3

ECOSYSTEMS

3.1 Introduction

Although Africa is home to 15 per cent of the world's population, it only has 9 per cent of the global water resources (Wang et al. 2014; United Nations Environment Programme [UNEP] 2010). Africa's scarce water resource situation is compounded by wastewater pollution. It is estimated that well over 80 per cent of the wastewater worldwide is released into the environment without treatment (United Nations Water [UN-Water] 2017). In low-income countries, an average of only 8 per cent of domestic and industrial wastewater is treated, compared to 70 per cent in high-income countries. As a result, in many regions of the world, water contaminated by bacteria, nitrates, phosphates, pharmaceuticals, microplastics and other chemicals is discharged into rivers and lakes, and ends up in the oceans, with negative consequences for the environment (UN-Water 2017). The relative lack of water on the African continent highlights the need to treat wastewater to improve surface and groundwater quality, enhance the natural water supply and reduce "stress and pressure" on available water resources (Omosa et al. 2014).

Untreated wastewater has implications for the health of both humans and ecosystems. In the seas and oceans, deoxygenated 'dead zones' caused by nutrient loading and the discharge of untreated wastewater are rapidly growing, affecting an estimated 245,000 sq km of marine ecosystems and affecting fisheries, livelihoods and food chains (UN-Water 2017). Freshwater ecosystems are also being impacted in similar ways. Waterborne illnesses from contaminated freshwater supplies and the degradation of freshwater systems have far-reaching implications for the well-being of communities and their livelihoods. Figure 3.1 is a schematic diagram showing the key natural and anthropogenic factors responsible for water contamination.

The Sustainable Development Goals (SDGs) call for universal access to clean water and sanitation for all. SDG 6 on clean water and sanitation aims at substantially improving the health of people, reducing water pollution and increasing recycling and reuse. Clean water and sanitation are one of the most fundamental goals, since water is the foundation of healthy ecosystems, thriving communities and therefore stable economic development. Water availability and quality are

Poor water and wastewater infrastructure, inadequate solid waste management and poorly managed faecal sludge management lead to land and water contamination

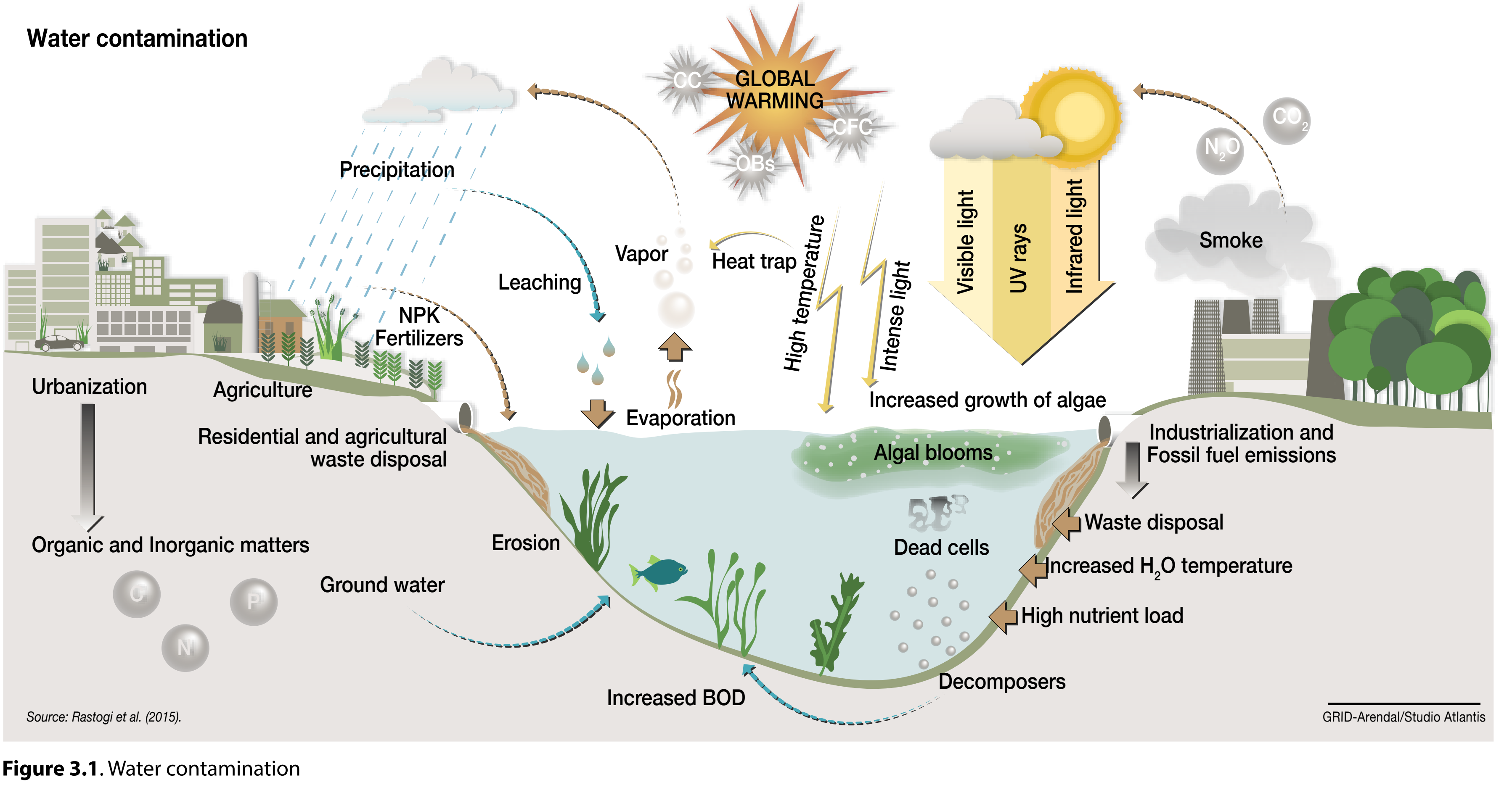


Figure 3.1. Water contamination

especially threatened by pollution, the impacts of climate change, population growth and increasing consumption (Brookes and Carey 2011).

Rapid urbanization, poor water and wastewater infrastructure, inadequate solid waste management and poorly managed faecal sludge management in urban areas lead to land and water contamination, with associated risks to the environment and human health. Africa has the largest percentage of households without access to improved sources of drinking water when compared to other continents, with the highest percentage located in rural areas (Bain et al. 2014).

Adequate wastewater treatment, proper sanitation provision and solid waste management are essential for preventing degradation of the environment and the potential consequences on human health. The consequences of releasing untreated or inadequately treated wastewater include harmful effects on human health, negative environmental impacts, and negative impacts on economic activities (UN-Water 2017). Figure 3.2 provides an idea of the number of water treatment or reuse plants in major countries around the world, with Africa generally lagging behind the rest of the world.

