Chapter 18

Impact of Wastewater on Surface Water Quality in Developing Countries: A Case Study of South Africa

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Abstract

Wastewater effluents are major contributors to a variety of water pollution problems. Most cities of developing countries generate on the average 30–70 mm^3 of wastewater per person per year. Owing to lack of or improper wastewater treatment facilities, wastewater and its effluents are often discharged into surface water sources, which are receptacles for domestic and industrial wastes, resulting to pollution. The poor quality of wastewater effluents is responsible for the degradation of the receiving surface water body. Wastewater effluent should be treated efficiently to avert adverse health risk of the user of surface water resources and the aquatic ecosystem. The release of raw and improperly treated wastewater onto water courses has both short- and long-term effects on the environment and human health. Hence, there should be proper enforcement of water and environmental laws to protect the health of inhabitants of both rural and urban communities. This study reports major factors responsible for the failing state of wastewater treatment facilities in developing countries, which includes poor operational state of wastewater infrastructure, design weaknesses, lack of expertise, corruption, insufficient funds allocated for wastewater treatment, overloaded capacities of existing facilities, and inefficient monitoring for compliance, among others.

Keywords: developing countries, health risk, pollution, surface water, wastewater effluents, wastewater treatment facilities

1. Introduction

Freshwater availability is one of the major problems facing the world, and approximately, one-third of drinking water requirement of the world is obtained from surface sources like rivers, dams, lakes, and canals [1]. These sources of water also serve as best sinks for the discharge of domestic and industrial wastes [2, 3]. The biggest threat to sustainable water supply in South Africa is the contamination of available water resources through pollution [4]. Many communities in South Africa still rely on untreated or insufficiently treated water from surface resources such as rivers and lakes for their daily supply. They have no or limited access to adequate sanitation facilities and are a high risk to waterborne diseases [5]. Since 2000, there has been a dramatic increase in the episodes of waterborne diseases in South Africa [6, 7].

Surface water has been exploited for several purposes by humans. It serves as a source of potable water after treatment and as a source of domestic water without treatment particularly in rural areas in developing countries. It has been used for irrigation purposes by farmers, and fishermen get their occupation from harvesting fish in so many freshwater sources. It is used for swimming and also serves as centers for tourist attraction. Surface water, therefore, should be protected from pollution. Major point sources of freshwater pollution are raw and partially treated wastewater. The release of domestic and industrial wastewater has led to the increase in freshwater pollution and depletion of clean water resources [8]. Most quantities of wastewater generated in developing countries do not undergo any form of treatment. In few urban centers, various forms of wastewater treatment facilities (WWTFs) exist but most of them are producing ill-treated effluents, which are disposed of onto freshwater courses.

In some developed countries of the world, adequate supply of potable water and improved sanitation facilities have been achieved. Strict environmental laws and monitoring for compliance prevent undue pollution to freshwater sources. Good waste management technologies and increased environmental protection awareness have contributed immensely to the success story. This has resulted in fewer cases of waterborne diseases reported compared to developing countries.

Many people in developing countries of the world still rely on untreated surface water as their basic source of domestic water supply. This is so because either there is an incessant supply of potable water or inadequate water supply systems. This problem is exacerbated in rural areas. Surface water is increasingly under undue stress due to population growth and increased industrialization. The ease of the accessibility of surface water makes them the best choice for wastewater discharge. Wastewater which comprises of several microorganisms, heavy metals, nutrients, radionuclides, pharmaceutical, and personal care products all find their way to surface water resources causing irreversible damage to the aquatic ecosystem and to humans as the aesthetic value of such water is compromised. These pollutants decrease the supply of useable water, increase the cost of purifying it, contaminate aquatic resources, and affect food supplies [9]. Pollution combined with the human demand for water affects biodiversity, ecosystem functioning, and the natural services of aquatic systems upon which society depends on.

Urban areas in most developing countries do have several wastewater management systems some of which are very effective and meet international standards, but many others are plagued with poor designs, maintenance problems, and expansion including poor investment in wastewater management systems. Most rural and poor communities often do not have any form of wastewater management systems. Effluents from large- and small-scale industries are usually channeled to surface water courses, which often result in pollution, loss of biodiversity in the aquatic ecosystem, and possibly health risk to humans.

