern technologies were developed in Germany and England for sewage treatment before discharging the treated effluent to land and hence to freshwater bodies. The methods applied for the treatment included large septic tanks, contact beds, trickling filters, and sand filters.

From the twentieth century, significant technological and scientific innovations were developed around the world for the implementation of wastewater treatment plants (WWTPs) that could handle the large volume of wastewater. Treated wastewater was then mostly discharged into rivers or oceans and less for soil fertilization. Due to several factors including population growth, urbanization, the growth of megacities, climate change, the increasing need for water in a variety of applications, and the development of advanced water reclamation technologies at the end of this century to the beginning of the twenty-first century, water reclamation and reuse have regained popularity. New technologies were able to produce water of any quality desired including drinking water.

The Situation of Wastewater Handling in African Countries

Water supply and sanitation are extremely low, particularly in sub-Saharan Africa (SSA). Wastewater handling remains worst in most African countries. The situation of wastewater reuse did not improve even with the increase in population in urban areas. Water technology and sanitation are still not a priority in many African countries. The situation of wastewater in many countries of Africa is comparable to the consideration of wastewater in some countries of Europe and America in medieval times with populations frequently suffering from many waterborne diseases. In countries like Burkina Faso and Nigeria, canals are conducting wastewater that is directly used by populations for irrigation of cereals and vegetables (Fig. 1, [8]). With total discharge wastewater estimated at 800 000 m^3/year in 2002 when Ouagadougou had a total population of 1.2 million people [9, 10], this amount is supposed to triple to about 2.400.000 m^3/year in 2022 as the population is estimated to be about 3 million in this capital city. Limited or mostly totally absent, existing sewer collection facilities conduct the discharge of untreated wastewater onto the streets or nearby water bodies. This important quantity of produced wastewater that is subsequently a source of environmental contamination and human health risks constitutes an ignored water resource in sub-Saharan countries like Burkina Faso where water scarcity is a real issue. In some other countries like South Africa and Nigeria, some facilities exist, and a portion of wastewater is canalized, collected, and treated at different wastewater treatment plants (WWTPs) in big cities. However, because of the growing population, the situation remains almost the same compared to smaller countries in Africa. In 2021, Lagos city has a population of about 15 million habitants who produce large amounts of wastewater. Since 2014, the production of wastewater in Lagos State alone was estimated to be about 1.4 trillion cubic centimeters of wastewater every day, according to government statistics [11]. With an estimated growth rate of 4.2% per year [12], Lagos's population can reach 24 million in 2030. Increasing populations and increasing industries mean an excessive increase in wastewater production with a major impact on water resources, the environment, and human health.

While South Africa is one of the African countries where wastewater is better handled and treated, sanitation related to wastewater remains worse in most urban areas. According to Harding et al. [13] who based their information on [14], over 80% of wastewater is released into the environment untreated and the situation is projected to worsen over the next decade in this country. Sato et al. [15], indicated that 70% of municipal and industrial wastewater is treated

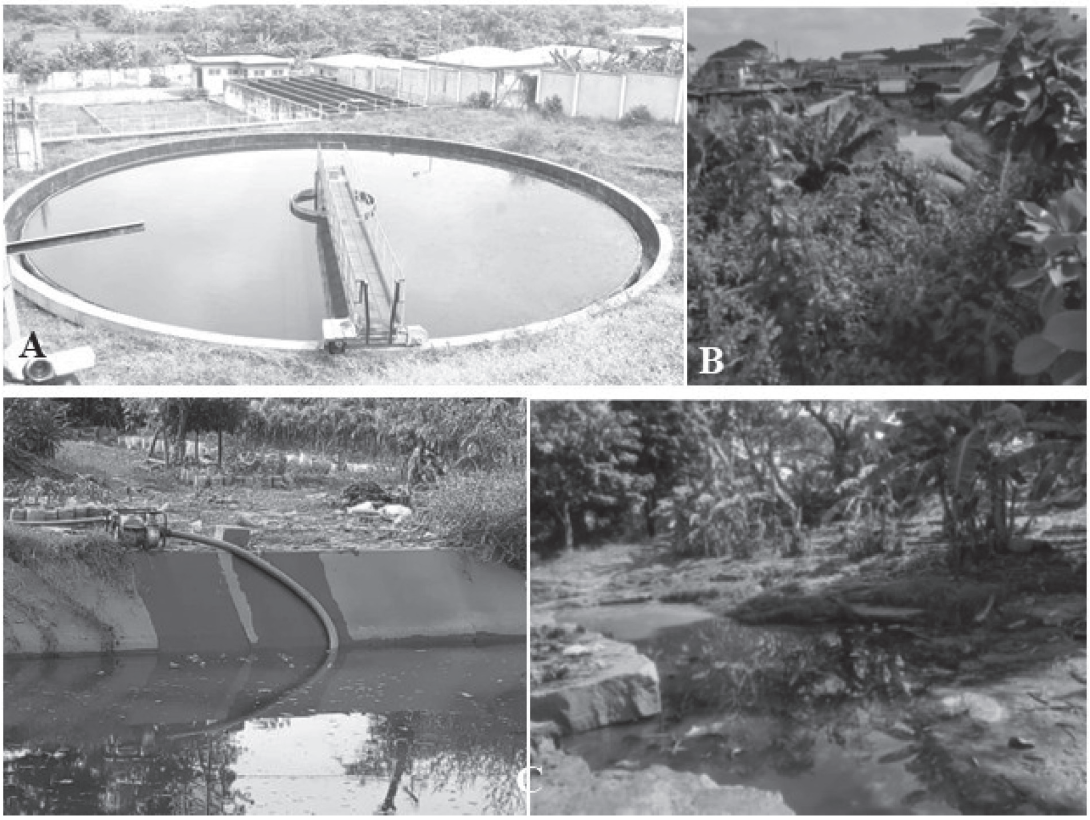

Fig. 1. Wastewater treatment systems and reuse for irrigation. A. Lagos Waste Water Management Treatment Plants (Nigeria) [7], B. Raw wastewater used for gardening in Lagos (Nigeria), C. Raw wastewater used for irrigation in Ouagadougou (Burkina Faso) for gardening and cultivation of crops.

