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REVIEW PAPER

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A Review on the Occurrence and Impacts of Nutrient Pollution in the Aquatic Ecosystem of Sub-Saharan Countries

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Abstract

Nutrient pollution significantly threatens ecosystem health globally and is aggravated by anthropogenic activities. In this case, algae grow faster than the ecosystem can handle. Apart from other reported effects, some algae blooms are toxic and produce toxins, leading to the deterioration of ecosystem health. These blooms are becoming prevalent, hence the possibility of increased diseases to the entire ecosystem and unsustainability. In many parts of the world, nutrient contamination poses a significant hazard to human health and the ecosystem. Effects of excessive nutrients in the environment include excessive growth of algae. Apart from the difficulties of handling excess nitrogen in the air that make it difficult to breathe, reduce visibility, affect plant growth, a recently reported altering the gut microbiome of a territorial reef fish. Therefore, the present study aimed to assess the nutrient (nitrate and phosphate) contamination in the Sub-Saharan African environment in various matrices including water, groundwater, wastewater, soil, sediments and surface waters to inform policy. In this case, this study investigates the status of nutrient pollution in Sub Saharan Africa, the potential source of nutrient pollution, the reported effects of nutrient pollution; How to overcome nutrient pollution in the environment. Among the measures recommended for nutrient, pollution management includes decreased use of fertilizers and pesticides or organic farming and considerations during the choice of detergents, soaps and household cleaners to nutrient-free products for environmental conservation.

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Introduction

Nutrients are chemicals that are required for organisms and ecosystems to function correctly. While ecological productivity may be distorted (Orians and Milewski, 2007), its excessiveness results in toxicity that may harm the environment (Shaviv and Mikkelsen, 1993). Nitrogen and phosphorus are nutrients that are natural parts of aquatic ecosystems. Nitrogen is also the most abundant element in the air we breathe. Nitrogen and phosphorus support the growth of algae and aquatic plants, which provide food and habitat for fish, shellfish and smaller organisms that live in water (Selman and Greenhalgh, 2010). Excessive nitrogen and phosphorus in the water can have a wide range of health, environmental, and economic consequences, therefore referred to as nutrient pollution (Leip *et al.*, 2015, Sanseverino *et al.*, 2016). Researchers reported nitrate and phosphate could pose a significant threat to freshwater macroinvertebrates when released into the aquatic environment without being treated (Camargo and Ward, 1992, Camargo and Ward, 1995).

Apart from established tolerance thresholds of various taxa towards organic pollution gradients, reports of freshwater macroinvertebrates in tropical African regions response to high nitrate and phosphate levels is lacking (Camargo and Alonso, 2006, Assessment, 2003). In freshwater ecosystems, sensitive macroinvertebrate groups may be driven to extinction by elevated nitrate and phosphate levels (Camargo *et al.*, 2005). Severe impacts of nutrient pollution from developed countries are available, such as the United States of America and China have reported an unsustainable ecosystem as a result of nutrient pollution (Lapointe *et al.*, 2017, Kuwayama *et al.*, 2020, Chen *et al.*, 2019, Chadwick *et al.*, 2020). Therefore, authorities in Sub-Saharan Africa (SSA) must initiate early measures to protect the environment from nutrient pollution. This study reviews literature on nutrient pollution that was peer-reviewed and published in academic journals, conference papers, books, book chapters, and reports. The primary search was between August and October, 2021. The area and the scope of this literature review were nutrient pollution and its effects in Sub Saharan Africa.

A study by Peng and colleagues looked into the consequences of air pollution, water pollution, and their spillover effects on health (Peng *et al.*, 2021). The Spatial Durbin Model revealed that for every 1 ton per capita per year rise in the average amount of soot/dust released by its nearby provinces, a province's ill-health score increased by 6.649. On the other hand, a province's ill-health score increased by 0.004 for every 1 ton per capita increase in wastewater released per year. Indicating that nutrient pollution contributes to the deterioration of ecosystem health and, therefore, may lead to unsustainable ecosystems if not adequately mitigated (Council, 1992, Chadwick *et al.*, 2020). While some coastal waters may benefit from moderate nutrient enrichment, over-enrichment disrupts the marine food chain, sustaining commercially valuable species. Nutrient pollution is a significant concern worldwide. Coastal waters, bays, streams, lakes, and rivers have claimed polluted for decades, resulting in an unhealthy ecosystem. As a result, it is critical to investigate and report nutrient pollution in SSA countries to take the required steps to ensure environmental sustainability. This study looks into the current state of nutrient pollution in SSA's aquatic ecosystems and how it affects ecosystem health.