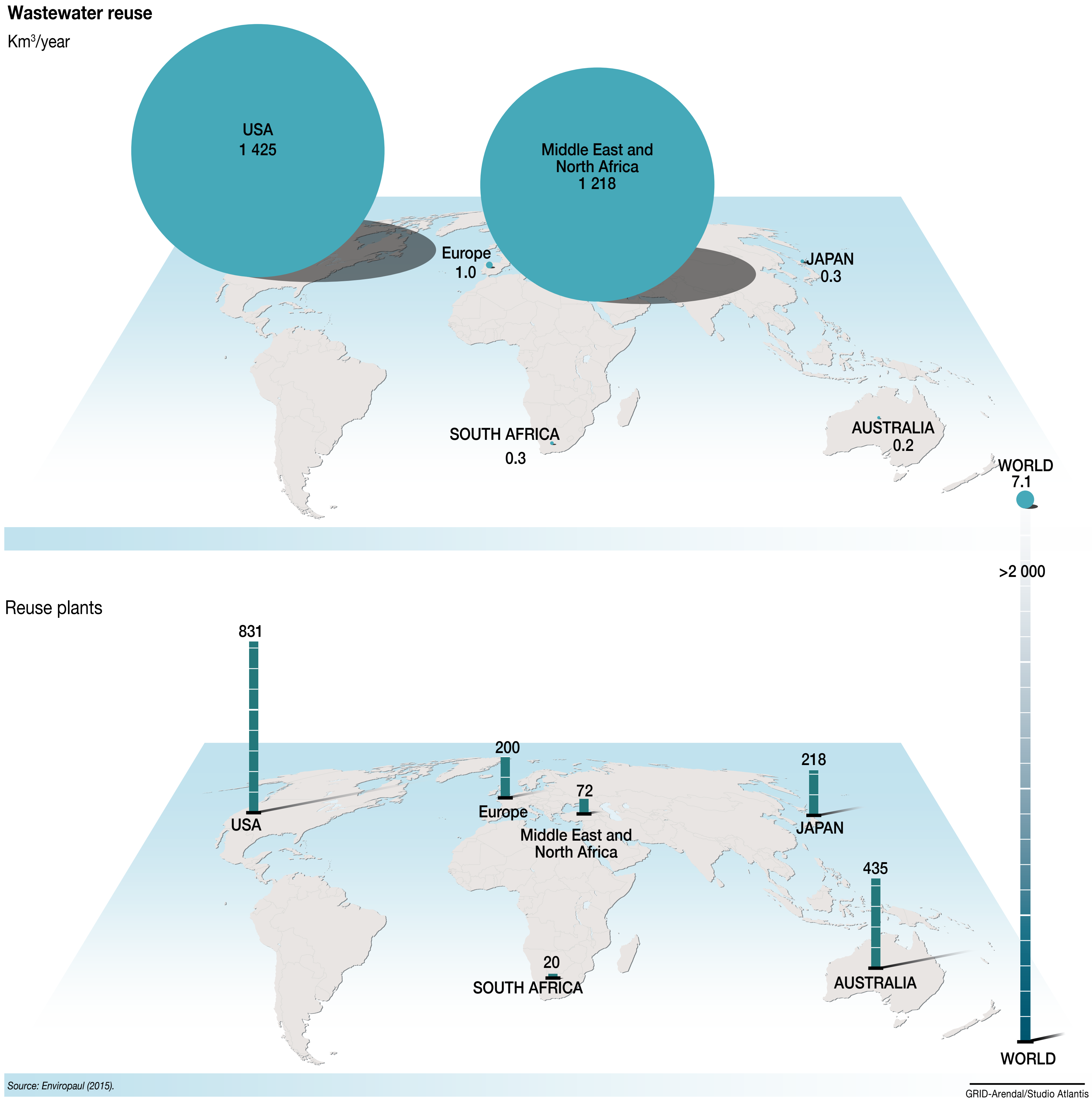


Figure 3.2. Wastewaster reuse in the world

3.2 The Concept of Ecosystems Health

A healthy ecosystem is stable and sustainable, and resilient to stress

An ecosystem consists of living organisms (biotic components), including humans interacting with their physical environment (abiotic components), which includes elements such as soil, water, climate and atmosphere (Van Jaarsveld et al. 2005). These biotic and abiotic components interact to form stable systems and are regarded as linked together through nutrient cycles and energy flows. Such ecosystems include agroecosystems, forest ecosystems, grassland ecosystems and aquatic ecosystems.

The productivity of an ecosystem depends on how organized and coordinated interactions among the components of these systems are. A healthy ecosystem is one that remains organized and autonomous over time – one that is stable, sustainable, active, free from 'distress syndrome' and resilient to stress (Costanza 2012). In a healthy ecosystem, there is balanced interaction among the various components and the whole natural system functions together to provide the many life-sustaining benefits we receive from nature which contribute to environmental and human health and well-being (Myers et al. 2013). Furthermore, a healthy ecosystem is stable and sustainable in its provision of goods and services used by human societies (Bukhard et al. 2008). It maintains its organizational structure, its vigour of function and resilience under stress and continuously provides quality ecosystem services for present and future generations in perpetuity (Lu et al. 2015). Healthy aquatic ecosystems are characterized by high species diversity and good water and habitat quality, among other aspects.

Ecosystem health is usually defined in terms of the non-appearance of pathological signs in a particular natural system. For example, lakes, ponds and rivers are healthy if they show no signs of diseased conditions such as contamination, loss of aquatic species or algal blooms (Rapport et al. 2001). High contamination, low aquatic species diversity, algal blooms due to eutrophication as a consequence of high nutrient input are indications of unhealthy freshwater ecosystems.

In a healthy ecosystem the whole natural system functions together to provide the many life sustaining benefits

3.3 Ecosystem Services

The many and varied benefits that humans freely gain from the natural environment and from properly-functioning ecosystems are known as ecosystem services (Redford and Adams 2009). These benefits include tangible products such as food and water, as well as non-tangible but important services such as climate regulation, recreational and cultural benefits. Ecosystems provide essential services that are necessary to maintain optimal ecosystem health. Ecosystem services are grouped into four broad categories: provisioning, such as the production of food and water; regulating, such as the control of climate and disease; supporting, such as nutrient cycles and oxygen production; and cultural, such as spiritual and recreational benefits (Millennium Ecosystem Assessment 2005). For example, freshwater ecosystems such as rivers and wetlands provide services such as clean drinking water, proteins (from fish/shrimp/crabs), fertile land for flood-recession agriculture and grazing, populations of wildlife for harvest, growing fruits and vegetables, fibre/organic raw materials, medicinal plants, inorganic raw material, flood mitigation and disease control (Forslund et al. 2009).

Savannah graslands are home to some of the world´s iconic species

Freshwater ecosystems such as rivers provide services such as clean drinking water and food

3.4 Untreated Wastewater and Ecosystem Health

Wastewater management – or lack of it – has a direct impact on the biological diversity of aquatic ecosystems. Disruption of the integrity of these ecosystems negatively affects their capacity to provide ecosystem services. The composition of municipal wastewater can vary considerably, reflecting the range of contaminants released by various domestic, industrial, commercial and institutional sources. There are growing concerns about emerging pollutants in domestic wastewater which include detergents, microplastics and medications that even at low concentrations may have long-term impacts (United Nations Educational, Scientific and Cultural Organization World Water Assessment Programme [UNWWAP] 2017). Figure 3.3 shows the sources and description of wastewater. The frequency indicates the rate of occurrence of the components.

Discharge of untreated wastewater can compromise the resilience and functioning of ecosystems. Untreated wastewater and farmland run-off often contain large amounts of plant nutrients, among others. When they reach rivers, lakes and coastal waters in high concentrations they can radically alter how ecosystems function, boosting the growth of aquatic plants, changing the composition of the flora and fauna and starving organisms in the water below – including fish – of oxygen. Untreated effluent can also lead to blooms of toxic algae that can make shellfish and freshwater dangerous to humans.

Low levels of contamination, high species diversity and high dissolved oxygen (DO) levels are associated with healthy ecosystems. In a broad sense, healthy ecosystems have the capacity to maintain social and biological functions that contribute towards the SDGs. The combined effect of ecosystem health is to sustain communities and provide economic opportunities, as well as human and biotic health. Untreated wastewater contaminants (Table 3.1) compromise the ecological health of aquatic media by contributing high amounts of nutrients and high biochemical oxygen demand (BOD) with resultant low levels of oxygen in the water column. This results in symptoms such as eutrophication, foul odours and fish kills, among others. The impacts of this make it impossible for aquatic ecosystems to support community livelihoods and contribute towards the sustainable goals of humanity.

Excessive macrophyte biomass blocks waterways, clogs drainage systems, impedes access to rivers and dams and contributes to flooding and the destruction of canals.

Macrophytes such as the common water hyacinth (Eichhornia crassipes) have a rapid growth rate and are highly adaptable to extreme conditions that contribute to its high degree of invasion. It is particularly dominant in the tropics and subtropics due to improper wastewater management and high nutrient loading in these areas (Villamagna and Murphy 2010). Water hyacinth spreads in the form of dense mats due to its complex root system and thus

Table 3.1. Typical composition of untreated domestic wastewater

Contaminants	Unit	Composition
Solids, total (TS)	mg/L	390–1230
Dissolved solids, total (TDS)	mg/L	270–860
Suspended solids, total (TSS)	mg/L	120–400
Five-day biochemical oxygen demand (BOD5)	mg/L	110–350
Total organic carbon (TOC)	mg/L	80–260
Chemical oxygen demand (COD)	mg/L	250–800
Nitrogen	mg/L	20–70
Phosphorus	mg/L	4–12
Chlorides	mg/L	30–90
Sulfate	mg/L	20–50
Oil and grease	mg/L	50–100
Volatile organic compounds (VOCs)	mg/L	<100–>400
Coliform, total	No./100 mL	106–1010
Faecal coliform	No./100 mL	103–108
Cryptosporidium oocysts	No./100 mL	101–102
Giardia lamblia cysts	No./100 mL	101–103

Source: Crittenden et al. (2012).