in high-income countries; 38% in upper-middle income; 28% in lower-middle income; and only 8% are treated in low-income countries. Moreover, in addition to the poor operation and maintenance that is a challenge for existing WWTPs in African countries, manufacturers in Africa cannot get applicable technologies to remove pollutants from their industrial wastewater due to limited available information and experiences [16]. This situation hardly changes and most of the time, the systems do not work properly conducting a limited treatment and releasing hazardous chemicals, heavy metals, and pathogens. In South Africa for example, effluent from household wastewater treatment (WWT) poses a challenge concerning disposal because it contains high concentrations of nitrogen (N) and phosphorus (P), which do not meet regulatory standards for discharge [17]. Using this effluent in agriculture could provide an innovative way of disposal in a manner and benefit society. However, in most countries, high-risk hazards remaining in wastewater could be an environmental and human health problem. Generally, the effluent is discharged from WWTPs to rivers, lakes, and seas, or directly reuse for irrigation in agriculture without disinfection. Wastewater irrigation can be both, a major health risk for farmers and consumers and a major economic contribution in terms of jobs and food supply. In SSA countries, where it is difficult to find clean water for irrigation around cities, wastewater that contain a great amount of organic matter and nutrients improves soil fertility, enhances plant development, increases agricultural productivity, and reduces the need for chemical fertilizers. The significant amount of produced wastewater in permanently growing cities in Africa is seen by farmers as an important water resource for irrigation. However, irrigation using wastewater is a real concern. In Ghana, both municipal food supply and safety are significantly affected by the urban sanitation situation and that is a major concern of the authorities who tried to ban the use of polluted water for irrigation purposes before the availability of proper wastewater collection and treatment infrastructures and good functioning of the existing ones [18]. Wastewater and polluted water irrigation are common practices in urban areas in Africa and banning the use of polluted water for irrigation seems to be impossible. Immediately finding suitable infrastructures and maintaining the existing ones for proper collection and treatment of the whole produced wastewater in urban areas could be some sustainable solutions.

There are major differences in the way wastewater is reused in African countries. In some locations, water reuse is practiced without much legal control. According to Nikiema et al. [19], this is the case in Accra (Ghana) where water from drains is reused for growing a wide range of vegetables, even when it undergoes no proper treatment. In Burkina Faso, the government has agreed with the reuse of wastewater and has therefore developed areas for market gardening using this resource under some restrictions (only for selected vegetables). But in Senegal, water is mostly reused for gardening or livestock watering. However, it is not always practiced even if a potential exists. The reasons of the low reuse of this potential resource in this country include the unsuitable location of the WWTPs which make inaccessible treated water to potential users [19]. Namibia, Tunisia, and South Africa stand apart from the rest of the continent in treating sewage sludge through a range of conventional and non-conventional systems and having national guidelines and regulations [18]. Nevertheless, we can assume that in countries like South Africa, the access to sanitation and sewage treatment is different from one urban area to another even though they have almost the same wastewater production. The situation of wastewater handling in the northern part of Africa occupied by Arabian countries could be comparable to some European countries. Wastewater in its great part is normally handled and reused in these countries. In Tunisia, most residents of large urban centers have access to various adequate sanitation systems and wastewater treatment facilities. The sanitation coverage is 85% for the population versus 96% in urban areas and 65% in rural areas [18]. According to these authors, the annual volume of reclaimed water is expected to reach 290 million m^3 in the year 2020 with about 30-43% used for agricultural and landscape irrigation in Tunisia. The situation is almost the same in north African Arabic countries except for some countries affected by civil troubles and wars like Libya were from 2011 with the death of President Khadafi and the ongoing war has degraded access to sanitation by the population in the country.

Innovated technologies for sanitation and wastewater treatment already exist and are used by developed countries. Low-income countries, especially SSA countries only need to look for more income, infrastructures, and low-cost technologies for efficient wastewater and sanitation thereby for human health and environmental protection. This supposes a real awareness of challenges related to wastewater and sanitation, an implication of local population, good governance, rational utilization of resources to be oriented in WWT and sanitation, and particularly a political will and commitment.

Wastewater Treatment Technologies and Facilities

Wastewater can often contain significant concentrations of organic and inorganic nutrients [20], heavy metals, and pathogens. They may be toxic and harmful to humans, crops, aquatic plants and fish. Cost-effective treatment that removes wastewater toxic and harmful constituents must be technically possible. Cost-effective treatment is a good solution for low-income countries. The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment [21]. The most appropriate wastewater treatment before reuse is that which produces an effluent meeting the recommended microbiological, chemical, and physical quality at a low cost [22].

