THE IMPACT OF WASTEWATER TREATMENT EFFLUENT ON WATER RESOURCES: A SOUTH AFRICAN PERSPECTIVE

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INTRODUCTION**

One of the major contributing factors to the many pollution challenges experienced in most parts of South Africa is the declining state of municipal and industrial wastewater and sewage treatment management. This contributes to environmental and human health problems. Globally, around 80 per cent of wastewater flows back into the environment either as untreated or partially treated, which poses risks to downstream ecosystems and people who rely on the river as a drinking water source.[1] Discharge of untreated or partially treated wastewater effluent occurs mostly due to inadequate maintenance of wastewater treatment works, which results in equipment and infrastructure failure, producing poor quality effluent.[2] The deterioration of the quality of a water resource has a significant impact on socio-economic development because such water cannot be used for bathing, drinking, industrial, or agricultural purposes.

Rapid water depletion and pollution have led to the decline of available water resources for human consumption and the compromising of ecological integrity. Freshwater resources constitute only 3 per cent of all water on the planet, with 2 per cent being found in icecaps and glaciers which cannot be utilised, and less than 1 per cent readily available in rivers, dams, and lakes.[3] Water is an essential component in the existence of every living organism; hence the protection of water resources is of utmost importance. Major contributors to water quality deterioration in South Africa's water resources are agricultural runoff, extensive coal mining activities, and industrial activities combined with a general decline in the operation and management of wastewater treatment infrastructure, especially sewage treatment.[4] Water resources of good quality are a precondition for economic development and ecological integrity.[5]

Rivers play an important role in domestic, industrial, and agricultural activities. However, they are easily polluted because of their critical role in transporting municipal and industrial pollution and runoffs from agricultural land.[6] Poorly treated effluent has a substantial impact on the aquatic ecosystem, agriculture, the local community, and their economy. Monitoring of effluent from wastewater treatment plants and the impact it has on the quality of water resources is crucial. Water quality monitoring and evaluation are important for pollution control as part of water resource management. The indiscriminate discharge of poorly treated and untreated wastewater introduces toxic substances into aquatic environments, degrading water quality to the extent that the surface water is unsuitable for human consumption and agricultural irrigation.[7] Recent studies in South Africa have also revealed that surface water has been contaminated by emerging pollutants such as personal care products and pharmaceuticals.[8]

Water quality assessment is therefore critical for identifying the major contributors to spatial and temporal variations in quality, which can benefit water resource management.[5] Based on the information from the effluent quality assessment, there is a need for the government to cooperate with the public in implementing protective measures that will improve the condition of the water resource.

DISCUSSION

The legal regime governing effluent discharge in South Africa

Legislation is fundamental for environmental management in numerous ways. For example, it assists with the regulation of resource use, protecting the environment and biodiversity, mediation, conflict resolution and conciliation, formulation of stable and unambiguous undertakings, and agreements. Although law is so crucial, it tends to have limitations in terms of meeting environmental management needs.[9]

The bill of rights enshrined in the Constitution of the Republic of South Africa outlines that everyone has the right to an environment that is not harmful to their health or wellbeing, and to have their environment protected for the benefit of present and future generations through reasonable legislative and other measures to prevent ecological degradation.[10] Clean and clear water is closely associated with an environment that is not harmful and the need to prevent pollution.[11] Water is essential for human health and the environment, and measures must be taken to ensure that it is not polluted to an unacceptable level;[11] hence, the National Water Act (Act 36 of 1998) was promulgated, deriving directly from the fundamental principles and objectives for the new South African Water Law and the National Water Policy's proposal for managing water resources.[12] The Act is the principal legal instrument relating to water resources management in South Africa and contains comprehensive provisions for the protection, use, development, conservation, management, and control of South Africa's water resources.