Integrated nutrients cycle

The nutrition cycle outlines how nutrients are transferred from the physical environment to living creatures and returned to the physical environment (Daily, 2003, Bormann and Likens, 1967). This fundamental function of each region's ecology is the transfer of nutrients necessary for life from the atmosphere into plants and animals and back again (DeAngelis, 2012). If the organisms that reside in that ecosystem thrive and sustain a consistent population, the nutrient cycle in that habitat must be balanced and stable (McFall-Ngai *et al.*, 2013). Globally, harmful algal blooms are a major environmental issue (Backer, 2002). Harmful algal blooms, such as red tides, blue-green algae, and cyanobacteria, can have severe consequences for human health, aquatic ecosystems, and the economy (Zohdi and Abbaspour, 2019, Carmichael, 2008, Hallegraeff, 2003, Backer, 2002). Fig. 1 represents the nutrient (Nitrogen/Phosphorous) cycle; nutrients circulate in the atmosphere; terrestrial and aquatic food webs.

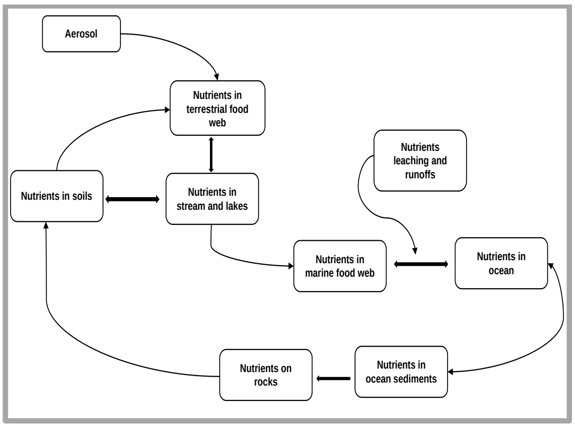

Fig. 1. Presents nutrient (Nitrogen/Phosphorous) cycle, nutrients circulate in the atmosphere; terrestrial and aquatic food webs.

Among the activities named as sources of excess nitrogen and phosphorus include agriculture, where animal manure and chemical fertilizers are not managed well (Vitousek *et al.*, 2009, Nahayo *et al.*, 2016, K. Sakadevan and Nguyen, 2017).

Nevertheless, when plants do not fully utilize these nutrients, they can be lost from the farm fields and negatively impact air and downstream water quality (Schröder *et al.*, 2004). The use of fossil fuels in industry, agriculture, transportation, electric power generation leads to generation and therefore increased nitrogen in the air (Akorede *et al.*, 2012, Cui *et al.*, 2013).

On the other hand, stormwater contributes to nutrient pollution as precipitation falls on our cities and towns; it runs across hard surfaces such as roads, rooftops and sidewalks and washout pollutants, including phosphorus and nitrogen, into local watercourses (Marsalek *et al.*, 2008, Grant, 2020, Joshi, 2010). Fig. 2 describes potential sources and effects of nutrient pollution in the environment.

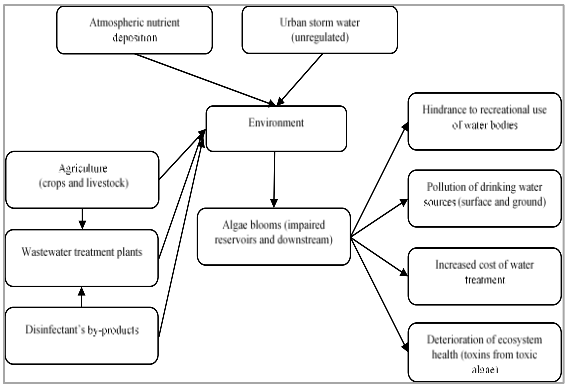

Fig. 2. Describes potential sources and effects of nutrient pollution in the environment, including unclear contribution from stormwater currently not regulated in Sub-Saharan Africa; Nutrients loads from atmospheric deposition; agricultural practices; wastewater treatment plants, and disinfection by-products increases nutrients pollution in the environments leading to non-resilient ecology.