Conventional wastewater treatment consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter, and nutrients from wastewater. The different stages of conventional wastewater treatment are preliminary treatment, primary treatment, secondary treatment, and advanced or tertiary treatment [23]. This technology is still used in some countries around the world, particularly low-income countries for wastewater treatment. However, because of research and development of new technologies, authors like Öberg et al. [12] found that this technology is time-consuming, costly, and inflexible to meet the challenges of the 21st century particularly for rapidly growing urban areas like Lagos in Nigeria. This could be a good situation for developing countries where one of the reasons explaining the lack of wastewater treatment is the cost of the treatment and maintenance of the system. They suggested that it would undeniably be valuable to have research showing the effectiveness of alternative solutions to centralized sewer systems. At the present stage, wastewater treatment processes are generally energy intensive and require high investment and operating costs [24, 25]. Therefore, technologies for efficient wastewater treatment performance and energy recovery need to be developed to meet the value of produced wastewater. Cost-effective methods have been developed. The biological treatment is one of the methods that have been demonstrated to be cost-effective. Biological methods are used for treating domestic and industrial waters by degradation of organic matter to nutrients and conversion of dissolved and suspended substrates into biomass which is separated and removed from the water [26]. Biological wastewater treatment is considered incredibly useful due to its eco-friendly nature, minimum usage of chemicals, and energy-saving nature [27]. The principle is the conversion of biodegradable wastes into simpler and harmless species through biological processes by various macro/microorganisms.

When this treatment is done using plants, the procedure is called phytoremediation which includes phytoextraction, phytostabilization, hemofiltration, phytodegradation, and phytovolatilization [28]. Phytoremediation is applied when purifying polluted water using constructed wetlands.

Microorganisms are used in different ways for wastewater treatment depending on the goals and the type of wastewater. Treatment of wastewater using microbial community is promoted as a cost-effective method that provides purified water for reuse purposes. Recently, High-Rate Algal Ponds (HRAPs) for wastewater treatment are promoted. Algae can rapidly assimilate organic pollutants into cellular constituents such as lipids and carbohydrates, thus achieving pollutant reduction in a more environment-friendly way [29]. During HRAPs processes, the shallow depth of ponds (0.2 to 1m) coupled with high nitrogen and phosphorus loads in presence of bacteria cells, allow microalgae to proliferate to high biomass concentrations [30, 31]. The cultivation of microalgae using wastewater as the nutrient source has multiple advantages such as 1) the treatment at low cost, 2) the reuse of wastewater, and 3) the biomass recovering for different purposes (e.g., biofuel and biogas production, biofertilizer). HRAPs are normally part of an Advanced Pond System [32]. The disadvantage is that wastewater HRAPs require more land than activated sludge systems. However, it is proved to be cost-effective and offers a far more attractive proposition from an environmental viewpoint [33].

Even though during HRAPs for wastewater treatment, bacteria occur together with algae in ponds, the main goal is the production of important biomass of algae. Algae and bacteria live together and dominate water habitats. As producers and decomposers, the two groups of the community interact and influence each other, and are areas of recent research interest [34, 35]. The need for simple, efficient, and cost-effective technologies for wastewater treatment [36] promoted research studies and leads to the concept of wastewater treatment using the algae-bacteria consortium. Through symbiosis between autotrophic microalgae and heterotrophic bacteria, produced O_2 and CO_2 are freely exchanged between them for their growth and metabolism. Coupled with a bacterial breakdown of organic compounds, microalgae can directly assimilate soluble organic compounds thus contributing to COD removal [30]. The advantages of such a symbiotic interaction are most apparent in a biological wastewater treatment process, in which energy-intensive mechanical aeration accounts for more than 50% of the treatment cost [37]. Therefore, this technology is proved to be more efficient in removing nutrients [38-40] than in HRAPs even though the first objective of HRAPs is the recovery of important produced algal biomass.

Anaerobic digestion (AD) for wastewater treatment is also found to be a good method of using bacterial community for the purification of wastewater with high-strength organic matter. During digestion, organic matter is converted to a more oxidized form (CO_2) and another more reduced form (CH_4). Most of the CH_4 is released to the gaseous phase which then leads to the effective removal of organic matter. In general, the anaerobic conversion occurs in two stages:

– The acidogenic stage: conversion of organic matter into organic acids by acidogenic organisms.
– The methanogenic stage: conversion of organic acids into methane, carbon dioxide, and water by methanogenic organisms. CH_4 is transferred to the atmosphere contributing to the removal of organic matter from water.

Other reactions occur during the digestion process. Before the acidogenic stage, the complex organic compounds (carbohydrates, proteins, and lipids) need to be converted into simple organic compounds, through the mechanism of hydrolysis [41]. In domestic sewage, organic nitrogen is converted into ammonia by ammonification taking place in sewage. Oxidation of ammonia occurs in sewage where nitrifying bacteria are present, and ammonia is transformed into nitrate which is converted to nitrite. Denitrification can happen in which nitrate is converted into nitrogen gas and conduct more removal of ammonia from waste.

Anaerobic digestion has a triple advantage: biomethane, clean water, and microbial biomass production. It offers an enormous opportunity to make wastewater treatment not only sustainable but also a basis to produce clean water that can be recycled for a variety of purposes [42].

Another technique for wastewater treatment is Microbial Fuel Cells. A parallel photoanode, immobilized on the surface of a rectangular substrate (wastewater), and a conductive (photo)cathode that is commonly placed in a single compartment built for wastewater treatment and energy generation [43] are called Microbial Fuel Cells (MFCs) for wastewater treatment. They show a better decontamination performance, especially for the removal of aqueous recalcitrant contaminants including many persistent contaminants [44]. This superior performance of MFCs is likely due to the co-existence of anaerobic and aerobic microenvironments, which allows many reactions that are inherently incapable by strict anaerobic or aerobic technologies [24]. However, MFCs are generally more suitable for treating medium and low-strength wastewaters with a relatively simple composition, while AD has a clear competitive advantage in dealing with high-strength wastewaters. According to Li et al. [23], MFC technology could be highly adaptable to a sustainable pattern of wastewater treatment for several reasons: (1) direct recovery of electric energy and value-added products; (2) good effluent quality and low environmental footprint; and (3) inherently amenable to real-time monitoring and control, which benefits good operating stability. Therefore, integrating AD for pre-fermentation [24] before MFCs will result in a better performance.