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According to the National Water Act, water use not only includes consumptive uses but also activities that pollute or have the potential to pollute or degrade a water resource.[13] Those activities include discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall, or other conduit controlled by another person authorised to carry out the purification, treatment, or disposal of waste or wastewater, depending on approval by an authorised person. To exercise the above-mentioned water use activities, authorisation by the relevant authority has to be granted through a Water Use Licence (WUL) or a General Authorisation (GA) for water use. Water use authorisation granted to a water user for the discharge of wastewater effluent into a water resource contains stipulated conditions, guidelines, and water quality limits within which the water use activity must be exercised. Wastewater poses a significant pollution threat to water resources and the environment; hence its discharge and management must be controlled.[14] The National Water Act stipulates limits for certain parameters, as shown in Table 1 below, especially effluent disposal in catchment areas.

Table 1. Wastewater limit values applicable to the discharge of wastewater into a water source according to the National Water Act[15]

Substance /Parameter	*General limit*	*Special limit*
Faecal coliforms per 100ml	1 000	0
Chemical oxygen demand (mg/l)	75	30
pH	55–9.5	5.5–7.5
Ammonia (ionised and un-ionised) as nitrogen (mg/l)	3	2
Nitrate/nitrite as nitrogen (mg/l)	15	1.5
Chlorine as free chlorine (mg/l)	0.25	0
Suspended solids (mg/l)	25	10
Electrical conductivity (mS/m)	70 mS/m above intake to a maximum of 150 mS/m	50 mS/m above background receiving water to a maximum of 100 mS/m
Orthophosphate as phosphorus (mg/l)	10	1 (median) and 2.5 (maximum)
Fluoride (mg/l)	1	1
Soap, oil, or grease (mg/l)	2.5	0
Dissolved arsenic (mg/l)	0.02	0.01
Dissolved cadmium (mg/l)	0.005	0.001
Dissolved chromium (VI) (mg/l)	0.05	0.02
Dissolved copper (mg/l)	0.01	0.002
Dissolved cyanide (mg/l)	0.02	0.01
Dissolved iron (mg/l)	0.3	0.3
Dissolved lead (mg/l)	0.01	0.006
Dissolved manganese (mg/l)	0.1	0.1
Mercury and its compound (mg/l)	0.005	0.001
Dissolved selenium (mg/l)	0.02	0.02
Dissolved zinc (mg/l)	0.1	0.4
Boron (mg/l)	1	0.5

According to ISS and the South African Water Research Commission, more than 67 per cent of wastewater treatment facilities investigated did not meet the minimum regulatory requirements. South Africa has strong wastewater management legislation that is equivalent to that of developed countries around the world; however, the key concern is non-compliance with the country's wastewater discharge regulatory guidelines.[16] Lack of enforcement is also a problem because of the reasons below, to name but a few:

- The existing regulatory capability in the water sector is inadequate both in terms of the number of skilled staff to carry out the regulatory requirements and the suitable tools for regulation, considering staff limitations and lack of financial resources.
- There is a huge challenge regarding the capacity to gather information, organise it, and continue to report on it, and the capacity of the regulatory powers to interpret and to give an appropriate and timeous response to that information.
- The performance of the Department of Water and Sanitation regarding the management of the regional and national water resource infrastructure has been inadequate.

The maintenance of water resource infrastructure is underfunded due to poor collection of water use charges.[17]

State of wastewater treatment and sanitary infrastructure

South Africa has established a significant wastewater management industry, with over 850 municipal wastewater treatment plants, vast pipe networks, and pump stations transporting and treating wastewater daily.[18] When compared to required national standards and international best practices, the municipal wastewater services industry is widely regarded as being far from acceptable.[18] Wastewater treatment infrastructures and sanitation systems have been placed under significant pressure in South Africa due to alarming population growth and rapid urban migration. Present conventional systems were designed to cater for a given population size; however, the population is surpassing the maximum carrying capacity of the existing treatment plants.[19]