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Environmental quality and antipollution legislations are the most widely used interventions to control and reduce environmental pollution [10, 11]. In most countries, environmental laws have been enacted by the government and enforced through its administrative structures [12]. The use of criminal sanctions has also limited pollution but the enforcement of these environmental laws remains inadequate [12, 13]. Enforcement of environmental laws in South Africa like other developing countries suffers major setbacks due to inadequate technical experts, insufficient funds, corruption, and low deterrent effects of sanctions [12, 13].

2. Surface water quality

Surface water is one of the most influenced ecosystems on earth, and its alterations have led to extensive ecological degradation such as a decline in water quality and availability, intense flooding, loss of species, and changes in the distribution and structure of the aquatic biota [14], thus, making surface water courses not sustainable in providing goods and services [14, 15]. For instance, the health of a river system is influenced by various factors, which include the geomorphology and geological formations, physicochemical and microbial quality of the water, the hydrological regimes, and the nature of instream and riparian habitats [15].

Water quality is described by chemical, physical, and biological characteristics of water that determine its fitness for a variety of uses and for the protection of the health and integrity of aquatic ecosystems [16]. Each aquatic ecosystem has the natural tendency to adapt and compensate for changes in water quality parameters through dilution and biodegradation of some organic compounds [17]. But when this natural buffering capacity of the aquatic ecosystem is exceeded due to the introduction of various classes of contaminants from point and nonpoint sources on a continuous basis, water pollution sets in.

In South Africa like most other developing countries in the world, surface water is usually used for domestic, recreational, and agricultural purposes mostly in the rural areas [9, 18]. Water quality is affected by both natural processes and anthropogenic activities. Generally, natural water quality varies from place to place, depending on seasonal changes, climatic changes, and with the types of soils, rocks, and surfaces through which it moves [5, 19]. A variety of human activities such as agricultural activities, urban and industrial development, mining, and recreation significantly alter the quality of natural waters and change the water use potential [16, 19].

Decrease in water quality can lead to increased treatment costs of potable and industrial process water [19]. The use of water with poor quality for agricultural activities can affect crop yield and cause food insecurity [4]. The presence, transport, and fate of heavy metals and organic compounds (which are toxic and persistent) in water bodies are a cause for serious concern globally [4]. Groundwater can be polluted through the release of chemicals contained in wastewater. Riverbeds and wetlands are threatened with increased sediment impoundments and the presence of toxic and persistent chemicals. Such pollution can persist long after their original sources have ceased.

The health of the aquatic ecosystem can be negatively affected by the presence of toxic substances. This is further exacerbated with high population of pathogens in the water. The use of microbiologically contaminated water for domestic and other purposes is detrimental to human health and the society at large [20]. These conditions may also affect wildlife, which uses surface water for drinking or as a habitat. Generally, for measuring water quality, the physical (turbidity, electrical conductivity, temperature, total dissolved solids, color, and taste), chemical (pH, COD, BOD, nonmetals, metals, and persistent organic pollutants, POPs), and biological (fecal coliform, total coliform, and *enterococci* count) analyses are usually performed [19].

3. Wastewater treatment

Wastewater comprises of all used water in homes and industries including storm water and runoffs from lands, which must be treated before it is released into the environment in order to prevent any harm or risk it may have on the environment and human health. The major types of wastewater are shown in **Figure 1**.

The major aim of wastewater treatment is to protect human health and prevent environmental degradation by the safe disposal of domestic and industrial wastewater generated during the use of water. One of the objectives of wastewater treatment is to recycle wastewater for reuse in irrigation, thereby preserving water resources, which is scarce in arid and semiarid regions of the world [21, 22]. In ancient times, there was no specific treatment given to wastewater. Instead, wastewater was channeled from buildings into waterways through gutters and canals, which eventually ended up in rivers, streams, lakes, and oceans, which were used by people [23]. This natural treatment process based on dilution was adequate presumably due to a smaller population and low population density as well as human activities, resulting in lower pollution load as compared to the present times [23].