Sewerage and septic systems are responsible for treating large quantities of wastewater. These systems do not continuously operate properly or remove enough nitrogen and phosphorus before discharging into waterways; therefore, wastewater released to the environment carries these nutrients (Cherotich *et al.*, 2021, Egor *et al.*, 2014, Banadda *et al.*, 2009). The presence of hard surfaces and landscaping can further enhance nitrogen and phosphorus run-off and thus nutrient pollution during wet weather (Grant, 2020, Schröder *et al.*, 2004, Sanseverino *et al.*, 2016, Li and Health, 2020). In this case, animal waste contributes excess nutrients to waterways, including certain soaps, detergents that contain nitrogen and phosphorus (Li *et al.*, 2010, Peng *et al.*, 2021). Information on the contribution of nutrient pollution on the presence and growth of diseases causing organisms in the environment is not clear. This study investigates the status of nutrient pollution in Sub Saharan Africa, the potential source of nutrient pollution, the reported effects of nutrient pollution; How to overcome nutrient pollution in the environment.

Global Reports of Nutrient Pollution and their Effects

Reports of nutrient pollution are globally available, evidenced by eutrophication (Bai *et al.*, 2018, Wang *et al.*, 2018). For example, in China, 31% of the rivers and six among nine central coastal bays have suffered from eutrophication as a result of elevated concentrations of phosphorus (P) and nitrogen (N) (Bai *et al.*, 2018). On the other hand, more than 60% of the monitored drinking water wells are severely contaminated (Gu *et al.*, 2013). Further, transfers of N and P from agriculture are the main contributors to the poor water quality (Su *et al.*, 2021, Zhang *et al.*, 2020). According to US EPA, anthropogenic activities cause excessive enrichment of nutrients such as nitrogen (N) and phosphorus (P) in water bodies. They are currently the utmost prevalent environmental problem facing the United States (Dubey and Dutta, 2020, Bhagowati *et al.*, 2019). The primary point sources of nutrients include watersheds, municipal and industrial wastewater treatment plants (WWTPs) (P. A. G. M. Scheren *et al.*, 2000, LYIMO, 2009, D. Dabya, 2002). The wastewater plants lacking design for removal of nutrients contributes much to pollution (Asteggiante and Geis, 2013, Bashar, 2018, Rahman *et al.*, 2016). Apart from other effects, reports of nutrient pollution results in a non-resilient ecosystem are available. That amplified by rapid population growth that primarily cause of worsening water quality, which results in increased inputs from WWTPs, rainwater run-off, and agricultural return flow (Adams *et al.*, 2020).

With phytoplankton blooms (>20 g l1) and bottom-water hypoxia, the Sundays and Swartkops Estuaries in South Africa are eutrophic (Adams *et al.*, 2020). As a result of WWTPs inputs and high water residence times, the nationally significant Knysna Estuary experiences eutrophic conditions associated with macroalgal blooms. In contrast, the Wildevolvlei and Zeekoe systems have transitioned to alternate stable states characterized by toxic cyanobacteria blooms (Adams *et al.*, 2020). Agricultural inputs from the Umfolozi system are threatening the health of the St Lucia Estuary, a UNESCO World Heritage site indicating the need for mitigation measures (Adams *et al.*, 2020). A study by Alex and Colleagues reported higher NO_3^- pollution in the wet season, which may be due to rainfall which accelerated the surface run-off that collects different materials from various settings into the groundwater sources, including nutrients. Hydrochemical techniques revealed that most nitrates originated from sewage effluents and organic wastes such as manure (Alex *et al.*, 2021). The output of various simulations on nutrients and other contaminants resulting from agronomic practices in farm plots practising cabbage and chrysanthemum cultivation revealed that most contaminants such as pesticides are from fertilizers and not leached beyond the top 10 cm layer. They indicate that excessive fertilizers can cause nitrate contamination to the groundwater in Cameron highlands.