The operation of a wastewater treatment plant beyond its design capacity compromises the treatment process, thus reducing its effectiveness in removing pollutants from the wastewater. Financial provisions related to maintenance and refurbishment of sanitation infrastructure have been neglected, which is evident in continuous service delivery failures across the country today.[19] The quality of effluent discharged into the water resources mostly indicates that there are operational problems within the treatment plants, either in a form of plant breakdown, poor or delayed maintenance, plants operating above their design capacities, or aging infrastructure which has reached the end of its useful life. The government, through the Department of Water and Sanitation, established an incentive-based regulatory programme named Green Drop in 2008 and the results of the programme have demonstrated the extent of maintenance challenges in South Africa. A report which was published in 2013 revealed that high volumes of untreated sewage flowing into the water resource, non-functional unit processes within the treatment work, and pipe leakages demonstrate a lack of planning, implementation, and management of the existing infrastructure by water services authorities. The report also revealed that only 50.4 per cent of the wastewater treatment plants scored more than 50 per cent in 2012/13 and, by implication, 49.6 per cent (almost half or 409 wastewater treatment works (WWTW)) in South Africa were issued with a purple drop (indicating a score of less than 30 per cent) during 2012–13,[20] indicating that these treatment works are performing poorly. In addition, 121 WWTW were in high-risk positions and had to be monitored as 'hotspots' to ensure that risk reduction and compliance measures were expedited and scaled up.[53] In April 2015, there had been at least 19 reported cases of WWTW overflowing into water bodies.[20]

Impact of wastewater effluent on water resources quality

Surface water in South Africa is used for drinking, agriculture, and recreational purposes, However most wastewater treatment plants discharge their effluents directly into rivers and around riverbanks. Low- and lower-middle-income countries are expected to experience the greatest increases in pollution exposure, owing to higher population and economic growth, especially in Africa,[21] as well as a lack of wastewater management systems.[22] In South Africa, the combined risk rating of wastewater treatment systems showed that 72 per cent of the systems were presenting a high or serious danger to the ecosystem.[23] This means that the majority of wastewater treatment facilities in the country are inefficient at handling the influent they receive.

Evidence of water resource quality deterioration caused by effluent discharge has been well documented, since the anthropogenic impact on natural environments, especially on aquatic ecosystems, is currently a topic of increasing concern. Urban wastewater treatment plant effluent as reclaimed water provides an alternative water resource, especially for urban rivers. However, the effluent has the potential to influence the quality of the rivers. Singh et al.[24] undertook a study to assess the impact of effluent and sludge from wastewater treatment plants in Jajmau, Kanpur (5 megalitres per day (MLD)), and Varanasi (80 MLD) located in India, on health, agriculture, and environmental quality in receiving areas. During peak (morning and evening) and non-peak hours (noon), raw, treated, and mixed treated urban wastewater samples were obtained from the inlet and outlet points of the two plants. The impact of treated wastewater pollutants (metals and pesticides) was assessed and the levels of pollution in different sample media such as water, soil, crops, vegetation, and food grains were determined. Water quality data generated showed that there were elevated levels of metals and pesticides in all environmental samples including water samples from the water body, which suggests that there was a serious impact on the receiving environment. The study also found that these pollutants in crops and food grains suggest that there might be adverse health impacts on communities consuming the crops.

In South Africa, water resource quality has also deteriorated drastically due to the constant disposal of industrial and domestic waste into the rivers.[25] Salination, eutrophication, and microbiological pollution are currently the main problem affecting water quality.[54] South Africa also faces challenges of poor water quality because of acid mine drainage (AMD) pollution.[26,27] The decline in water quality can lead to rising treatment costs of potable and industrial process water. The poor quality of water used for agricultural purposes can have an impact on crop yield and cause food insecurity.[28] The presence of toxic substances can harm the aquatic ecosystem and is further worsened by a high pathogen level in the water. The use of microbiologically polluted water for domestic and other purposes is harmful to human health and to the general public.[54]