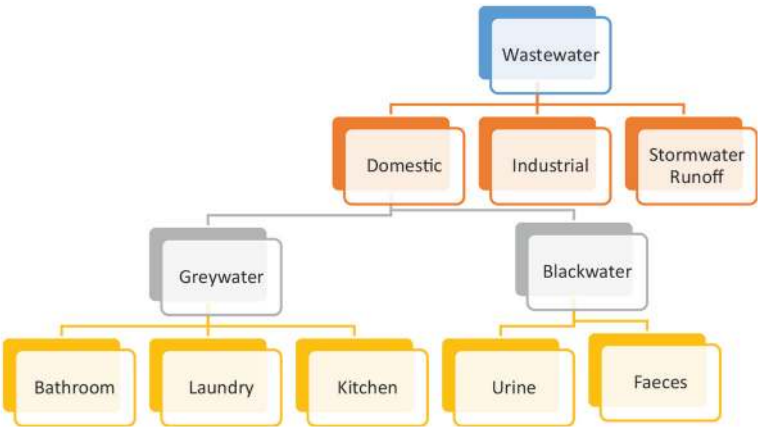

Figure 1. Types of wastewater.

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Increase in population and industrial growth led to the generation of a high quantity of untreated wastewater channeled to water bodies as raw water [24]. Eutrophication, fish kill, and cholera outbreaks have commonly been reported in communities that use contaminated water for domestic and other purposes [24]. This necessitates the consideration of a more advanced technology in treating wastewater. Wastewater treatment facilities were initially designed to remove/decrease conventional pollution parameters (BOD_5, COD, total suspended solids, and nutrients) from the wastewater stream so that the final effluents do not constitute new sources of pollution [25]. However, it has been discovered that the wastewater organic load contains high levels of a variety of hazardous organic pollutants, and thus, additional treatment steps and control measures become very necessary [21, 25].

The quality of wastewater varies according to the types of influents the WWTFs receive such as domestic wastewater, dry and wet atmospheric deposition, urban runoff containing traffic-related pollution, or agricultural runoff [25]. The range of contaminants becomes broader when industrial wastewater is included into the raw water stream that enters a WWTF [25–27]. Recently, it has been shown that WW effluents contain emerging organic contaminants such as persistent organic pollutants (POPs), brominated flame retardants, per-fluorinated compounds, and pharmaceuticals, which are not removed during the treatment process [25, 28]. Wastewater treatment technology is fast changing so as to meet the current day challenge.

In many countries, urbanization is growing at an unprecedented rate, and such development is often unbalanced with much of the disposable municipal expenditure devoted to high-profile infrastructure with waste disposal and management coming well down in the list of priorities in terms of allocation of funds [29]. A study conducted by Saving Water South Africa [30] showed that less than half of the South African wastewater treatment plants (WWTPs) treat wastewater they receive to a safe and acceptable level [31]. The health risk from wastewater usually comes from microbial pathogens, nutrient loads, heavy metals, and some organic chemicals [31, 32]. Bacteria are the most common pathogens usually found in treated wastewater and cause several infections and diseases particularly to young, pregnant, immune-compromised and aged people [31, 33].

Most wastewater treatment facilities in South Africa dispose their effluents directly to nearby rivers or streams, which are used by the surrounding villages for their various water needs. Ogola et al. [34] demonstrated from their study on wastewater treatment facilities in Limpopo Province of South Africa that wastewater is rarely treated to acceptable standards, and this was further confirmed by Edokpayi [35] and Pindihama et al. [36]. Their findings suggest that inadequate investment in wastewater treatment infrastructure, shortage of skilled manpower, poor planning or corruption [31] could have resulted in the poor performances of wastewater treatment facilities in that region.

Wastewater needs to be adequately treated prior to its disposal or reuse in order to protect receiving water bodies from contamination [31]. The discharge of poorly treated wastewater usually affects water users downstream and contaminates groundwater [31]. Waste stabilization ponds (WSPs) are usually used to provide an effective and low-cost means of handling domestic wastewater for smaller towns and communities [34]. The use of WSPs is advantageous over the conventional WWTPs because they are very simple to design, operate, and maintain and do not necessarily need skilled manpower [37]. However, Jagals et al. [38] conducted a study on WSPs in the Free State Province of South Africa; their results revealed that most of the municipal waste stabilization ponds were performing less than the required standard. They recommended the implementation of a frequent monitoring program. Wastewater has also been implicated as a possible source of heavy metals, polycyclic aromatic hydrocarbons (PAHs), and microbial contamination to soils, surface water, sediment and groundwater [39–41]. The inadequate storage facility in most WWTPs often gives room to untreated wastewater loss into the surrounding lands and rivers, especially during heavy rains and flooding.