Different other common technologies have been scientifically demonstrated to be effective in wastewater treatment. They can work normally and provide clean water if the process occurs well followed with good maintenance.

1) Constructed wetland is an artificial shallow basin filled with substrate, usually soil or gravel, and planted with vegetation that has tolerance to saturated conditions [45, 46]. Constructed wetlands are used for wastewater

management to protect existing ecosystems [45]. Constructed wetlands for the management of different types of wastewaters can take various forms but all comprise water, vegetation (emergent and/or floating), and substrates that are saturated for much of the time. Influent wastewater is simultaneously treated through oxidation or reduction, plant uptake, sorption, filtration, precipitation, sedimentation, biodegradation, predation, volatilization, filtration, photolysis, nitrification, denitrification, die-off, inactivation by UV [45]. To this author, there are two types of constructed wetlands: (a)- surface flow wetlands characterized by areas of open water and are most like natural wetlands, sometimes containing floating and submerged plants in addition to emergent plants, (b)- subsurface flow wetlands are more controlled systems in which flow occurs predominantly through the substrate, either as horizontal subsurface flow or vertical flow. Subsurface flow wetlands are often used to treat smaller wastewater flows compared to surface flow systems, due to their higher construction and maintenance costs. They are typically used for secondary municipal wastewater treatment for small communities or specialized wastewater from industrial processes. Constructed wetlands are not stand-alone treatment plants but should be deployed as part of a treatment train for wastewater management. Normally, pre-treatment of wastewater is necessary before passage through a constructed wetland.

2) Membrane filtration is recommended for advanced water reclamation [47]. The procedure involves passing the wastewater through membranes with small pores [27]. The performance of membranes is usually evaluated through rejection and permeates flux. Pre-treatment using a first method to remove great particles before application of any membrane filtration is necessary to efficiently separate pollutants or recycle valuable chemical products and meanwhile to produce high-quality water [48, 49]. Membrane filtration can be classified based on the size of the pores on the membranes and can be classified in order of decreasing permeability as follows: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), and the electrodialysis process.

3) Nanotechnology using nanomaterials can be used successfully to treat wastewater and obtain purified water. Nanomaterials can offer a wide range of applications such as catalytic membranes, nanosorbents, bioactive nanoparticles, and metal nanoparticles such as iron, silver, and titanium oxides [50, 51]. Their properties such as high reactivity, large surface area, easy separation, small size, high catalytic properties, and presence of many active sites for binding of pollutants [52] are successfully applied in wastewater treatment. Nanosorbents, nanocatalysts, nanostructured catalytic membranes, and nanofiber technology are nanotechnology methods used for the degradation of organic pollutants, inactivation of microorganisms, anti-bio fouling action, and physical separation of water contaminants. The important feature of nanotechnology is that it can be incorporated with any other existing technologies to modify and/or clarify the concept with ease [53].

Infrastructure for Effective Wastewater Recycling

The lack of adequate infrastructure for water collection or treatment causes the bulk of domestic and/or industrial wastewater to be discharged without any treatment, with damages health and the environment [19]. The installation of adapted infrastructure for wastewater collection, treatment, and control will help avoid damages mainly observed in low-income countries around the world. Historically, the primary goal of the wastewater infrastructure has been to provide sanitation and protect the ecosystem through the collection and end-of-pipe treatment of wastewater to meet the discharge standards [53].

Connection Networks

Sewerage systems include the collection of wastewaters from their sources, transport, including pumping stations, delivery to a treatment facility, treatment, and disposal of solids generated during the treatment process [55]. To succeed in the treatment of wastewater in any urban or semi-urban area, the connection from the houses and existing industries to municipal sewerage pipelines is the first challenge to be met. There are two types of sewer networks for wastewater drainage to a wastewater treatment facility. Combined sewer networks are installed for the disposal of wastewater and stormwater in one network. For combined sewer networks, pipelines are sized to accommodate large rainfall events and significant amounts of stormwater and equipped with relief points to prevent flooding [55, 56]. During large amounts of rainwater, water tends to be discharged directly to the sea or river conducting to environmental pollution. To avoid pollution effects on the environment, separate sewer networks are promoted and commonly used. Separate networks conduct separately either stormwater or produced wastewater sewer.

The wastewater sewer network is usually divided into smaller units consisting of the lateral, collector, trunk, and intercepting sewer [56].

– Lateral Sewers are the smallest in the network and receive sewage from the community and then discharge it into the collector sewer.
– Collector Sewers receive sewage from two or more lateral sewers and tie into the main interceptor.
– A trunk Sewer is the main sewer that receives flow from two or more collectors.
– Intercepting Sewers are usually constructed from precast reinforced concrete pipes. Intercepting sewers receive wastewater from both the collector and trunk sewers and transport the wastewater to the treatment plant.

Table 1. Water quality parameters.

Total suspended solids		Total dissolved solids	
		Conservative dissolved solids	Non-conservative dissolved solids
Settable suspended solids	Colloid suspended solids	Ions: calcium, magnesium, sodium, potassium, sulfate, chloride, carbonate, bicarbonate Metals: chromium, iron, cadmium, nickel, zinc, mercury Persistent organics: pesticides, chemicals	Ions: Nitrate, Nitrite, organic nitrogen Biodegradable organics: BOD, COD Coliform bacteria: total and fecal

Pump Stations

In case no higher elevations for automatically pumping of wastewater, pump stations (lift stations) must be installed to ease wastewater drainage to the treatment station. The pump works under the control of a computer or is electrically monitored. The components of the pump or lift station are centrifugal pumps, motors, power sources, controls, wet wells, and discharge conduits. According to Water Environment Federation [57], there are several different types of lift stations including the following: single-family (home) grinder pumps; low-pressure force main systems which also include grinder pumps; lift stations that discharge to gravity via a force main and can be accomplished using the suction lift or submersible centrifugal pumps; wet pit/dry pit which typically would have a longer force main and would discharge to a larger pressure pipe called an interceptor force main, or could also discharge to a gravity interceptor both carrying flow to a wastewater resource recovery facility (WRRF) for treatment.