Vaal River is one of the longest rivers in South Africa and is considered the most utilised river in the country because of its role as a primary source of water for the most important industries situated around Gauteng Province.[2] The river flows through Vereeniging, Vanderbijlpark, and Sasolburg, which are major industrial areas in South Africa.[29] Due to such activities taking place within the catchment, the river has been subjected to massive pollution from wastewater treatment works, runoff from mines, industrial effluents, and agriculture runoff. In 2006, there were two events of pollution from sewage flowing in the Vaal River Barrage which caused significant fish deaths.[2] There have been warnings from past years that pollution from wastewater treatment effluent in the Vaal River Barrage could lead to the outbreak of a water-related epidemic, similar to the typhus outbreak in Mpumalanga's Delmas in 2005. According to a report written by Rand Water,[30] Secunda sewage works, which discharges effluent into a tributary of the Vaal River, was found operating above design capacity and the discharged effluent had problems in complying with parameters such as ammonia, conductivity, nitrate, sulphate, and chemical oxygen demand. The report also outlined that Embalenhle sewage works, which is also discharging into a tributary of Vaal River, was operating above its design capacity by 2.4 ML/day, indicating that there would be a constant overflow of raw sewage which would have a significant impact on both microbiological and physicochemical parameters of the receiving water.[30] According to the water quality data obtained for the discharged effluent, it was also observed that the water was not compliant with the standards set for parameters such as ammonia, nitrate, chemical oxygen demand, conductivity, and alkalinity. Therefore, it can be concluded that poorly treated effluent discharged into the Vaal River has a negative impact on the quality of the water resource, hence the condition of the river is poor.

Table 2 below gives an overview of the water quality of South Africa's water resources and the main contributors to their pollution.

Rapid population growth in urban areas puts pressure on the existing wastewater treatment plants, leading to improper treatment of sewage which ultimately flows into the water resources. This causes deterioration in the ecological integrity and the quality of the receiving water bodies. Seanego and Moyo[32] conducted a study to assess the effect of sewage effluent on the physicochemical and biological characteristics of the Sand River situated in Limpopo, South Africa. Polokwane Wastewater Treatment

Table 2. An assessment of the overall water quality situation in various provinces in South Africa[31]

Province	*River system*	*Impact detected/described*	*Source of pollution*
Eastern Cape	Mthatha area	Rivers contain large numbers of pathogenic organisms and high concentrations of nutrients, salts, and endocrine-disrupting compounds (EDCs).	Treated, partially treated, and untreated urban and industrial effluent.
Kwazulu Natal	Umngeni River system	Elevated concentrations of pesticides and nutrients. Large numbers of pathogenic organisms and high concentrations of nutrients, salts, and EDCs.	Return flows and seepage from agricultural lands. Contaminated runoff from urban centres and informal settlements, combined with discharges of treated, partially treated, and untreated urban and industrial effluent.
Free State	Caledon and Modder River systems	Large numbers of pathogenic organisms, high concentrations of nutrients and salts, and moderately high concentration of EDCs. Periodic blooms of toxic cyanobacteria Microcystis aeruginosa have been recorded from the Krugerdrift dam.	Discharges of treated, partially treated, and untreated urban effluent, as well as contaminated runoff from urban centres and informal settlements. Return flows and seepage from agricultural lands result in elevated concentrations of pesticides and nutrients reaching the rivers.
Mpumalanga/ Limpopo	Eastern River systems; upper Olifants River system	Lowered pH values (sometimes to <3.0) and elevated concentrations of metal ions (especially aluminium, iron, cadmium, zinc, and cobalt) and total dissolved salts, dominated by sulphate. Large quantities of inorganic and organic compounds in the river. Large numbers of pathogenic organisms and high concentrations of nutrients, salts, and low to moderate concentrations of EDCs.	Operating and defunct coal mines contribute large volumes of AMD. Heavy industries in the Witbank and Middelburg area (mainly iron and steel works). Discharges of urban and industrial effluents, as well as contaminated runoff from larger towns, smaller urban centres, and informal settlements (many lacking proper and/or functioning.
North West	Crocodile (West) River system	Large numbers of pathogenic organisms and high concentrations of nutrients, salts, and low to moderately high concentrations of EDCs (all these substances pose health risks to humans and livestock that may consume the water).	Discharges of large volumes of treated, partially treated, and untreated urban effluent, especially from the northern areas of the Witwatersrand, as well as contaminated runoff from urban centres and informal settlements.
Western Cape	Cape Town urban rivers	Receiving urban rivers contain large numbers of pathogenic organisms and high concentrations of metal ions, nutrients, salts and EDCs.	Contaminated runoff from urban areas and informal settlements: discharges of treated, partially treated and untreated domestic and industrial effluent.