Weber et al. [21] showed from their studies the presence of a wide range of contaminants of emerging concerns in wastewater even after the conventional treatment process. Such contaminants include pesticides, polycyclic aromatic hydrocarbons, and pharmaceutical and personal care products. Bundschuh et al. [22] reported on the impacts of wastewater, that concerns have been largely associated the presence of microorganisms, while other toxic and persistent components like heavy metals and POPs have not been given appropriate consideration. Treated wastewater often contains some pollutants such as POPs and heavy metals which are not removed in the treatment processes. The use of such water for irrigation may lead to the accumulation of those contaminants in soils which can be bioavailable for uptake to plants and animals. Thus, providing a pathway through the food chain to man. They also have biological effects on soil fauna and flora after long-term application [39, 42, 43].

The cultivation of vegetables in soils irrigated with wastewater containing high concentrations of toxic metals usually take up such metals and accumulate them in edible and nonedible parts of the vegetables in quantities large enough to cause potential health risks both to animals and humans consuming these metal-rich plants [44–48]. Heavy metals have special features that make them toxic even at very low concentrations. They are nonbiodegradable and persistent in various environmental media and can accumulate in plants and animals [45]. The oral route has been identified as the major pathway through which heavy metals enter into the human body. Consumption of food crops from farmlands irrigated with wastewater and ill-treated wastewater effluents could make people who feed on them at risk to several diseases, some of which only become evident after many years of exposure [49, 50].

Wang et al. [43] reported the accumulation of polycyclic aromatic hydrocarbons (PAHs) in soils irrigated with wastewater such that the concentration of PAHs was found to be higher in soils very close to the main entrance of the wastewater and decreased gradually with distance away from the plant. Once these pollutants are released into the environment, they are capable of persisting for a long period of time. PAHs can affect humans and animals both externally and internally. On the skin, they cause several inflammations which are often associated with itching and irritation. They can also cause cancer and are endocrine disruptors [51]. Most studies on the impact of wastewater on the receiving watershed in South Africa are often limited to the microbiological quality of the discharged effluent [38, 39].

3.1. Impact of wastewater discharge onto surface water in South Africa

The release of raw and ill-treated wastewater onto water courses has both short- and long-term effect on the environment and human health. Freshwater sources have been negatively impacted by wastewater. Such impacts are dependent on the composition and concentration

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of the wastewater contaminants as well as the volume and frequency of wastewater effluents entering surface water source [52]. Eutrophication of water sources may also create environmental conditions that favor the growth of toxin producing cyanobacteria, and exposure to such toxins is hazardous to human beings.

3.1.1. Environmental impact

Poorly treated wastewater can have a profound influence on the receiving watershed. The toxic impacts may be acute or cumulative. Acute impacts from wastewater effluents are generally due to high levels of ammonia and chlorine, high loads of oxygen-demanding materials, or toxic concentrations of heavy metals and organic contaminants. Cumulative impacts are due to the gradual buildup of pollutants in receiving surface water, which only become apparent when a certain threshold is exceeded [18, 21, 34, 39]. All aquatic organisms have a temperature range for their optimum function and survival [51]. When there are sudden changes within those ranges, their reproductive cycle, growth, and life can be reduced or threatened. Owing to the organic load of wastewater, discharged effluents from wastewater treatment facilities usually contribute to oxygen demand level of the receiving water. There is increased depletion of dissolved oxygen (DO) in surface water that receives ill-treated wastewater. From previous studies, the levels of DO in the effluent of various wastewater treatment facilities in South Africa are usually lower than the required standard of 8–10 mg/L [53, 54]. DO level below 5 mg/L would adversely affect aquatic ecosystem. DFID [55], Momba et al. [39], and Morrison et al. [56] stated that the effect of ill-treated wastewater on surface water is largely determined by the oxygen balance of the aquatic ecosystem, and its presence is essential in maintaining biological life within the system.