Power Supply

Power could be obtained from electricity used to supply the urban zone. Electricity can also be obtained locally from the photovoltaic power supply by installing the required infrastructure able to accumulate solar energy. Solar voltaic cells with battery storage can be used [58, 59] for this purpose. During anaerobic digestion or biomass cultivation for wastewater treatment, energy from digested wastewater or produced biomass could be reused for power supply. For example, the U.S. wastewater treatment industry is focused on energy-efficient operations combined with approaches to recover energy from the wastewater stream [60]. Biogas recovery is an accepted and widely implemented practice in the wastewater treatment industry. The most common biogas recovery path is the capture of methane generated during the anaerobic digestion of biosolids. If the power supply does not work, treatment plants cannot operate properly.

Lab and Instruments for Water Quality Monitoring

A laboratory must be equipped with instruments such as a dissolved oxygen meter, multiparameter meter, and redox meter to directly measure the following parameters from wastewater: dissolved oxygen (DO), temperature, pH, conductivity, redox (reduction/oxidation potential), turbidity, chlorine. Concentrations of these analytes can be significantly changed during transport and storage [61]. Samples should be taken with containers, and conserved for analysis of parameters that are total suspended solids and total dissolved solids [62, 63]. They must be by the national or international standards. Total suspended solids comprise settable suspended solids and colloid suspended solids. Total dissolved solids comprise conservative dissolved solids and non-conservative dissolved solids (Table 1).

The laboratory must be equipped with apparatus and related chemicals to regularly measure these parameters in wastewater. That will help monitor treatment efficiency and work to obtain quality effluent meeting the standards.

Treatment Facility Design

Most of the time, modern wastewater treatment technologies particularly for municipal wastewater derive from the conventional treatment plant (Fig. 2.1). For example, HRAPs, algae bacterial consortium cultivation (Fig. 2.5, Fig. 3A) and constructed wetlands (Fig. 2.6, Fig. 3B) are typically used for secondary municipal wastewater treatment. Digestion is done using secondary sludge in a modern digester ([64], Fig. 2.2, Fig. 3C) and can be done before MFCs wastewater treatment resulting in a better performance (Fig. 2.3). Pre-treatment consists of using any other methods (physical-chemical, biological treatments or mostly the less performant membrane filtration) to remove large particles and solids to facilitate filtration. Nanotechnology (Fig. 2.4) can on the other hand be incorporated into any other technologies.

Concepts of the Modern Wastewater Reuse Systems

In modern times, wastewater is diversely reused. After treatment, wastewater effluent is reused for some human activities (Direct wastewater reuse purposes). Products or organic matters obtained from wastewater are recovered (Table 2) for reuse purposes (Indirect wastewater reuse purposes).

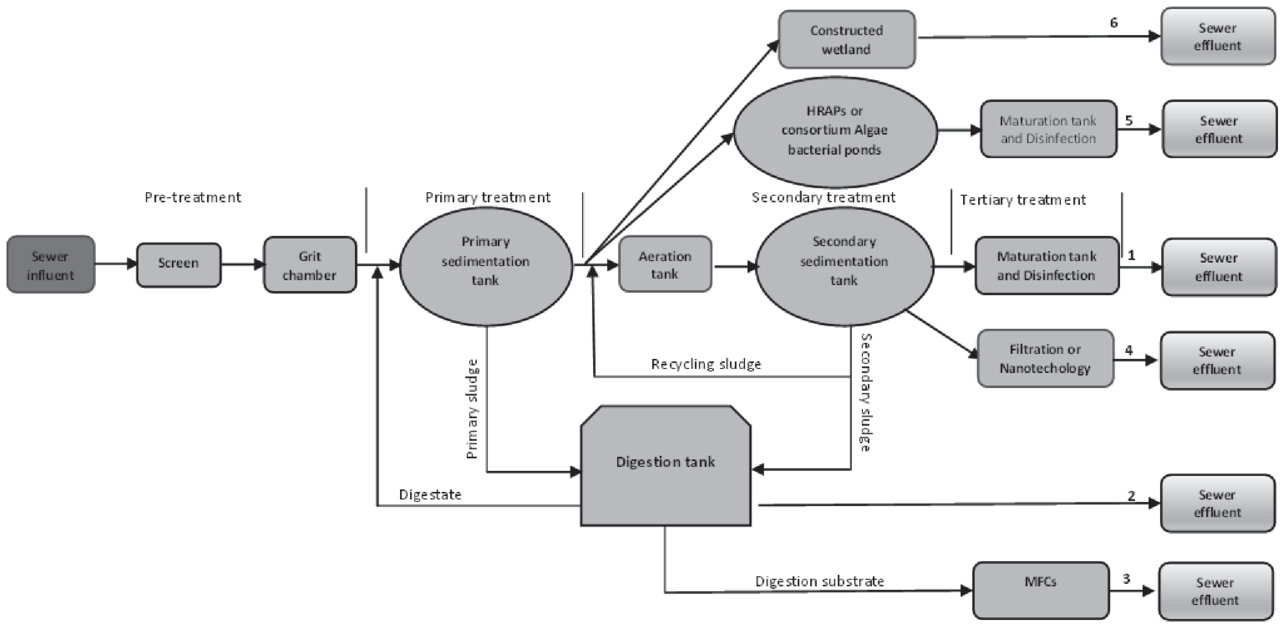

Fig. 2. Conventional wastewater treatment process and derived integrated technologies.
Notes: 1. Conventional wastewater treatment process, 2. Anaerobic digestion integrated into conventional wastewater treatment, 3. Anaerobic digestion followed by MFCs integrated into conventional wastewater treatment, 4. Filtration or nanotechnology integrated into conventional wastewater treatment, 5. HRAPs or consortium algae bacterial cultivation are used as secondary treatment during the conventional process, 6. Constructed wetland integrated into the conventional process as secondary treatment.