Works (WWTW) discharges effluent into the Sand River, which is used extensively by farmers downstream for irrigation. Polokwane is generally a water-scarce area and, to conserve water, artificial recharge of the local Polokwane aquifer using treated effluent is practised. The Sand River sub-catchment is a main tributary of the Sabie River catchment and a Limpopo River right-hand tributary.[32] Polokwane is 200 kilometres upstream on the Limpopo River. The Polokwane Pasveer WWTW discharges its effluent into the Sand River, while the Seshego WWTW discharges into the Blood River, a tributary of Sand, which ultimately flows into the Limpopo River. Eight sampling sites were established, two of which were situated upstream of the Polokwane Pasveer WWTW, and the remaining six sites were situated downstream of the wastewater treatment plant.

The results revealed that suspended solids, ammonia, chemical oxygen demand, and E. coli in the Polokwane WWTW maturation ponds were above the licence limits. Analysis of variance also indicated that there were no significant differences in temperature, conductivity, salinity, pH, oxygen, and flow rate between the upstream and downstream sites. There was, however, a significant difference in phosphorus and nitrogen at the sites downstream due to effluent discharge. The study has indicated that due to increased urbanisation, Polokwane WWTW is discharging effluent of poor quality. High coliform levels also pose a potential threat to the downstream water users and also negatively affect the quality of the artificially recharged aquifer.

International impact of wastewater effluent on water quality

Due to advances in many developed countries, wastewater treatment and the quality of wastewater effluents in municipalities have improved. Despite this improvement, the wastewater still places the aquatic environment at risk. Licensing is utilised globally as the basis of all regulatory methods to protect the aquatic environment.[33] However, emerging pollutants and pathogens are a challenge to the licensing processes and have no standards set to protect the aquatic ecosystem. Nonetheless, some developed countries and regions such as the European Union and the US have introduced some legislative guidelines for monitoring of selected contaminants of emerging concern to develop future regulation.[34,35] For example, the European Commission published Directive 2014/893/EU prohibiting rinse-off cosmetics containing microplastics from bearing the Ecolabel symbol, which is given to products with the lowest environmental impact.[36,37]

Globally, there are also problems in some countries where partially treated or untreated effluent is discharged directly into the rivers, posing environmental and health problems as is the case in South Africa. For example, Yu et al.[38] conducted a study in the Xiaohe River, an urbanised stream located in Hebei Province, to determine the impact of municipal wastewater effluent on dissolved organic matter quality and microbial community composition. The Xiahe River is approximately 86 km long and it originates from the Wufengshan, receiving sewage effluent in its major water source. There are four wastewater treatment plants namely Qiaodong, Qiaoxi, Douyu, and Zhaoxian discharging tailing water into the Xiaohe River. The results of the study show that in general, total nitrogen was observed to be high and total phosphorus was relatively low. It is worth noting that sections with heavy pollution indexes (COD and nitrogen species) were downstream of the sewage effluent outflow. Results also indicated that wastewater treatment plant effluent has a great influence on the quality of the receiving water resource because it exerts significant effects on receiving water organic quantity and quality, and then influences the microbial communities' structure and function.