Osuolale and Okoh [57] reported that DO concentration in two WWTPs in Eastern Cape province of South Africa was in the range of 3.9–9.6 mg/L and 6.9–9.4 mg/L, respectively, from September 2012 to August 2013. For most of the study period, the levels of DO measured in one of the WWTPs were lower than the concentrations of 8–10 mg/L, which is characteristic of unpolluted water except in December 2012 (9.6 mg/L). Momba et al. [39] recorded DO levels in the range of 3.26–4.57 mg/L in their investigation of the impact of inadequately treated effluents of four wastewater treatment facilities in Buffalo City and Nkonkobe Municipality of Eastern Cape Province of South Africa. Concentrations below 5 mg/L can have a negative effect on aquatic organisms in the water resource [39]. Igbinosa and Okoh [58] reported a DO concentration in the range of 4.15–6.26 mg/L in autumn, 4.99–5.38 mg/L in summer, 4.85–11.22 mg/L in winter, and 4.96–6.69 mg/L in spring. This shows that seasonal variations have significant influence on the levels of DO in surface water. The presence of degradable organics in wastewater is responsible for the low levels of DO determined when compared to surface water sources. Low DO values can lead to the malfunctioning of some fish species and can eventually lead to the death of fish [58].

BOD and COD usually give an estimate of organic pollution in water and wastewater. They are important wastewater quality parameters as they are used to measure the efficiency of most wastewater treatment facilities. Surface water is expected to have low BOD/COD values to sustain aquatic life. High levels of BOD and COD can cause harm to aquatic life, especially fish. Low levels of BOD and COD in river systems indicate good water quality, while high levels indicate polluted water. There is an inverse relationship between the BOD/COD levels and DO concentrations. When large biodegradable organics are present in water as it is the case with most wastewater, DO is consumed by bacteria. When this happens, the DO level drops below a threshold point, with negative impact on life as they are unable to continue their normal life sustaining processes such as growth and reproduction. Such decrease affects fish and other aquatic life. The levels of COD reported for the effluent of several WWTFs in South Africa is presented in **Table 1**.

WWTF's location	COD (mg/L)	References
Eastern Cape Province I	4.6–211	[56]
Eastern Cape Province II	10.33–88.33	[56]
Alice WWTP, Eastern Cape Province III	7.5–248.5	[57]
Thohoyandou WWTP, Limpopo Province	50–105	[31]
Siloam WSPs, Limpopo Province	82–200	[58]

Table 1. COD levels of the effluent from wastewater treatment facilities in South Africa.

The South African guideline value for COD in wastewater is 75 mg/L but this level was exceeded for most of the sampling months in the WWTFs. From **Table 1**, wastewater effluent is a major contributor to organic pollution in surface water of South Africa.

The influx of nutrients such as nitrites, nitrates, and phosphorus into water bodies can induce eutrophication. Generally, nitrogen-containing compounds are abundant in many wastewater streams, and the inadequate treatment of them can lead to their introduction on the receiving watershed with their attendant consequences. Eutrophication can result when nutrient-rich wastewater effluents are discharged onto water courses. This can lead to algae blooms and growth of plants in the aquatic ecosystem. When this happens, turbidity of the water increases, plant and animals' biomass increases, sedimentation rate increases, species diversity decreases, and anoxic conditions may develop, and this could give rise to change in dominant species of the aquatic biota [35]. Nitrate nitrogen and phosphorus levels capable of inducing eutrophication have been reported by several authors for wastewater effluents in South Africa [31, 53, 58].

3.1.2. Health impacts

Contamination of surface water with pathogenic organisms in wastewater could result in the transmission of waterborne diseases for people who use the water resource for domestic and other purposes downstream [59, 60]. About 25% of all deaths worldwide are the result of infectious diseases caused by pathogenic microorganisms [61]. Scientists have identified about 1400 species of microorganisms that can cause ill health, including bacteria, protozoa, protozoan parasites, parasitic worms, fungi, and viruses [4]. The major concern of wastewater discharge onto freshwater courses is the impact they have on public health. Wastewater consists of various classes of pathogens which are capable of causing diseases of various magnitude to man. Unlike some of the environmental impacts that can take a long time before they manifest, pathogens cause immediate negative health impact on people that use contaminated surface water resource for domestic, agricultural, and recreational purposes. Some common pathogens found in untreated and ill-treated wastewater are presented in **Table 2**.