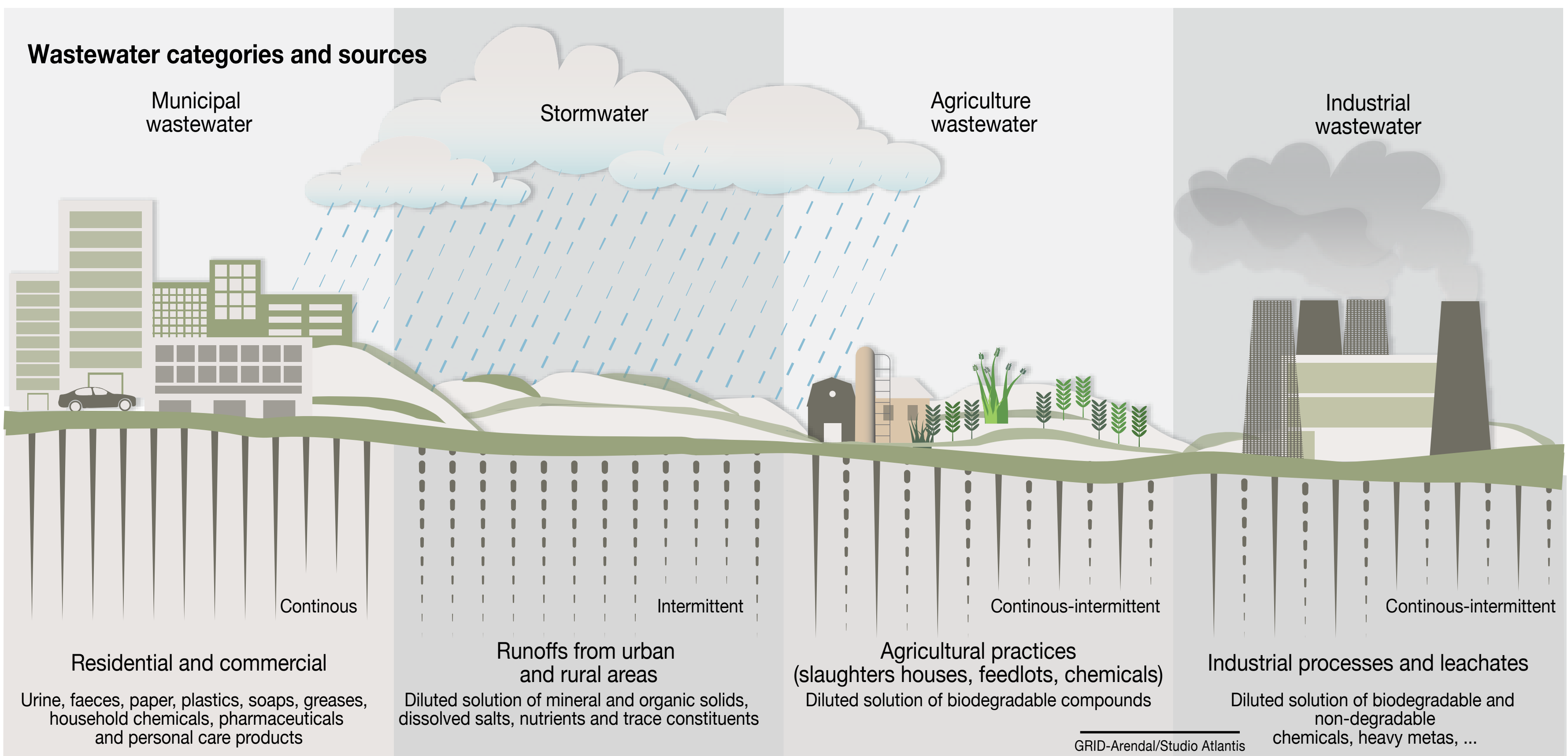


Figure 3.3. Wastewater categories and sources

Box 3.1. Threats to ecosystem health

Control of water hyacinth (*Eichhornia crassipes*) in South Africa alone costs several millions of rand per year – an average of R277 (US$20) per hectare (Van Wyk and Van Wilgen 2002). The widespread economic damage is almost the same as the ecological effects that result in the displacement of indigenous flora and fauna through habitat alteration (Byrne et al. 2010). A peri-urban mangrove area of the Mikindani forest on the banks of Tudor Creek near Mombasa Island in Kenya is primarily affected by the sewage discharge from the Mikindani residential estate and the Municipality of Mombasa. The site receives nitrogen and phosphorus that are discharged through sewage into the mangrove system on a daily basis, with negative effects on ecosystem functionality, eventually leading to dense growth of algal blooms in the aquatic environment (Bartolini et al. 2011).

interferes with boat navigation and fishing. It also blocks canals and further reduces the penetration of light, dissolved oxygen and other nutrients, adversely affecting the ecology of water bodies. Thus, pollutants from wastewater can be a threat to both ecosystem and human health.

Often, the discharge of untreated effluent results in the deposition of large amounts of organic matter, pharmaceuticals and chemical substances such as heavy metals that have major detrimental effects on the present micro- and macrofauna. Excessive nutrient loading can lead to eutrophication and oxygen deficiencies that ultimately alter the energy relationship and water balance, disrupting the structure and function of the biotic community. Excessively turbid effluent discharge can also result in the deposition of sand and grit into the aquatic system, disrupting sediment characteristics and hindering natural water flows. In addition, the overall hydrological and physicochemical environment is often affected by many of the micro- and macrofauna within these water bodies, exhibiting distinct physiological tolerance levels.

The discharge of untreated effluent into water bodies results in the deposition of organic matter which supports the proliferation of water weeds

Water weeds thrive in nutrient rich water bodies

3.5 Contamination/Degradation of Ecosystems

Although wastewater could be an important source of essential nutrients for plants, many environmental, sanitary and health risks are also associated with the use of wastewater for crop irrigation due to the presence of toxic contaminants and microbes (Khalid et al. 2018). The use of wastewater for crop irrigation in the agricultural sector has the potential for both negative and positive effects on the soil quality/productivity, crop production, and human health (Qadir et al. 2010).

There are some environmental risks associated with the use of untreated or partially treated wastewater in irrigation, including soil contamination, groundwater pollution and surface water degradation (Connor et al. 2017).

Wastewater for irrigation adds nutrients, dissolved solids, salts and heavy metals to the soil. Over time, excessive amounts of these elements may accumulate in the root zone with possible harmful impacts on soil. The long-term use of wastewater could result in soil salinity, waterlogging, breakdown of soil structure, overall reduction in productive capacity of soil and lower crop yields. Impacts depend on factors such as the source, use intensity and composition of wastewater, as well as soil properties and the crops' own biophysical characteristics (UN-Water 2017). Wastewater application changes some physicochemical properties of the irrigated soil. Studies have shown that the application of wastewater significantly changes the soil's physical, chemical, and biological properties (Becerra-Castro et al. 2015), which can, in turn, alter the biogeochemical behaviour (mobility and bioavailability) of metals and other nutrients. In addition, wastewater may also carry viruses, bacteria, nematodes and protozoa, which can cause different diseases (Uyttendaele et al. 2015).

In summary, the variation in soil properties as a result of wastewater application can have a significant impact (both positive and negative) on the soil quality and crop productivity.

3.5.1. Soil

Wastewater is used in agriculture in many parts of Africa and this practice has implications for both human and ecosystem health. In several African cities, agriculture based on wastewater irrigation accounts for 50 per cent of the vegetable supply to urban and rural areas (Drechsel and Keraita 2014). Farmers are generally not concerned about environmental hazards associated with wastewater irrigation resulting in both soil and eventually vegetable contamination – their main focus is on maximizing their yields and profits. Heavy metals in contaminated wastewater pose several risks to humans through assimilation pathways such as the ingestion of plant material (in the food chain). Heavy metals also destroy soil organisms that are responsible for nitrogen fixation, increase drainage and soil aeration. Although the metal concentrations in domestic wastewater effluents are usually relatively low, long-term irrigation with wastewater can eventually result in heavy metal accumulation in the soil (Wuana and Okieimen 2011). These metals are important as they can decrease crop production due to the risk of bioaccumulation and biomagnification in the food chain. They also pose the risk of superficial and groundwater contamination through water seepage from the contaminated soils.

Cultivation of Spinach using wastewater in Zamfara State, Nigeria contains (in descending order): high levels of iron, (Fe), cadmium (Cd) and copper (Cu) (Salawu et al. 2015). Similarly, carrots, green peppers and lettuce sold in some markets in Accra, Ghana contain high levels of arsenic (As), Cd, chromium (Cr), copper (Cu), Fe, palladium (Pd) and zinc (Zn). These vegetables were cultivated using wastewater from major drainage systems spotted close to the vegetable farms (Addae 2015). Figure 3.4 illustrates the sources and sinks of heavy metals.

Box 3.2. Soil contamination with wastewater in the Niger Delta, Nigeria

A rural community in the Niger delta experiences soil contamination as a result of wastewater discharge from a cassava processing plant. Cyanide and magnesium levels were harmful to the soil when measured against the safe levels for agricultural and other purposes. The presence of the metals decreases the production of the affected area (Izonfuo, Bariweni and George 2013). Cassava processing activities are now extensively carried out in many rural and urban centres in Nigeria. Its wastewater has been reported to be toxic and poisonous. Cyanide in cassava wastewater is another major cause for concern, as when cyanide interacts with (soil) water, it produces a weak acid. Cyanide in soil has been reported to be herbicidal.