Conversely, Degregori and Colleagues reported that eutrophication affects gut microbiomes of fish (*Stegastes nigricans*) (Degregori *et al.*, 2021). The results of 16S RNA sequencing studies further revealed, hindgut and foregut microbiomes of S. nigricans had more alpha diversity than unenriched controls (Degregori *et al.*, 2021). Furthermore, the gut microbiomes of *S. nigricans* differed significantly between treatments (Degregori *et al.*, 2021). These changes were not observed in the microbiomes of the turf algae consumed by *S. nigricans*, indicating that the gut microbiome changes were autochthonous. In combination, these results provide a novel example of endogenous microbial shifts in wild vertebrates caused by simulated anthropogenic stress (Degregori *et al.*, 2021). Therefore, the implementation of nutrient pollution mitigation strategies is essential for the sustainability of the ecosystem.

Status of Nutrient Pollution in Sub-Saharan African Environments

Mangroves are one of the most prolific coastal ecosystems, but they are vulnerable to anthropogenic pollution because of their location at the land-sea interface. Lugendo and Kimei studied anthropogenic contamination in five Tanzanian mangrove ecosystems, comprising non-polluted (Mbegani and Ras Dege), one moderately polluted (Kunduchi), and two contaminated (Mzinga and Kizinga) sites (Lugendo and Kimirei, 2021). The use of stable 15N isotopes to assess the suitability of mangrove leaves, roots, sediment, and gastropods as indicators of anthropogenic nitrogen pollution (Lugendo and Kimirei, 2021). The enrichment of δ15N increased from non-polluted < moderate < polluted (Lugendo and Kimirei, 2021). Polluted areas fed by freshwater streams, likely to absorb significant loads from residential sewage from adjacent settlements and industrial and agricultural effluents (Lugendo and Kimirei, 2021). This study further proposed mangrove leaves, aerial roots, sediment, and gastropod (T. palustris) can reliably use as nitrogen pollution indicators. Marine contamination along Kenyan Coast is claimed to originate from land (Okuku *et al*., 2019). A decade pollution survey (2008 -2018) to determine the levels of various pollutants, including nutrients in biota collected from selected locations, sediment and water in Kenya was done (Okuku *et al*., 2019). Results indicates the need for continuous monitoring to protect both ecosystem and human health (Okuku *et al*., 2019). Table 1 presents the occurances and distribution of quantitative levels of nutrients in different matrices in Sub Saharan African environments.

Table 1. Occurrence and Distribution of Quantitative levels of Nutrients in Different Matrices in Sub- Saharan Africa Environments.

Country	Nutrient	Concentrations	Matrix	Study period	Source	References
Kenya	PO43−-P	<0.10 - 1560.00 μg/L	Seawater	2019	Anthropogenic from the mainland to marine	(Okuku *et al*., 2019)
	(NO2− + NO3−)-N	<0.10 -1320.00 μg/L				
	NH4+-N	<0.10 -3280.00 μg/				
	Phosphates	0.022-0.039mg/L	Stream water	2021	Anthropogenic pollution	(Cherotich *et al*., 2021)
	Nitrates	0.038-0.163mg/L				
	Ammonium	0.034-0.118mg/L				
	Phosphates	0.217-1.131mg/L	Sediments		Reservoir and potential source if sediments are resuspended	
	Nitrates	0.199-0.603mg/L				
	Ammonium	9.394-26.73mg/L				
	Orthophosphate concentrations	0.326, to 0.422 and 0.524 mg/L	Coral reef	2018-2019		(Kaimba *et al*., 2019)
	Ammonia	<0.1 to 6.0 μgN/L	Lake water	March 2008 to December 2020.	Anthropogenic activities	(Walumona *et al*., 2021)
	Nitrate	5 to >150 μgN/L				
	Phosphate	15 to >900 μgP/L				
Tanzania	Nitrogen	16.44 mg L-1	mangrove leaves, roots, sediment	2021	Anthropogenic inputs > 10‰ δ15N values	(Lugendo and Kimirei, 2021)
		Ranged from 1.1 to 357.7 mg-NO3/l	Wastewater	2018	Anthropogenic activities	(Pantaleo *et al*., 2018)
		2.3 to 32.6 mg-NO3/l	Boreholes			
	Nitrite	0.0- 20 μ/mol	coastal beach waters	2008-2009	Anthropogenic activities	(LYIMO, 2009)
	Nitrate	0.2 - 54μ/mol				
	Phosphate	0.3 – 45 μ/mol				
	The concentrations of NO_3^-	ranged from 2.4 ppm to 929.6 ppm during the dry season and from 2.4 ppm to 1620.0 ppm during the wet season	boreholes, shallow wells	2017-2018	Anthropogenic activities	(Alex *et al*., 2021)
	Total phosphate	0.26 to 0.54 mg/l	River water		Anthropogenic activities	(Malale *et al*., 2018)
	Total nitrogen	0.8 to 1.71 mg/l				
	Total nitrogen	1,472.20 ± 97.52 μg TN L −1 hr−1		2018		(Shayo *et al*., 2018)
	Total phosphate	143.69 ± 4.98 PO4-P L −1 hr−1				