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Agent	Species	Disease
Bacteria	*Campylobacter jejune*	Gastroenteritis (possibly long-term sequelae e.g., arthritis)
	Escherichia coli	Gastroenteritis
	E. coli O157:H7	Bloody diarrhea, hemolytic uremic syndrome
	Helicobacter pylori	Abdominal pain, peptic ulcers, gastric cancer
	Salmonella spp.	Salmonellosis, gastroenteritis, diarrhea (possibly long-term sequelae e.g., arthritis)
	Salmonella typhi	Typhoid fever
	Shigella spp	Dysentery (possibly long-term sequelae e.g., arthritis)
	Vibrio cholera	Cholera
Helminths	*Ascaris lumbricoides* (roundworm)	Ascariasis
	Ancylostoma duodenal and *Necator americanos* (hookworm)	
	Clonorchis sinensis (liver fluke)	Clonorchiasis
	Fasciola (liver fluke)	Fascioliasis
	Fasciolopsis buski (intestinal fluke)	Fascioloidiasis
	Opisthorchis viverrini	Opisthorchiasis
	Schistosoma (blood fluke)	Schistosomiasis (Bilharzia)
	Trichuris (whipworm)	Trichuriasis
	Taenia (tapeworm)	Taeniasis
Protozoa	*Balantidium coli*	Balantidiasis (dysentery)
	Cryptosporidium parvum	Cryptosporidiosis
	Cyclospora cayetanensis	Persistent diarrhea
	Entamoeba histolytica	Amoebiasis (amoebic dysentery)
	Giardia lamblia	Giardiasis
Viruses	Adenovirus	Respiratory disease, eye infections
	Astrovirus	Gastroenteritis
	Calicivirus	Gastroenteritis
	Coronavirus	Gastroenteritis
	Enteroviruses	Gastroenteritis
	Echovirus	Fever, rash, respiratory and heart disease, aseptic meningitis
	Poliovirus	Paralysis, aseptic meningitis
	Hepatitis A and E	Infectious hepatitis
	Parvovirus	Gastroenteritis
	Norovirus	Gastroenteritis
	Rotavirus	Gastroenteritis
	Coxsackie viruses	Herpangina, aseptic meningitis, respiratory illness, fever, paralysis, respiratory, heart and kidney disease

Table 2. Pathogens found in untreated wastewater (adapted with permission from WHO [60]).

Several episodes of disease outbreaks such as diarrhea and cholera have been reported in various provinces of South Africa with wastewater effluents as the major contributor. In 2004, Mail and Guardian [62] reported a cholera outbreak in Delmas region of Mpumalanga Province of South Africa where 380 cases of diarrhea and 30 cases of typhoid fever were recorded. Similarly, sickness and death were recorded in KwaZulu-Natal and Eastern Cape Provinces of South Africa where sewage spills occurred on surface water sources [53, 63]. South Africa suffered a cholera outbreak in 2003 when 3901 cases were reported in Mpumalanga Province, the Eastern Cape Province, and Kwazulu-Natal Province, and 45 deaths were confirmed. In 2004, 1773 cases of cholera were reported in Mpumalanga's Nkomazi region, which borders Mozambique, and 29 people died. Also in the same year, 738 people were diagnosed with cholera in the Eastern Cape Province, of which 4 died [63]. And 260 more cases were reported in the North West Province of which two people died. In early 2014, a diarrhea outbreak was reported in Limpopo province [64]. Forty-five people were admitted to hospital for treatment after contracting diarrhea. In almost all the cases stated above, the use of contaminated water as a source of domestic water was implicated to be the major cause of the epidemics. Several studies have shown that wastewater effluents still contain high amount of fecal coliforms which do not conform, to the 1000 cfu/100 mL in the DWA guideline for wastewater discharge [6, 31, 38, 39, 58, 59, 65].

4. Conclusion

Surface water will remain as an alternative source of water to meet domestic water demand mostly in rural areas of the world if potable water is not supplied on a regular basis. Wastewater effluents should be treated efficiently so as not to pose a health risk to the users of surface water resources. The major cause for the failing state of wastewater treatment facilities in South Africa as well as other developing countries includes inadequate coverage of wastewater treatment facilities in both urban and rural areas, poor operational state of wastewater infrastructure, design weaknesses, expertise, corruption, insufficient funds allocated for wastewater treatment, overloaded capacities of existing facilities, and inefficient monitoring for compliance with recommended guidelines. Enforcement of water and environmental laws must be in place to protect the environment and the health of numerous people that still depend on surface water as their major source of water supply.

Acronyms

WWTP	Wastewater treatment plant
WWTF	Wastewater treatment facilities
DO	Dissolved oxygen
COD	Chemical oxygen demand
BOD	Biochemical oxygen demand
WHO	World Health Organization
DWAF	Department of Water Affairs

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