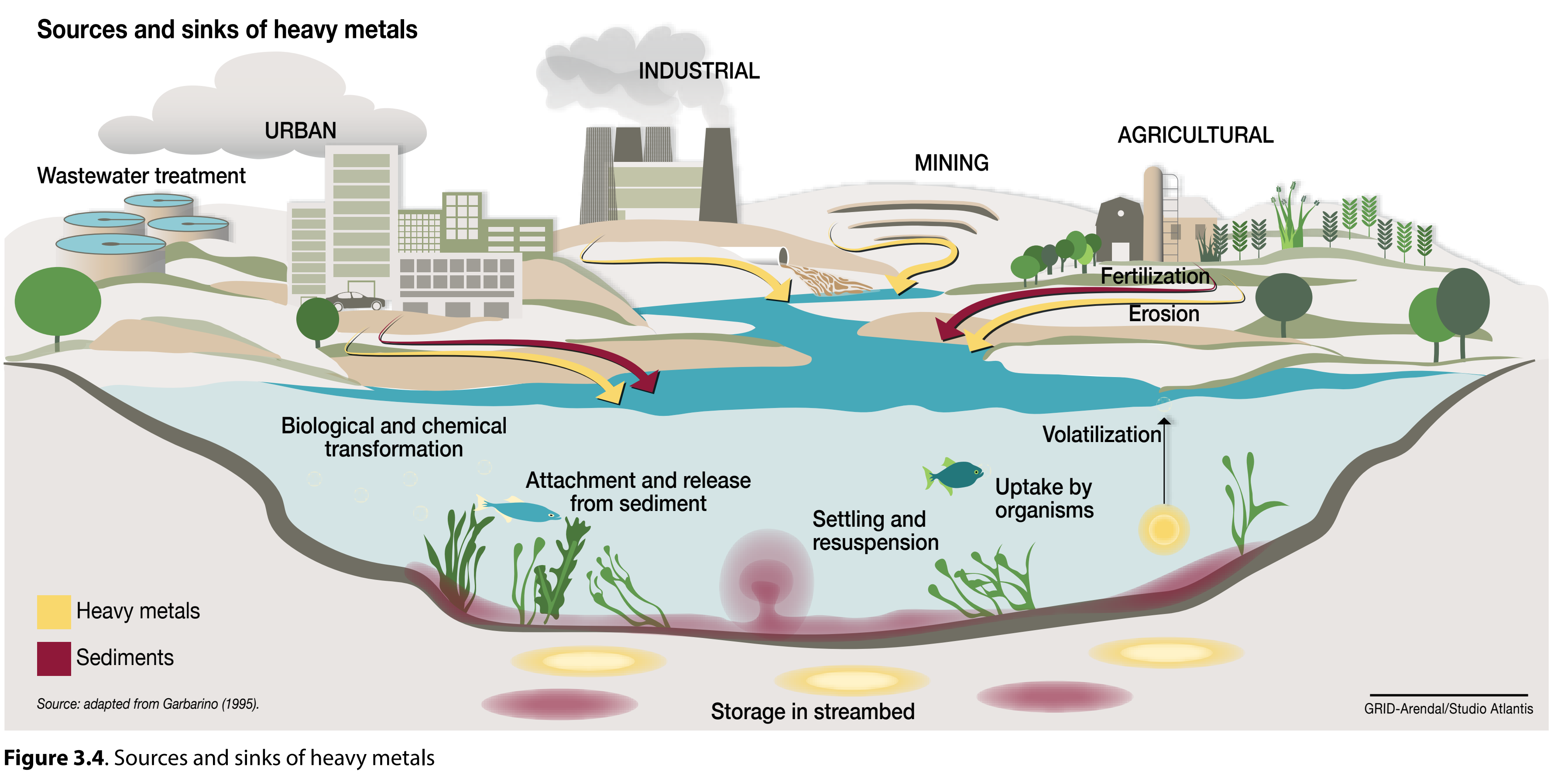


Figure 3.4. Sources and sinks of heavy metals

Sources of heavy metals in soil

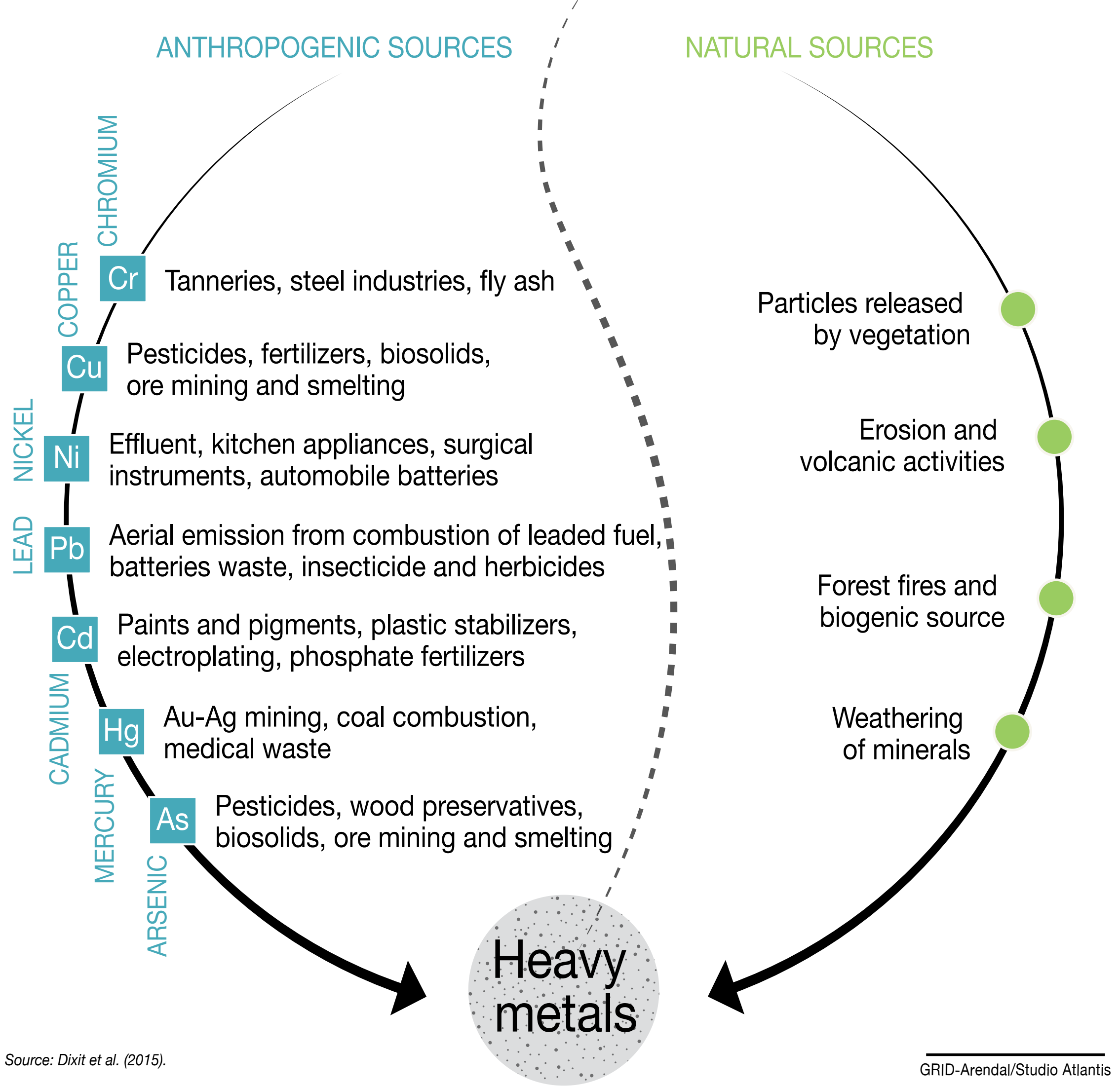


Figure 3.5. Sources of heavy metals in soil

Wastewater use in agriculture can result in the contamination of soil, crops and water sources. There is an inherent risk of contamination having harmful effects on exposed soil organisms. Even when soil acts as an efficient living filter to remove, deactivate and transform the pollutants contained in wastewater, there are some pollutants that it cannot fully eliminate. Moreover, sludge from wastewater may contain synthetic substances such as microplastics, microfibers and heavy metals, and when used as compost, it may negatively impact the effectiveness of soil as a treatment system by poisoning the degrading microorganisms, destroying the physical structure of the soil or damaging the natural cycles occurring within the soil (Durán–Álvarez 2014). Figure 3.5 shows the various sources of heavy metals in soil.

3.5.2. Air

The operation of wastewater treatment plants (WWTPs) results in direct emissions of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Some of these emissions are released in the course of biological processes employed in the treatment plants. In addition, there are indirect emissions resulting from the generation of the energy used in the plants.

Methane and nitrous oxide are potent GHGs with a higher global warming potential than carbon dioxide (Intergovernmental Panel on Climate Change [IPCC] 2013; Delre 2018). Although there are international guidelines for estimating the methane and nitrous oxide emissions from WWTPs, how well these estimations resemble actual estimates at specific treatment plants is unknown; and GHG emissions from WWTPs may actually be higher than is estimated (Delre 2018). Greenhouse gas emissions from WWTPs must be reduced, as climate change poses risks to humans and to the environment.

Box 3.3. Recovery of greenhouse gas emissions

The emission of greenhouse gases (GHGs) resulting from the various types of treatment of municipal solid waste found in the town of Yaounde was analysed by researchers. Four management systems were taken as the basis for analyses. System 1 was the traditional collection and landfill disposal of refuse, while in System 2, the biogas produced in the landfill was recovered to produce electricity. In Systems 3 and 4, in addition to the collection, a centralized composting or biogas plant was introduced before the landfill disposal. A life cycle inventory of the four systems was made, enabling the quantification of the flux of matter and of energy consumed or produced by the systems. Landfilling without recovery of methane emitted the most amount of GHGs. It led to the emission of 1.7 tons of carbon dioxide equivalent (tCO_2E) per ton of household waste. Composting and methanation allowed for a comparable level of emission reduction of 1.8 and 2 tCO_2E/t of municipal solid waste (MSW), respectively. In order to reduce the emission of GHGs in waste management systems, it is advisable to, first of all, avoid the emissions of methane coming from the landfills. System 2 seemed to be a low-cost solution to reduce the emissions of GHGs (2.2 to 4 $/$tCO_2E$). System 2 was calculated to be the most effective at the environmental and economic level in the context of Yaounde. Therefore, traditional collection, landfill disposal and biogas recuperation to produce electricity is preferable in moist tropical climates (Ngnikam et al. 2002). The Gabal el Asfar is another example of a plant designed to recover greenhouse gases. The Gabal el Asfar wastewater treatment plant does not only have capacity to serve 12 million people by treating 2.5 million m^3/day of wastewater, but also to generate 18.5 MW of power which is enough to meet 70% of the plant's electricity demand.

Sunderland wastewater treatment plant in South Africa emitting gases into the atmosphere

3.5.3. Surface water

The discharge of untreated or partially treated wastewater into the environment results in the pollution of surface water, and this in turn affects the amount of water resources available for direct use. Since 1990, water pollution has been increasing in most rivers in Africa, due to the increasing amounts of wastewater (UN-Water 2017).

Organic pollution (measured in terms of BOD) can have significant impacts on inland fisheries, food security and livelihoods, severely affecting poor rural communities that rely on freshwater fisheries. Severe organic pollution already affects around one-seventh of all river stretches in Africa, Asia and Latin America and has been steadily increasing for years (UNEP 2016; UNWWAP 2017).

Table 3.2 highlights the problems, causes and effects of poor sanitation on ecosystem health.