Country	Nutrient	Concentrations	Matrix	Study period	Source	References
Uganda	Nitrogen Phosphorus	0 – 2.8 mg L−1 mg L−1	water	2019 - 2020	Anthropogenic activities	(Turyahabwe *et al.*, 2020)
	Total phosphorous Total Kjeldahl nitrogen	214 mg L−1 1467 mg L−1	Wastewater	2018	Anthropogenic activities	(McCord *et al.*, 2020)
	Nitrogen and Phosphorus	Wastewater and pit latrines lost approximately 2 - 20% of total N and less than 1% of total P mass input to groundwater	Groundwater flow lines	2012 - 2013	Anthropogenic activities	(Nyenje *et al.*, 2013)
	Phosphorus	74%	Wastewater			
	Phosphorus	83%	Wastewater	2015	Anthropogenic activities	(Bateganya *et al.*, 2015)
	Nitrate	0.233-0.577 μg ml-1	Wastewater	2014	Anthropogenic activities	(Egor *et al.*, 2014)
	PO4-P NH3-N NO3-N	0.02 mg/l to 19.3 mg/l 0 to 2.36 mg/l 1.8 mg/l to 314.4 mg/l	River water	2011	Anthropogenic activities	(G Wali *et al.*, 2011)
Rwanda	Total nitrogen Total phosphorous	Influent 64.78 to effluent 34.61 mg/l Influent 14.05 to effluent 5.41 mg/l	Wastewater	April to September 2019	Anthropogenic pollution	(Theoneste *et al.*)
	Total nitrogen Total phosphorous	25.43±5.82 mg l-1 1.25±0.95 mg l-1	Fish pond	April to September 2019	Anthropogenic pollution	(Niyotwambaza *et al.*, 2010)
S. Sudan	Nitrogen	40 mg L-1 NH3-N and 5 mg L-1 NO3-N	Influent	2012	Early initiation and integration of wetlands for removal of nutrients	(Ladu *et al.*, 2012)
Cameroon	Nitrate Phosphate Nitrite Ammonia	0.72 – 3.41 mg L-1 0.63 – 1.35 mg L-1 0.010 – 0.045 mg L-1 0.07 – 0.19 mg L-1	River water	August - October 2012	Anthropogenic pollution	(Khalik *et al.*, 2013)
	Nitrate Phosphate	7 to 10 times higher	Sediments			
Botswana	Total nitrogen Total phosphorous	0.222 to 0.698 mg L-1 0.042 to 0.131 mg L-1	River water	June 2008 to June 2010	Anthropogenic pollution	(Gondwe *et al.*, 2017)
Zimbabwe	Nitrogen Phosphorus	13.5 mg/L 2.6 mg/L	River water	June 2000 to December 2001.	Anthropogenic pollution	(Nhapi and Tirivarombo, 2004)

The practice of releasing raw or partially treated wastewater in urban water bodies makes the issue of nutrient pollution a transboundary effect (Ukwe and Ibe, 2010, Lintern *et al.*, 2020). For example, Guinea current large marine ecosystem stretches from Guinea Bissau to Angola. It encompasses sixteen nations in West and Central Africa and is restricted by different bathymetry, hydrography, chemistry, and trophodynamics, with the Guinea current serving as the unifying characteristic (Ukwe and Ibe, 2010). Pollution from domestic and industrial sources such as nutrient pollution, overfishing, and poorly planned and managed coastal and offshore developments and near-shore activities have resulted in the rapid degradation of vulnerable inshore and offshore habitats and shared living marine resources, jeopardizing the economies and health of the population (Ukwe and Ibe, 2010). Reports of available treatment schemes in Zambia to be incapable of removing nutrients are available (Sinkala *et al.*, Zgambo, 2003, Alsterhag and Petersson, 2004), leading to nutrient pollution. A similar scenario in Malawi, where nutrient pollution originates from effluents, indicating proper sanitation infrastructure may help manage nutrient pollution in our environment (León *et al.*, 2003, Hranova *et al.*, 2005). Further reports indicate that in Angola and Namibia, the Okavango River Basin extracts 18.13 per cent of the mean annual flow for urban water supply and irrigates 108,992 hectares of barren Kalahari sandy soils that require high fertilization rates (Vushe, 2019). Indicating the river system's high leaching and, as a result, nutrient pollution (Vushe, 2019, Vushe *et al.*, 2016, Woltersdorf *et al.*, 2016). In most areas affected by nutrient pollution higher contribution is from anthropogenic activities.