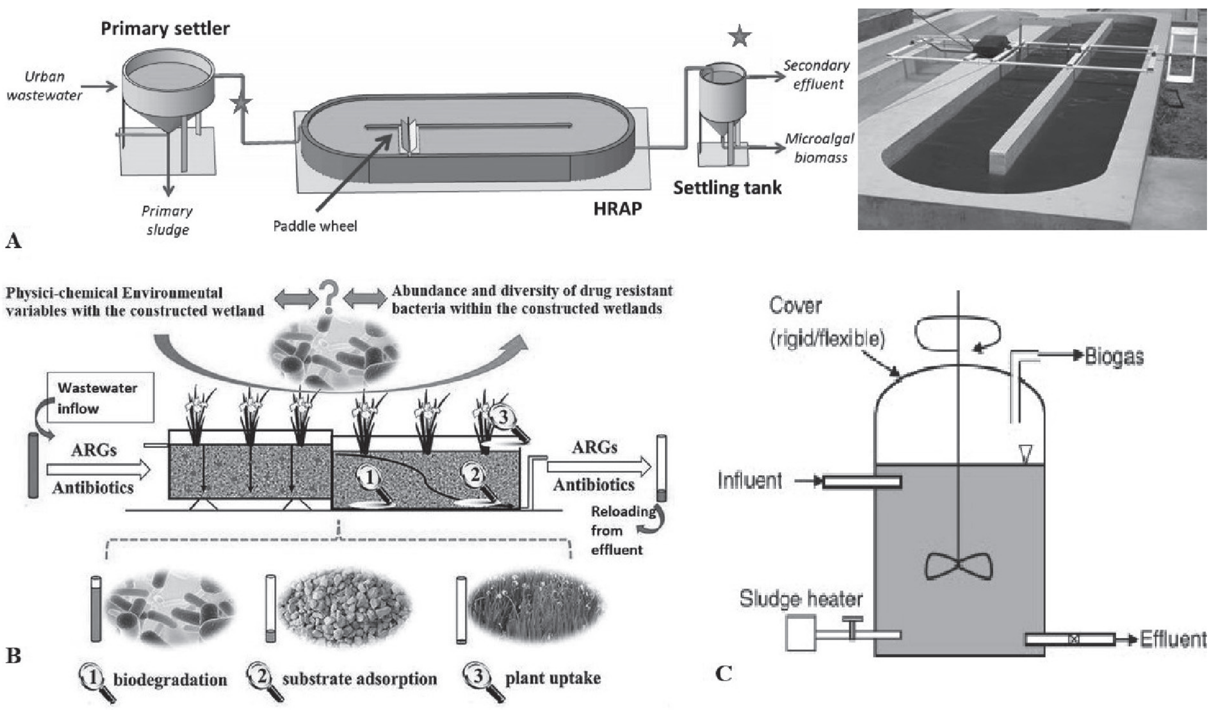

Fig. 3. Some wastewater treatment systems. A. HRAPs or algae bacterial consortium cultivation for wastewater treatment and biomass recovery [58, 59], B. constructed wetlands [45], C. digester for wastewater treatment [64].

Direct Wastewater Reuse Purposes

Direct wastewater reuse purpose (DWRP) in the view of this study supposes the reuse of treated wastewater itself for any purpose. Nowadays, according to the characteristics of wastewater to be treated and the reuse targeted purpose, a treatment process can be applied to meet the standards related to this reuse purpose [4-6]. Historically, agricultural and landscape irrigation has been and continues to be the largest use

Table 2. Summary of reuse purposes.

Types	Products	Reuse categories
Direct wastewater reuse purposes (DWRP)	Water supply	Agricultural and landscape irrigation
		Disposal to surface and groundwater systems: irrigation, industrial use (cooling water, boiler feed water, …), domestic use, drinking water source
		Recreational and environmental use (recharge of lakes and ponds, streamflow augmentation, …)
		Non-potable reuses: car washing, toilet flushing, street cleaning, water for cooling, vaporization
		Potable ruses: clean water supply for drinking, washing, cooking, clothes washing
Indirect reuse purposes (IWRP)	Biomass recovery	Agriculture: fertilizers, biocides as insecticides, herbicides, algicides, and fungicides
		Medicine: toxins as antitumors (against cancer)
		Biofuels: biodiesel, biogas
	Energy supply	Biogas
		Direct electricity

of untreated wastewater. Modern reuse supposes that wastewater should be treated to produce a safe effluent that meets the reuse purpose. Disposal of effluent to the surface water or groundwater systems that could be reused for any purposes (irrigation, industrial use, domestic use, drinking water source) is qualified as unplanned reuse. If sewer is stored and planned for any purpose, this is qualified as planned reuse. During the planned reuse of sewer effluent for agriculture, sewer effluent is reused for irrigation of different crops such as vegetables, maize, rice, fodder, and any other crops for livestock. Properly treated to acceptable effluent water quality leads to diversify water reuse practices beyond agricultural and landscape irrigation, to recreational and environmental use, non-potable urban uses, industrial reuse, groundwater recharge and potable reuse [65].