Some emerging contaminants have been detected in the Yangtze River Delta region of China; 44 analytes were found at all 28 sampling sites, the majority of which were industrial chemicals such as 1H-benzotriazole and organophosphate flame retardants.[39] In Nigeria, many abattoirs discharge their effluents directly into streams and rivers without prior treatment. A study was conducted by Osibanjo and Adie[40] to assess the impact of effluent from Bodija abattoir on the quality of the Oshunkaye stream in Nigeria. Specific water quality parameters were used to investigate the effluent and stream water qualities (before and after mixing with the effluent). Five effluent samples were collected to represent different activities within the abattoir, while two samples were collected upstream and downstream of the Oshunkaye stream into which the abattoir effluent is discharged. Parameters that were determined include pH, temperature, total solids, total suspended solids, chemical oxygen demand, oil and grease, nitrates, phosphates, chloride, lead, cadmium, nickel, copper, and zinc. The study revealed that there was pollution generated by Bodija abattoir effluent which is causing the quality of the water resource to deteriorate. The physiochemical parameters showed the negative impact of the abattoir effluent on the stream, thus rendering the water not suitable for domestic, agricultural, or industrial use.

Ngwira and Lakudzala[41] conducted a study to assess the quality of industrial effluent from a soft drinks manufacturer in Lilongwe, Malawi to determine the impact of pollution in the Nankhaka River. Both the effluent and river water samples from the different locations were analysed for pH, suspended solids, total dissolved solids, phosphate, nitrates, chemical oxygen demand, biochemical oxygen demand, and faecal coliform using standard methods. It was observed that the parameters analysed from effluent samples were non-compliant with the Malawi standard recommended for effluents discharged into the inland waters. The study suggested that effluent from the industry pollutes water in the river rendering it unfit for human consumption and harmful to the aquatic ecosystem.

Impact of discharged effluent on the aquatic ecosystem

Ecotoxicology integrates ecology into the study of the adverse effects of stressors such as chemicals on living organisms by analysing the influence of stressors not only on individual organisms but also on communities and the whole environment.[42] Some effects of wastewater discharge into aquatic bodies cut across the whole spectrum of biological organisation, while others are felt at molecular, individual, species, or population levels.[43] Habitat destruction through sedimentation and debris deposition is one of the examples of the effect that is felt at the ecosystem level.[43]

Effluent discharge has the potential to significantly alter many different aspects of the aquatic systems, including nutrient uptake efficiency, organic carbon content, bacterial levels, and hydrologic characteristics.[44] One characteristic of wastewater treatment plant effluent that often impacts receiving water is its nutrient content.[44] Domestic wastewater generally consists of high concentrations of nitrogen in either organic or inorganic form. Organic fraction coexists with the dissolved inorganic nitrogen (nitrate, nitrite, and ammonium) and the gaseous forms (N_2 and N_xO_y). The transformations among the different pools of nitrogen in the wastewater and aquatic ecosystems are mainly mediated by biological processes. However, abiotic processes and ambient conditions concur to regulate nitrogen cycling because they influence the activity and abundance of living organisms and the structure of their communities. Bacterial activity and hydrolysis convert organically bound nitrogen such as urea and protein to ammonia and ammonium nitrogen.[45] Both inorganic and organic nitrogen in the aquatic environments exist in continuous size distribution, from dissolved organic compounds to macroheterotrophs.

An excessive amount of nitrogen, particularly nitrate, has a significant impact on the quality of water and the health of an aquatic ecosystem. Nitrogen is one of the critical limiting nutrients for plants and cyanobacteria, and one of concern for the eutrophication of freshwater systems. Excessive growth algae in response to nutrient increases on the water body can result in a bloom of single or multiple species depending on variables such as pH, temperature, and dissolved oxygen, which has some negative impacts on the aquatic ecosystem. Such occurrence is called algal bloom and encompasses red tides, brown tides, and toxic and noxious blooms.[46] Toxic forms such as cyanobacteria can have a serious direct impact on a variety of life forms such as invertebrates and vertebrates, and cause hypoxia, foul odour, and tainted fish products, depleting dissolved oxygen in water resources. In rivers receiving nutrient inputs from wastewater, ammonia nitrogen can directly affect dissolved oxygen concentration. Wastewater that is discharged into receiving waters characterised by alkaline pH values could exacerbate ammonia nitrogen toxicity and threaten the viability of various fish species.[44]