Effects of Nutrient pollution

Nutrient pollution may lead to the disruption of vital ecological functions of ecosystems. For example, essential ecosystem functions on coral reefs were altered by nutrient pollution (Silbiger *et al.*, 2018). Reports of water bodies becoming eutrophic are available globally, including sub-Saharan Africa (Nyenje *et al.*, 2010, Ferreira *et al.*, 2015, Adams *et al.*, 2020, Janse and Van Puijenbroek, 1998, Tomascik and Sander, 1987). The rate of water bodies becoming eutrophic is projected to increase as anthropogenic activities increases leading to increased nutrient pollution. Such activities include animal farming to overcome the need for a growing population, modern agricultural practices, and the use of home cleaning agents and detergents containing nutrients (Ferreira *et al.*, 2015, Patricia M. Glibert *et al.*, 2018).

The direct environmental implications of eutrophication include an increase in suspended particles due to widespread macroalgal blooms, a loss in water clarity, and an increase in precipitation rate, which has destroyed benthic habitat due to shade of submerged vegetation (Dorgham, 2014, Janse and Van Puijenbroek, 1998, Tomascik and Sander, 1987, Worm *et al.*, 2006, Tomascik and Sander, 1985).

On the other hand, A 96 hours acute toxicity test to investigate the sensitivity of *Neorpela spio, Baetis harrisoni,* and *Tubifex* spp. to phosphates (PO_4-P) and nitrates (NO_3-N) at various concentrations (Elias, 2020). Results revealed the presence of lethal effects, including increased mortality with concentration and exposure time among tested species of different sensitivities (Elias, 2020).

Phosphate and nitrate are toxic to the three studied organisms under the test conditions, with *Neorpela spio* displaying the highest acute effect compared to *Baetis harrisoni* and *Tubifex* spp (Elias, 2020). For *N. spio*, 3.2 mg NO3-N/L and 2.4 mg PO4-P/L, 5.6 mg NO3-N/L and 4.8 mg PO4-P/L *for B. harrisoni*, and 128 mg NO3-N/L and 24 mg PO4-P/L for T. spp., 100 per cent cumulative mortality was observed (Elias, 2020). The Tanzanian nitrate recommended lower and upper limits of 10 and 75 mg NO3-N/L for drinking water caused higher mortality to N. spio and B. harrisoni. Significant mortality at the recommended nitrite (20 mg NO3-N/L) and phosphorus (6 mg PO4-P/L) concentrations for municipal and industrial wastewaters indicate the need for reformation of policies (Elias, 2020).

Muhando and Coallegues (2013) investigated the distribution and abundance of corallimorpharians (*Cnidaria anthozoa*) in Tanzania with various aspects of the coral reef environment. The results indicated a positive relationship between the per cent cover of corallimorpharians and water turbidity. Corallimorpharians were observed to dominate more disturbed reef areas affected by higher nutrient loads (Christopher A. Muhando *et al.*, 2003). Indicating that nutrient pollution has a significant impact on species distribution and abundance in any ecosystem.

Conclusions and Recommendations

Anthropogenic influences are said to contribute more to nutrient pollution, and a variety of impacts have been listed that lead to non-resilient ecology. There is a greater need for resilient ecosystems. Appropriate waste and wastewater management strategies such as the inclusion removal of nutrients in the design of treatment schemes are required. On the other hand, future management planning should include more sustainable farming methods and enhanced wastewater treatment as a trade-off between economic development and environmental protection.

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