Indirect Reuse Purposes

Indirect wastewater reuse purpose (IWRP) means the use of wastewater to obtain an alternative product that is used for the desired purpose. Indeed, during wastewater treatment, biomass and biogas can be obtained, recovered, and differently used. The main utilizations of biomasses are the following:

Production and Recovery of Biomass

Prokaryotic organisms such as bacteria and cyanobacteria, and eukaryotic organisms such as algae, fungi and protozoa are microorganisms found in wastewaters. Algae, cyanobacteria, and bacteria dominate wastewater and natural water habitats. Wastewater characteristics are sometimes favorable to the development of algae and bacteria. Therefore, wastewater is used for the cultivation of separate algae and bacteria or a consortium of algae and bacteria. The biomass obtained is used for many purposes.

Fertilizers

Composting of cultivated biomass is a way of converting produced biomass into functional products useful as fertilizers in agriculture. Composting can be done from algal biomass, algae bacterial biomass or a combination of algae, bacteria, and the separated organic matter of wastewater. After anaerobic digestion for wastewater treatment, digestate can also serve as fertilizer for agriculture. Algal biomass contains macronutrients as well as micronutrients, some growth regulators, polyamines, natural enzymes, carbohydrates, proteins, and vitamins to improve vegetative growth and yield [66, 67]. According to Tuhy et al. [68], in ancient Brittany, algae were used as natural fertilizers and were introduced directly into the soil or composted with organic matter depending on the region.

Algal Uses in Medicinal and Agriculture

Cyanobacteria produce secondary metabolites including cyanotoxins. Different toxins extracted from cyanobacteria have proved to exhibit cytotoxic properties, which provide good opportunities for manufacturing anticancerous drugs [69, 70]. Cryptophycins isolated from *Nostoc* sp. [71], cryptophytes isolated from *Nostoc linckia* and *Nostoc spongiaeforme* [72] were found to exhibit antitumor activity against cancer. For agriculture, several cyanotoxins, which are derived from cyanobacteria, exhibit various bioactivities and may serve as biocides. Biocides from cyanotoxins show growth inhibitory response on microorganisms including bacteria, viruses, fungi, and some invertebrates such as crustaceans, and bivalves [69, 73]. They are known to be potential active biological compounds that could be applied in crop fields as insecticides, herbicides, algicides, and fungicides due to their allelopathic effect [74, 75]. The application of formulated toxins to use in agriculture could have a low negative ecological impact and simultaneously maintain the growth of producers.

Biofuel Production

Algal biomass contains three main components: carbohydrates, proteins, and natural fats/oils. Algal biofuel options include three conversion processes [31]. The chemical conversion includes transesterification of the lipid fraction to biodiesel. The biochemical conversion consists of fermentation of the carbohydrate fraction to bioethanol and anaerobic digestion of the whole biomass to produce biogas. The thermochemical conversion involves the thermal decomposition of algal organic components into liquid or gaseous fuels and can be divided into hydrothermal liquefaction, pyrolysis and gasification [76, 77]. Because most of the natural oil made by microalgae is in the form of triacylglycerol, which is the right type of oil for biodiesel production, microalgae are the exclusive focus in the algae-biodiesel arena. In addition to biodiesel, microalgae can also be used to generate energy in several other ways. Some species of algae can produce hydrogen gas under specific growing conditions. Algae biomass can also be burned like wood or digested anaerobically to produce methane biogas to produce heat and electricity. Algal biomass can also be processed by pyrolysis to produce bio-crude oil.

Wastewater for Energy Production

Anaerobic digestion optimization is a common practice to increase the energy self-sufficiency of WWTPs [78]. Biogas is used to control the temperature of the reactor, and generate electric energy using combined heat and power (CHP) engines fueled, the excess being burned in a flare. As revealed by these authors, some WWTPs of Catalonia (Spain) produce between 39% and 76% of the total electric energy consumed in the WWTP. Smith et al. [79] found that anaerobic membrane bioreactors (AnMBRs) generate methane-rich biogas directly through the anaerobic conversion of organics in domestic wastewater that must be balanced against system energy consumption to reduce net energy use.

As previously demonstrated, another way of recovering energy from wastewater is MFCs. Even though this technology is considered as a promising technology that still faces major challenges in wastewater treatment, it has been proven to enable the recovery of energy from wastewater [25]. In MFCs, the biochemical energy contained in the organic matter is directly converted into electricity in what can be called a microbiologically mediated “combustion” reaction. It allows energy recovery and shows better decontamination performance [24, 80].

Challenging Perspectives

The following perspectives are developed on (a) wastewater sanitation and wellbeing, (b) infrastructures and their maintenance, (c) integrated technologies, and (d) antimicrobial resistance. They are much more addressing developing countries and less developing countries.

a) Wastewater sanitation and wellbeing

The growing population and rising economy have resulted in increased consumption of water and discharge of wastewater [16] to the environmental water bodies. Rapid urbanization brings along several challenges related to water quality, environmental degradation, and health risks, particularly for low-income countries that are often unserved or have poor sanitation facilities [17]. Making wastewater treatment a reality can reduce sanitation challenges around the world. Increasing sanitation by wastewater collection and treatment using adapted technologies is a key point to achieving the MDGs of the UN at its Target 6.3 by 2030 and over. When meeting the disposal and reuse criteria, wastewater highly contributes to less environmental pollution, healthy reuse of wastewater and by-products for activities by the societies and both contributing to human well-being. Therefore, wastewater instead of being a waste is a resource for human activities every day. Wastewater that meets irrigation standards is known to be safe for farmers and of important nutrient content and fertilizers for crop cultivation with high yield. That could provide clean food to the population and contribute to food security, especially in developing countries. Meeting the criteria is challenging but an effective treatment of wastewater could bring more opportunities. The treatment of wastewater for the generation of sufficient electricity could be sustainable, especially for developing cities in third-world countries which suffer from inadequate power supply [81]. However, meeting the standards and criteria for wastewater disposal for reuse is a real challenge mostly in low-income countries but scientists, populations and policymakers should work to make it a reality all over the world.