Phosphorus is an essential nutrient for plant growth in freshwater systems and is often a limiting nutrient in water bodies. Since it is a limiting nutrient to freshwater systems, its input can cause the proliferation of algae. It was considered the main contributor to eutrophication in freshwater systems. The high concentration of orthophosphate causes blooms of blue-green algae.[47] Sewage treatment plant effluent, irrigation, urban development, and industrial effluents are all major sources of total phosphorus. Orthophosphate measures the inorganic oxidised form of soluble phosphorus. This form of phosphorus is readily available for algal uptake during photosynthesis and energy production.

Major sources of phosphorus in a form of orthophosphate in water bodies are sewage treatment plant effluent, agriculture, urban development, and industrial effluents. Just like nitrogen, an excessive amount of phosphorus on a water resource has a negative impact since it also stimulates excessive growth of algae and certain alien aquatic plants. Depending on the assimilative capacity of a water body, the algal population can reach very high values which cause a series of problems such as the depletion of dissolved oxygen in water, mortality of aquatic lifeforms, and bad odour especially in lakes and reservoirs. An increase in heterotrophic bacteria, which feed on organic matter from algae and other dead organisms and consume dissolved oxygen in the water, may cause anaerobic conditions in the bottom of a lake or a dam.

Wastewater consists of pathogenic bacteria and viruses which have a detrimental impact on both human health and the health of an aquatic ecosystem. Coliform bacteria such as E. coli are mostly used as indicator organisms of the presence of pathogenic bacteria in water. Since detecting, isolating, and identifying various forms of microbial pollutants in wastewater is often challenging, costly, and time-consuming, indicator organisms are often used to assess the relative risk of a specific pathogen's potential presence in wastewater.[45] A water body receiving treated effluent from wastewater treatment works may incorporate into itself a wide range of pathogenic microorganisms. This may not generate a direct impact on the aquatic organisms themselves but may affect some of the prevailing uses of water resources such as potable water supply, irrigation, and bathing.[45]

Bacteria and other organisms in freshwater such as lakes and rivers utilise oxygen to metabolise the sewage they accompany. While breaking down biodegradable solids in the wastewater, these microorganisms can cause hypoxic (oxygen-depleted) dead zones. These dead zones lack sufficient oxygen needed by aquatic lifeforms such as fish to survive.

Ecological impacts of wastewater treatment plant effluents on the river ecosystem are of great concern, however it is difficult to assess these effects as most rivers and streams receiving wastewater treatment effluents are also affected by other stressors. Pereda et al.[48] conducted a study in which a whole-system manipulation experiment following a before-after/control-impact design was used to assess the impact of wastewater treatment plant effluent on a stream. Exclusion of the influence of other potentially confounding factors was done by diverting part of the effluent of the Apraitz wastewater treatment plant into a small, unpolluted stream and studying its effect on the ecosystem structure and functioning for over two years (that is, one year prior to the effluent diversion and one year after the effluent diversion).

The Apraitz wastewater treatment plant consists of a sequential biological reactor that treats the wastewater of a population that is greater than 90,000 and is derived from urban and industrial sources. The resulting effluent is released into the Deva River with a mean discharge flow of 10.9 m^3/s. Ten meters downstream from the WWTP effluent release point, the Deva River receives the waters of the Apraitz stream, a small unpolluted stream draining a 7 km^2 catchment over sandstone and shale with a mean discharge of 0.12 m^3/s. To conduct the study, two 100m-long reaches in the Apraitz stream were defined, namely a control (upstream) and an impact (downstream). Both reaches were studied every month for two years (4 April 2016 to 30 June 2018), one year before and one year after diverting part of the WWTP effluent to the impact reach.