Factors contributing to the contamination of freshwater include overexploitation of both water and organisms, water pollution, habitat destruction (modification of natural flow regimes) and wetland drainage for agriculture, all of which are linked to human activities. Habitat destruction and modification includes deforestation, urbanization and agricultural impacts such as leachates of agrochemicals from farmlands. Other factors contributing to the decline of surface water are global environmental processes such as climate change, global warming and acidic deposition. It is envisaged that if lake sediments become warmer and hold less oxygen in response to climate change, the contribution of phosphorus from lake sediments may increase as phosphorus is released under anaerobic conditions (Gibbons 2015). This will thereby enhance the likelihood of increasing the release of nutrients into water bodies resulting in eutrophication. Damming modifies the natural flow of rivers and is considered one of the greatest threats to the health of freshwater.

Box 3.4. Degradation and oxygen depletion in freshwater sources

Many freshwater sources in Africa are polluted due to encroachment and other anthropogenic activities. In Kwara State, Nigeria, the Moro Lake – the second largest dam in Ilorin – has very low levels of Dissolved Oxygen (DO), indicating a decline in ecosystem health. This is as a result of the cumulative effect of human activities such as sewage disposal where oxygen is used in decomposing organic matter, resulting in high BOD (the amount of oxygen required by microorganisms to degrade organic matter) and low DO concentration (Mustapha and Omotoso 2005). Likewise, in the Odaw river basin of Ghana, DO levels decrease from the upstream to the downstream portion of the river, confirming high solid and organic matter pollution downstream. BOD also increases from upstream to downstream. The Odaw River is one of the rivers in Africa that are highly polluted (Ansa et al. 2017) due to human activities. High levels of DO, lower levels of BOD and the absence of coliform bacteria are essential for aquatic life forms and are an indication of a healthy ecosystem. Contaminated freshwater affects the health of humans and organisms that depend on it for survival.

Organic pollution can negatively affect the health of fish and other aquatic life

Table 3.2. Common freshwater ecosystem problems, causes and effects

Problem	Causes	Effect
Excess algae	High nutrient loads (elevated amount of nutrients in wastewater)	Produces unsightly algal blooms
Exotic species	Introductions; high nutrient load	Reduces native species and use of lakes or reservoirs
Shallow water depth	Several causes, including dead algae and sediment input within wastewater from catchment areas	Restricts boating and swimming
Turbid water	Silt and sediment load into water bodies	Reduces aesthetic value
Toxins	Heavy metals in wastewater	Restricts fish and seafood consumption
Acidity	Wastewater containing acidic substances	Leads to low pH that restricts the biological community
Salinity	Wastewater containing salts	Leads to high salt levels that restrict the biological community

Source: Crittenden et al. (2012).

Water is contaminated by both natural and human activities

3.5.3.1. Eutrophication of streams and lakes

Eutrophication is the process of nutrient enrichment and the associated excessive plant growth in water bodies. It is part of the natural ageing process of lakes and is normally accelerated by human impacts. In their most basic forms, these nutrients are nitrogen and phosphorous, and they favour overgrowth of algae and grazing on bacteria, which then results in oxygen depletion. Eutrophication either occurs naturally or is either artificially or culturally human-induced. Natural eutrophication depends only on the local geology or the natural ageing of lakes and streams that takes about a thousand years to occur. It also depends on the natural features of the catchment. Artificial eutrophication is normally caused by nutrients from agricultural fields, domestic sewage and industrial waste. Eutrophication caused by agriculture is mainly a result of the use of fertilizers on farms and urban lawns.

Excessive amounts of the nutrients (nitrogen and phosphorus) contained in untreated or partially treated wastewater sometimes invade water sources, causing eutrophication. Eutrophication is characterized by a rapid increase in plant life that can lead to algal blooms that stop sunlight from penetrating the water body, causing plants below the surface to die. The decomposition of dead plants uses up oxygen in the water. Algal blooms are therefore dangerous to fish because they use up a lot of the oxygen in the water. They can also have a strong, objectionable smell and can affect the taste of water, hence they render the aquatic ecosystem unfit for other uses. Eutrophication increases the cost of water treatment and puts pressure on the water supply budget of African countries. Eutrophication of freshwater habitats increases their vulnerability to invasive alien species such as water hyacinth, which thrives under high nutrient conditions (Reddy et al. 1989; Coetzee and Hill 2012). Water hyacinth is considered one of the world's most problematic weeds, causing siltation, increased acidity and deoxygenation, among other effects. Several coastal and inland areas of Africa are affected by cyanobacterial (algal) blooms, as shown in Figure 3.6.

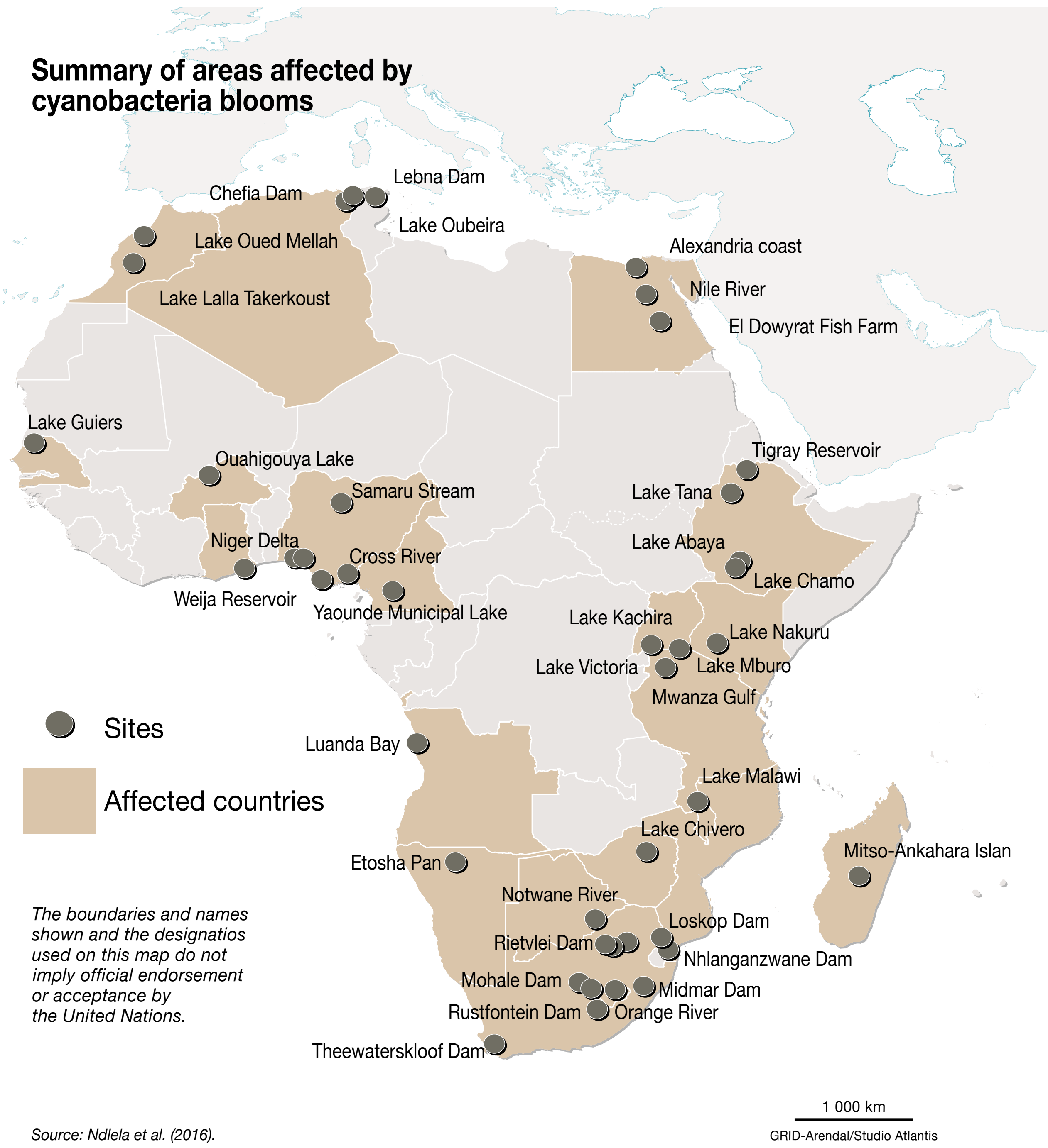


Figure 3.6. Summary of areas affected by cyanobacteria blooms in Africa

Eutrophication does not only result in the increase in water weeds but also increased costs for water purification

Box 3.5. The effects of eutrophication

Problems of eutrophication are felt most strongly where human, economic and public health interests are affected by its consequences. The key effects of eutrophication are on:

- The water supply
- The economy
- Ecosystems
- Public health and community

Water supply

Effects on the water supply include the blockage of water filter systems by algal biomass. Filamentous algae are able to penetrate water filters (for example, Oscillatoria sp.). Penetration of these algae into water supply systems affects the taste and odour of the water, impacting its quality. Algal breakdown products, mainly mucopolysaccharides, are able to chelate the iron (Fe)/aluminium (Al) added as coagulants, leading to increased numbers of metal complexes entering the water supply (Hayes and Greene 1984). Precipitation of metals under low pH conditions causes industrial use problems such as problems in the production of carbonated water for the soft drinks industry.

Economic impact

Eutrophication also results in increased costs of treating drinking water due to the need to dose reservoirs with copper sulfate. It has been reported that in Ghana, due to encroachment and dumping of raw sewage into the Weija Reservoir, the Ghana Water Company Limited – operators of the Weija treatment plant – spend close to GHC 40,000.00 a day (US$2,000.00 at the 2011 exchange rate) to treat water at the dam before it is supplied to consumers. It has been suggested that the cost of treating water from Weija far exceeds the cost of treating water at the Kpong WWTP, where water from the Volta lake is treated. At the Weija WWTP, alum, chlorine and lime are used to treat the water, whereas at the Kpong WWTP, only chlorine and lime are used. The addition of alum in the water treatment process at Weija is to remove excessive pollutants (Awuku-Apaw 2011).