b) Infrastructures and maintenance

The lack of infrastructures and the existing poor ones is the first challenge developing countries face. Flashing toilets, connection networks, and wastewater treatment plants are insufficient and practically not existing in urban areas (Fig. 4). The existing ones are even found to be worse. Most of the time the existing wastewater treatment systems do not work because overused and have no maintenance. Insufficient infrastructure for wastewater collection and treatment, and unsuitable treated water quality (high pathogen and salinity levels) as mentioned by Nikiema et al. [19] are real problems for the environment and users in countries like Burkina Faso. Wang et al. [16] noticed that in Kenya, at the Kisumu district in Kenya, all three of the existing pump

Fig. 4. Wastewater collection systems and treatment in Burkina Faso. A. canalization of wastewater, B. wastewater influent, C. wastewater effluent.

stations (Sunset Hotel, Kendu Bay, and Mumias road) were broken down and resulting in the overflow of sewage at manholes upstream of the pump stations.

All these situations indicate that so far, sanitation seems to be not a priority in SSA countries. It is therefore urgent that research projects and activities followed by immediate actions from policymakers be undertaken in developing new infrastructure for sustainable and cost-effective management of wastewater in low-income countries, particularly in SSA.

c) Integrated technologies

The process of wastewater treatment is to transform wastewater into a useful effluent, which enables reuse, by returning to the water cycle [82]. For efficient wastewater treatment to meet this goal, integration of technologies is encouraged as applicating a single system is found to be inefficient. Wastewater treatment generating reusable resources for purposes could be cost-effective. Implementation of cheap treatment methods will significantly increase the amount of wastewater to be treated worldwide. A good combination of technologies could lead to meet the challenge of cost-effective wastewater treatment. The combination of technologies is characterized as a novel and efficient way leading to the removal of complex and recalcitrant particles in highly concentrated wastewater. Therefore, this study demonstrated the possibility of integrating different technologies into the conventional activated sludge process (Fig. 2). Treatment processes such as constructed wetlands, HRAPs or consortium algae bacterial cultivation, and anaerobic digestion that could be followed by the MFC process, membrane filtration or nanotechnology for wastewater treatment can be integrated into a conventional process to obtain useful effluent. Different combinations have been proposed by several studies. For example, for perfect wastewater treatment during membrane filtration, different integrated systems are proposed by many authors such as Wintgens et al. [83], Goh et al. [84], Ahmad Mutamim et al. [27], Phattaranawik et al. [85], Dasgupta et al. [86], Sawadogo et al. [86].

d) Antimicrobial resistances

Urban wastewaters and mostly hospital wastewaters are important sources of pharmaceuticals. These compounds are often resistant to biodegradation in aquatic and terrestrial ecosystems [82, 88]. Therefore, the release of antibiotics into natural water bodies mainly comes from the effluents of municipal sewage treatment plants (STPs) and pharmaceutical manufacturing plants. Among pharmaceuticals, antibiotics that have a microbial origin, act selectively on pathogenic bacteria [89]. Multiple antibiotics are commonly used in hospitals worldwide. Of particular concern are antibiotic residues increasing in the environment which can induce antibiotic-resistant genes (ARGs) from extended exposure at relatively low concentrations [89]. Antibiotic-resistant pathogens have emerged and are being disseminated among human and animal populations worldwide. Antimicrobial resistances lead to the impossible medication of diseases resulting from some pathogenic bacteria affecting human beings and animals. The release of antibiotics into the environment is a worldwide problem. From wastewaters and fecal sludge in developing countries, the proliferation and spread of Antimicrobial Resistant Bacteria (ARB) and Antimicrobial Resistant Genes (ARGs) to different environmental compartments of the world is becoming a reality. Therefore, before discharging wastewater into the environment, antibiotic residues need to be removed even though this usually involves high cost [88]. Different techniques have been studied for the effective removal of antibiotics and pharmaceuticals from urban wastewater. Among them are adsorption by activated carbon (AC), clay mineral (Bentonite), Biochar (BC), nanomaterials, electrobiochemical technologies (chemical oxidation, electrocoagulation), hybrid MFC-coupled constructed wetland, aerobic membrane bioreactor system, Advanced oxidation processes (AOPs), ozonation, membrane treatment [1, 82, 90-92].

Conclusions

Wastewater that is daily produced all over the world is a fundamental risk to the environment and human health. However, if efficiently treated and managed, wastewater is a real reusable resource for development of daily activities. Agriculture that feeds people around the world is the first activity using an important quantity of wastewater.

Nevertheless, for a safe environment and human health, wastewater must be reused after a convenient treatment providing influents meeting established standards and criteria. For that, required infrastructure, treatment facilities and technologies must be available and used.

However, this is and remains a real challenge, particularly for low-income countries in the world.

Practical technologies are proposed for cost-effective wastewater treatment. However, to make available infrastructure and facilities that help meet this challenge, involvement of local populations, utilization of scientific results, good governance, rational utilization of resources to be oriented in wastewater treatment and sanitation, and particularly a political will and commitment in low-income particularly the African ones must be a reality.

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Conflict of Interest

The authors declare no conflict of interest.

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