Physiochemical parameters of the water were analysed downstream, at the end of both reaches, and directly at the effluent outflow during periods of effluent release. The pH, temperature, electrical conductivity, nitrate, nitrite, chloride, sulphate, phosphorus, ammonium, and dissolved oxygen saturation were measured using handheld probes. Also, the concentration of the main groups of emergent pollutants was measured including herbicides, hormones, lifestyle products, industrial chemicals, and pharmaceuticals during the first month after diversion.

The results showed that the effluent was 3°C warmer than the stream water, with electrical conductivity three times higher than the stream, dissolved oxygen concentration two times lower, and nutrients (phosphorus, nitrogen) and dissolved organic carbon with concentrations of four and 90 times higher than the stream, respectively. The effluent also showed a high concentration of emergent pollutants, mostly pharmaceutical products used to treat hypertension. The study showed that even well-treated and highly diluted wastewater treatment plant effluents can cause significant effects on the ecosystem structure, and the quality and function of a water resource. Despite high dilution, the intermittent effluent diverted to significantly affected water characteristics during release periods, reducing pH and dissolved oxygen while increasing electrical conductivity and concentrations of nutrients and emergent pollutants. Similar effects of effluent inputs on stream water quality have been reported in other water resource systems.[49] Dissolved organic matter from wastewater treatment plants poses a threat to the receiving water bodies and their microbial community.

Hartbeespoort dam is one of the most important dams in South Africa due to the magnitude of activities the dam supports. Hartbeespoort dam water is primarily used for domestic use (12 per cent) and irrigation (82 per cent) with just 6 per cent released for ecological purposes.[50] The dam was constructed between 1921 and 1923 to store water from a catchment area of approximately 4120 square kilometres, primarily to provide water to large government irrigation schemes in Brits.[50] Since the dam is downstream of Gauteng Province, South Africa's economic heartland, it has become extremely eutrophic.[51] The dam is located downstream of Johannesburg's largest wastewater treatment plants,[52] contaminating receiving streams and eventually the Hartbeespoort dam with poorly treated effluent. The Hartbeespoort dam's water quality has been a concern since the 1950s, and it has been referred to as a maturation pond, meaning that the dam could be regarded as a large waste stabilisation pond to finish wastewater treatment that began in upstream sewage plants.[50] Phosphorus and nitrogen from wastewater treatment plants in the catchment were the main nutrients involved in the eutrophication of the dam, with phosphorus being the main cause of eutrophication in freshwater, according to several scientific studies.[50]

CONCLUSION AND FUTURE RESEARCH

South Africa has made significant progress in the provision of water for human and economic development. However, access, conservation, protection, equitable use, and the management of this scarce resource continue to be one of the most fundamental problems facing development in South and Southern Africa. Treated and poorly treated effluent from wastewater treatment plants discharged into the water resources has had a significant impact on the functioning, integrity, and quality of the water resource and associated ecosystem. Several studies have been conducted on the impact of wastewater effluent on the receiving environment and they confirm that there is still a lot of work to be done with regards to improving effluent quality to protect our water resources.

Based on the literature review conducted, poor effluent quality can be attributed to factors such as poor maintenance of wastewater treatment works, the emergence of complex pollutants from industries that cannot be removed by conventional wastewater treatment plants, and shortage of skilled personnel to operate wastewater treatment works effectively. Water legislation has been developed; however, there is a lack of enforcement and compliance. Legislation, regulations, and policies that may play a part in controlling emerging contaminants in the African continent are still lacking and need to be developed. It is therefore recommended that the responsible authorities of the respective countries be vigilant and aggressive with regards to compliance monitoring and enforcement of effluent discharge laws and regulations to ensure minimal pollution in rivers and streams. Future research should therefore focus on:

(i) careful analysis and monitoring of emerging pollutants such as microplastics, complex pharmaceutical products in wastewater, their removal efficiency, and impact on aquatic ecosystems;
(ii) development of advanced treatment technologies with the ability to remove emerging pollutants present in both domestic and industrial wastewater; and
(iii) creating a better understanding of the complex aquatic systems and their assimilative capacity.

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