Ecosystem impact

Eutrophication can result in very low levels of oxygen that cannot support aquatic life forms. The increased nutrient load leads to increased phytoplankton productivity. This can result in increased detritus on lake bottoms followed by increased sediment oxygen demand, leading large areas of the lake bottom to experience a lack of oxygen, a condition known as becoming 'anoxic'. When a lake bottom becomes anoxic, nutrients may be released from the sediment, further causing the water body to remain in a eutrophic state. Increased use of aluminium sulfate as the primary coagulant in water treatment – particularly during times of high algal crop presence – results in higher levels of dissolved aluminium in the water supply. There are perceived links between aluminium levels and encephalopathy in renal dialysis patients (Hayes and Greene 1984). Cyanobacteria (or 'blue-green algae') produce toxins such as neurotoxins and hepatotoxins produced by species of microcystis, oscillatoria and anabaena. Deaths of birds, mammals, amphibians and fish due to cyanobacterial toxins have been reported around the world. Cyanobacterial toxins can cause swimmers in freshwater lakes and other water bodies to experience gastrointestinal upsets and skin rashes through contact and ingestion of water containing scum.

3.5.4. Groundwater

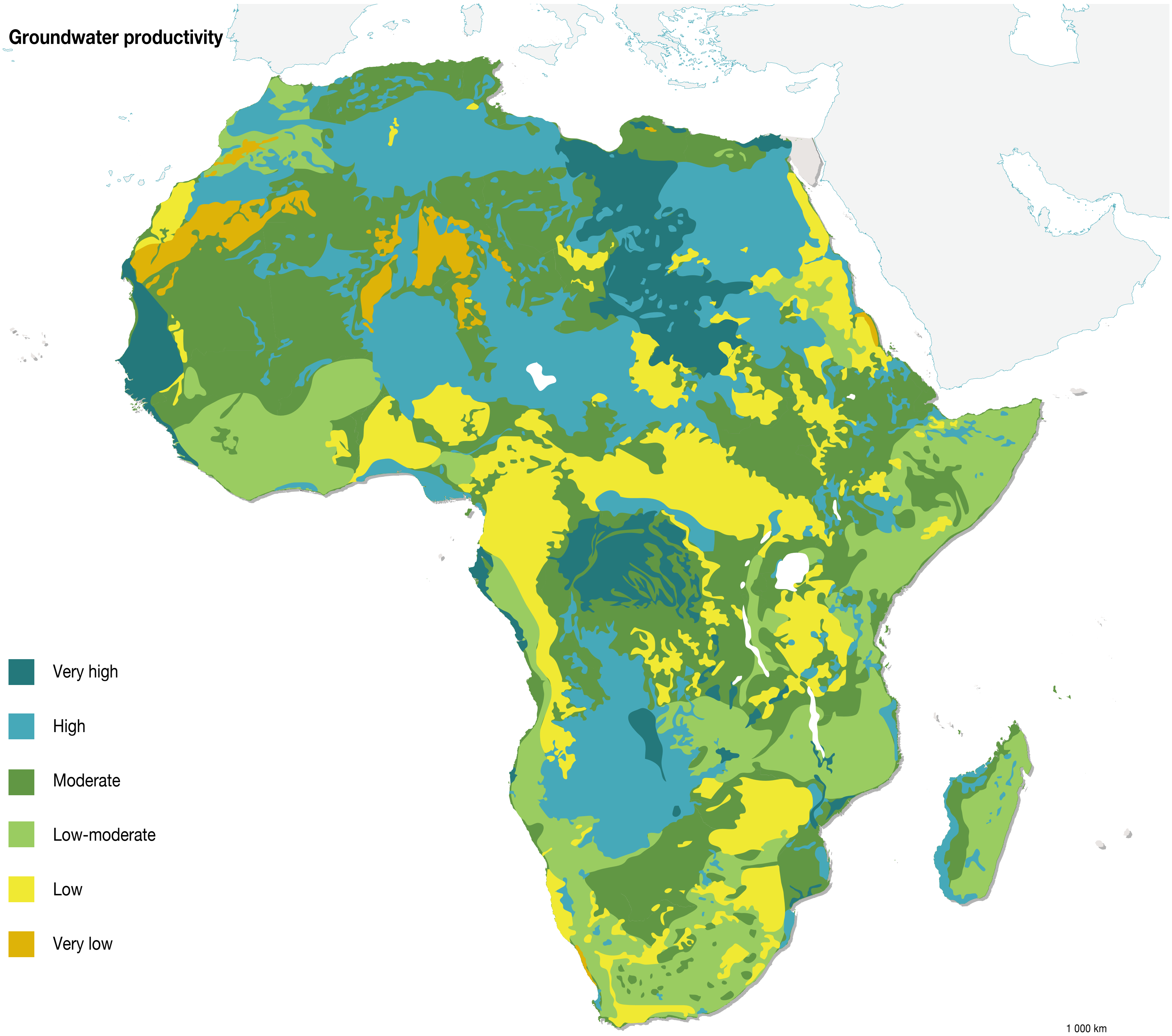
Groundwater is the main water source for meeting growing demand for domestic and livestock rearing in rural, dispersed communities and small urban towns across Africa (Masiyandima and Giordano 2007; Adelana and MacDonald 2008). Figure 3.7 shows the pattern of groundwater productivity in Africa.

Although groundwater quality is highly dependable in many parts of Africa, wastewater contamination is putting it at risk. Percolation of excess nutrients, salts and pathogens from wastewater through the soil may lead to the degradation of groundwater (UNWWAP 2017). The actual impact is, however, dependent on a range of factors, including the scale of wastewater use, the quality of the groundwater, the depth of the water table, soil drainage and soil characteristics (for example, porous or sandy). In irrigated areas with shallow groundwater tables, the impact of irrigation with inadequately treated wastewater on groundwater quality is likely to be substantial (UNWWAP 2017). There are several pathways through which wastewater contaminates groundwater, including irrigation, seepage from wastewater treatment facilities and landfills.

Wastewater may contain pathogenic bacteria and viruses and has the potential both to recharge groundwater aquifers (a positive aspect) and to pollute groundwater resources (a negative externality). There is a link between groundwater and surface water, as groundwater contributes to surface water and vice versa. Groundwater contributes to stream flow generation in the form of baseflow, which is the contribution of groundwater discharge to streamflow. Furthermore, streamflow contributes to the recharge of groundwater (Todd and Mays 2005). Groundwater plays a crucial role in the health of ecosystems in rivers and wetlands, thereby offering valuable ecosystem goods and services such as water supply, flow regulation, contaminant removal and food, as well as recreation and aesthetic value (Weight 2008). Interactions between groundwater and surface water play a fundamental role in the functioning of riparian ecosystems (Kalbus, Reinstorf and Schirmer 2006).

Some of the common contamination sources of groundwater include untreated waste from septic tanks, toxic chemicals from underground storage tanks and seepage from leaky landfills (see Figure 3.8). In addition, pesticides and fertilizers also find their way into groundwater supplies over time. Road salt, toxic substances from mining sites and used motor oil find their way into wastewater and leach into underground water (Groundwater Foundation 2018). Furthermore, rocks that contain certain minerals such as fluoride may gradually dissolve, altering the chemical composition of aquifers and rendering the water unsafe for consumption.

Groundwater is the main water source for meeting the growing demand for domestic and livestock rearing in rural, dispersed communities and small urban towns across Africa



Source: British Geological Survey, 2011.

1 000 km

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Figure 3.7. Groundwater productivity in Africa

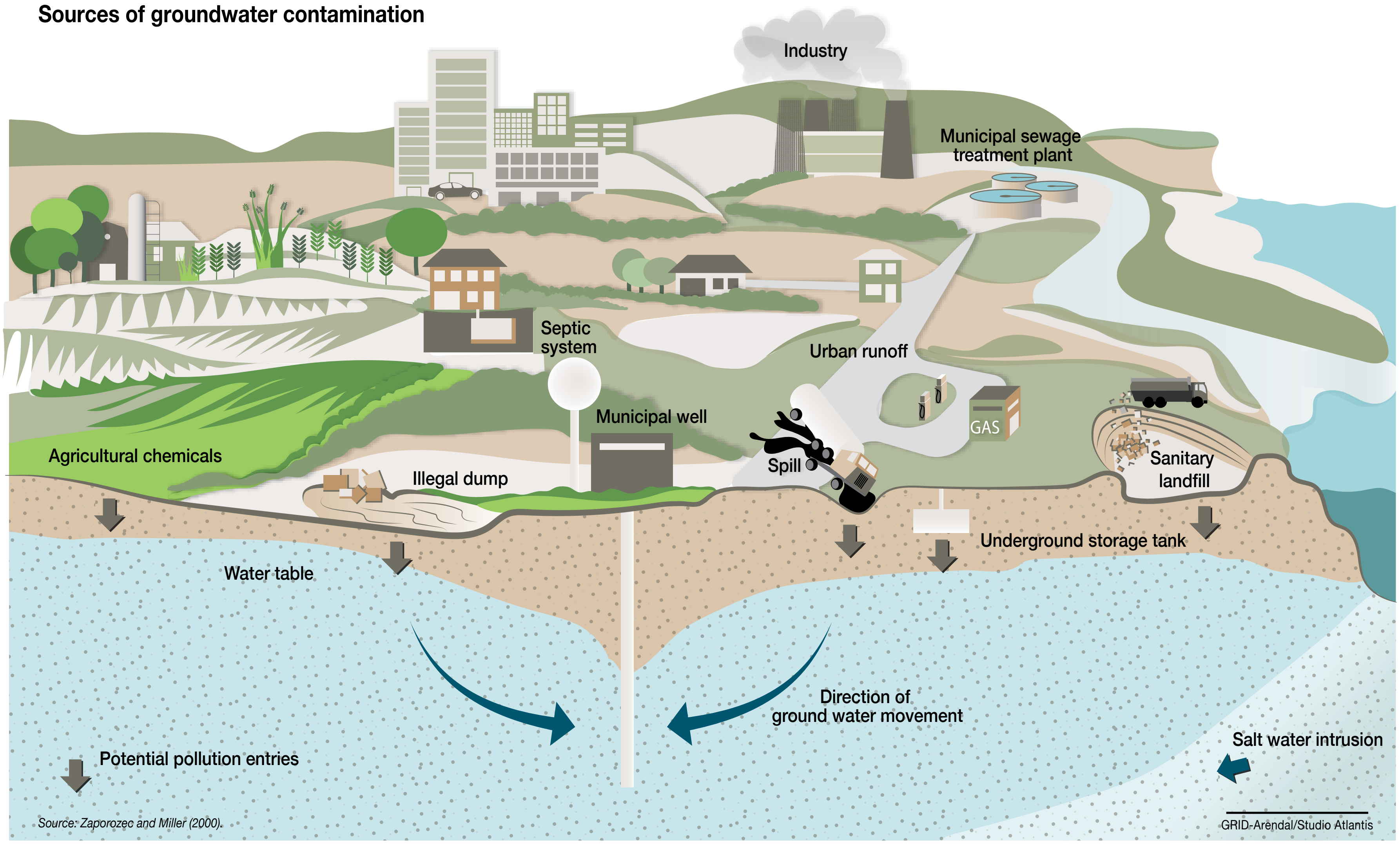

Figure 3.8. Sources of groundwater contamination

3.5.4.1. Septic tanks/Pit latrines

Septic tanks and pit latrines can contaminate groundwater. Septic tanks are on-site wastewater disposal systems used in homes, offices or other buildings that are not connected to a city sewer system. This method is widely used in many parts of Africa. Septic systems are designed to slowly drain away human waste underground at a slow, harmless rate. However, improperly designed or poorly maintained septic systems can leak bacteria, household chemicals and other contaminants into groundwater.

In some West African and Middle Eastern countries, the majority of the rural population uses pit latrines and countries where pit latrine use is prevalent also tend to have high rates of groundwater use (Tillet 2013). Studies have associated pit latrine use with the transport of microbes (typically faecal coliforms) and chemicals (for example, nitrate, phosphate, chloride, and ammonia) through soil into water sources. Most groundwater contamination occurs downstream of pit latrines (Groundwater foundation 2018).

Groundwater in unsewered urban areas could be heavily contaminated by on-site sanitation activities and could be an important source of nutrients exfiltrating into streams. For example, in Kampala City, Uganda, it was evident that substantial amounts of wastewater originated from the pit latrine and infiltrated an aquifer. As a result, nutrient concentrations down gradient of the pit latrines were found to be very high, which affected groundwater quality (Nyenje et al. 2013).

In Addis Ababa, Ethiopia, most households (about 75 per cent) have pit latrines that are either emptied when full or discharged to open drains, and the effluent gradually seeps into groundwater (Debela et al. 2018). Both shallow and deep wells found in the city are rich in nitrate, suggesting that faecal sludge, farms, livestock and wastewater from surrounding drains may contaminate the groundwater. Even protected spring waters that are usually assumed to be free from contamination were also found to be rich in nitrate. There was a fourfold increase in nitrate concentration at sites where there is high volume of sewage discharge (Debela et al. 2018). Over 80 per cent of the city's population lives in slum districts with very poor housing that is overcrowded and has little or no urban service provision (United Nations Human Settlements Programme [UN-Habitat] 2014).

Example of an unimproved pit latrine (see arrow) in Bambui, Northwestern Cameroon.

Only a small proportion of the city is served by conventional sewerage systems, while most areas rely upon on-site sanitation (Beyene et al. 2015). Open defecation remains a common practice, especially in urban-slum areas in most Sub-Saharan African countries. Most households have pit latrines that are either emptied when full or discharged to open drains. There are also flush toilets and septic tanks, again often discharging to open drains (Nakagiri et al. 2015). Public toilets are not common but communal pit latrines that are shared between several households are widespread, while others resort to open defecation.

3.5.4.2. Landfills

Landfills are sites where waste materials are deposited and buried. Waste management in Africa is often characterized by uncontrolled dumping and open burning, with limited cases of disposal to sanitary engineered landfills, or diversion of waste away from landfill towards reuse, recycling and recovery (Mwesigye et al. 2009; Mohammed et al. 2013).

According to UNEP (2015), 19 of the world's 50 biggest dumpsites are located in Africa, all in sub-Saharan Africa. Uncontrolled dumping of waste in African cities has the potential to cause significant direct and indirect impacts on communities and receiving environments (UNEP 2018).

Groundwater can be contaminated by leachate from waste

Leachate from landfills can contaminate groundwater. Engineered sanitary landfills are lined at the bottom to prevent groundwater pollution and also include features such as leachate collection and treatment systems; and groundwater monitoring, among others. However, if there is no bottom layer or the surrounding rocks are fractured, contaminants or effluents from the landfill (car battery acid, paint, household cleaners, among others) can make their way down into groundwater (Groundwater Foundation 2018).

3.5.4.3. Run-off

Storm water or run-off from urban and industrial areas usually contains substances such as oil, heavy metals, chemicals, sediment and other hydrocarbons infiltrating the soil to contaminate groundwater. If infiltrated into the soil, these contaminants have the potential to degrade soil and groundwater quality and, therefore, are cause for concern. Nutrients and sediment washed from farm lands are also leached through soil into groundwater (Groundwater Foundation 2018). Despite the gloomy picture of groundwater contamination with polluted water, South Africa and Namibia are making progress by treating storm water and wastewater and injecting it into aquifers.

Studies have shown that contaminant concentrations in urban run-off can vary widely by season, location, traffic volumes and rainfall volumes and intensity. If infiltrated into the soil, these contaminants have the potential to degrade soil and groundwater quality. Poor storm water quality can potentially contaminate surface and groundwater potable water supplies, making these water sources unusable, or more expensive to treat. Run-off from urban areas negatively impacts water quality in downstream aquatic ecosystems. Increased toxins, nutrients and other contaminants, as well as higher water temperatures and changes in stream flow rates, can impact the health of aquatic ecosystems.

Storm water or run-off from urban and industrial areas contains substances such as oil, heavy metals, chemicals and sediments that can infiltrate and contaminate groundwater

McCarthy et al. (2012) noted that urban storm water is one of the largest sources of contaminants for surface waters. The microbiological pollution most often found in urban storm water originates from failing or non-existent sanitation systems, as well as inappropriate waste disposal and hygiene habits, with the single most frequently encountered pollutant being raw sewage, followed by household greywater ('sullage'). Urban storm water run-off is an important conduit of microbial pathogens and other hazardous substances, and has the potential to disseminate diseases quite widely given that the destination of much of the urban storm water is the nearest river or other watercourses such as lakes, marshes and wetlands (Neil et al. 2014). Figure 3.9 shows the percentage of the global population with access to improved sanitation. Sub-Saharan Africa falls within the lowest percentage band.

3.5.5. Coastal and marine environment

The coastal zone has come under immense pressure due to population increase, among other factors. As much as 40 per cent of the world's population lives within 100 km of the coast, resulting in substantial development pressure for infrastructure, housing and roads, among others (Hewawasam 2002). Population increase in the coastal zone results in a high amount of waste generated with concomitant pollution of the coastal and marine ecosystems. Also, the contaminative effect of increasing technological development and industrialization has been known to disrupt and destroy the fragile coastal ecology via indiscriminate discharge of industrial and municipal waste into coastal waters and the sea (Sawant and Bhave 2014). Despite the substantial progress made in reducing fuel oil contamination, persistent organic pollutants and radioactive substances in the coastal and marine environment (UNEP/Global Programme of Action [GPA] 2006), other problems have grown worse. Physical alteration and destruction of habitats, nutrient over-enrichment, marine litter and untreated wastewater discharge are the four problems identified for priority action (UNEP/GPA 2006). Increased nutrient load to coastal and marine waters leads to increased phytoplankton productivity. Algae and autotrophs use up oxygen and begin to die off. Aerobic decomposers

Box 3.6. Wastewater discharge on coral reefs

Run-off and sewage discharges from tourist resorts can have serious adverse impacts on coral reef communities. These impacts result from both the contaminants contained in the discharges and from the freshwater carrier itself. Of the many components of sewage, the nutrients nitrogen and phosphorus appear to have the most severe adverse impacts. The main effects of nutrients on corals appear to be indirect. The higher nutrient levels result in increased algal growth, which can ultimately lead to complete destruction of the delicately balanced coral reef ecosystem. The available evidence implies that denitrification and phosphorus removal are necessary treatment requirements if acceptable levels (after dilution) of these components are to be achieved (Hawkins and Roberts 1992).

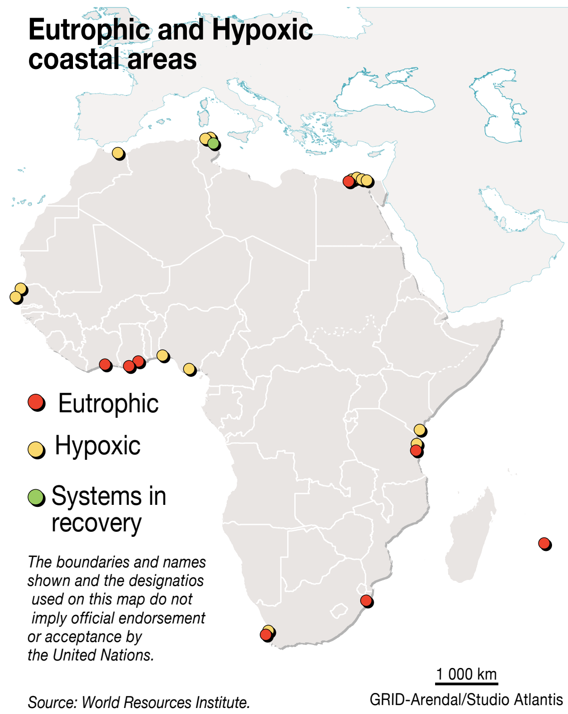

Figure 3.10. Eutrophic and hypoxic coastal areas of Africa

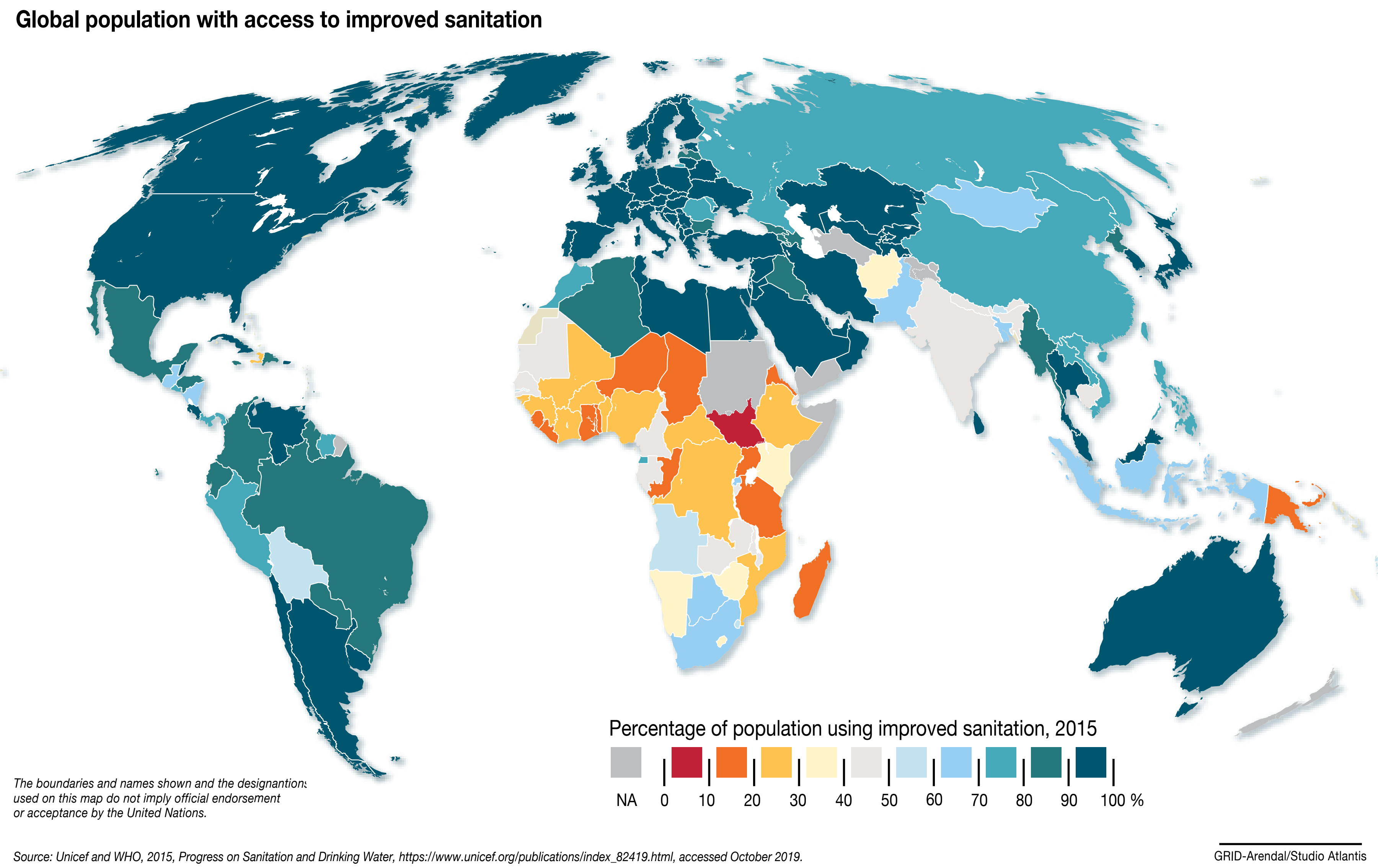

Figure 3.9. Percentage of global population with access to improved sanitation (2015)

(bacteria) multiply and use up even more oxygen. As a consequence, the entire water column is devoid of oxygen (a phenomenon known as 'hypoxia'), causing aerobic organisms (for example, fish) that rely on oxygen to die. Figure 3.10 shows eutrophic and hypoxic coastal areas of Africa.

There is rising concern over the increasing damage and destruction of essential and economically important coastal ecosystems like mangrove forests, coral reefs and seagrass beds. The number of oxygen-deficient 'dead zones' has doubled every decade since 1960, with the rise linked to nutrient run-off (nitrogen and phosphorus) originating from sources like farming and animal waste (Mehta et al. 2015). Nutrient over-enrichment has also triggered toxic algal blooms in different offshore waters of the world (Lam and Kuypers 2011). Despite national and international efforts to reduce marine litter, this problem has steadily grown worse. Around 70 per cent of marine litter ends up on the seabed, 15 per cent on beaches and a further 15 per cent is floating (Macic et al. 2017).

3.5.6. Wetlands

Wetland ecosystems provide a variety of services vital for human well-being. They serve a number of purposes, including water purification, water storage, climate regulation, flood regulation, coastal protection, recreational opportunities, processing of carbon and other nutrients, stabilization of shorelines, and support of plants and animals (Millennium Ecosystem Assessment 2005). Wetland systems are directly linked to groundwater and are crucial regulators of both the quantity and quality of water found below the ground. Groundwater, often recharged through wetlands, plays an important role in water supply, providing drinking water to an estimated 1.5–3 billion people (Millennium Ecosystem Assessment 2005). The ability of wetland systems to store or remove nutrients and to trap sediment and associated metals is highly efficient and effective but each system has a threshold. An overabundance of nutrient input from fertilizer run-off, sewage effluent or non-point pollution will cause eutrophication. The capacity of wetland vegetation to store heavy metals depends on the particular metal, oxygen and pH status of wetland sediments and overlying water, water flow rate ('detention time'), wetland size, season, climate, type of plant and other factors.

Wetlands filter and clean water through physical (e.g. sedimentation and sorption), chemical (including absorption and oxidation) and biological processes (mostly uptake by macrophytes). They slow down the flow of water so that any sediment in the water settles, thereby clarifying the water. Therefore, water flowing through a wetland area may be considerably cleaner upon its exit from the wetland. Some wetlands have been found to reduce the concentration of nitrate by more than 80 per cent (Millennium Ecosystem Assessment 2005). However, wetlands can become 'hotspots' of contamination – waste can build up to concentrations high enough to have detrimental effects on wetland functions. Unfortunately, the threshold between where pollution loadings are tolerated and where they will do damage to wetlands is not easily determined. As a consequence of pollution, the capacity of many wetlands to provide clean and reliable sources of water has been reduced.

Wetlands are increasingly being destroyed at a fast rate in several parts of Africa. For example, about 60 per cent of South Africa's wetlands have been destroyed or degraded as a result of indiscriminate ploughing and overgrazing, application of chemicals and fertilizers, damming and the removal of vegetation (Kulani 2006). The Niger Delta in Nigeria – one of the largest, most important wetland systems in the world – has experienced severe environmental degradation due to the extraction of natural resources. Additionally, residents who depend on the deteriorating wetland now struggle to earn basic living amenities (Adam 2016). The wetlands of Lake Chad continue to disappear due to drought and intensified anthropogenic use. Concern for life extends not only to the migratory birds which seasonally inhabit the area or the various flora and fauna found among the shallow lake, but also to the livelihoods of the local people, located on the borders of Cameroon, Chad, Niger and Nigeria. The Lake Chad Basin Commission (LCBC) regulates and controls the resources of the area and is actively seeking new methods of water management to restore the lake to normal levels. The LCBC explains that the significant decrease in the water flow will require new management techniques that promote efficient use, with additional research to find new sources of freshwater for the region (Food and Agriculture Organization of the United Nations [FAO] 2009).

A degraded wetland in Uganda

Box 3.7. Nature-based purification of wastewater

Wetlands only cover about 2.6 percent of the planet but play a disproportionately large role in hydrology. They have a direct impact on water quality by filtering toxic substances from pesticides and from industrial and mining discharges. Natural wetlands, woodlands (also called 'riparian forests'), and manmade or constructed wetlands, which are freshwater ecosystems, filter out pollutants including metals, sediments, nitrogenous compounds, oils and viruses that make their way into freshwater sources. Wetlands are able to eliminate 20–60 percent of metal, 70–90 percent of nitrogenous compounds and 90 percent of sediment from freshwater sources (Mitsch et al. 1999). Wetlands reduce the incidence of flooding by absorbing and hindering the movement of floodwaters towards nearby residential areas. Wetland ecosystems also serve as habitats for microbes, flora, fauna and migratory birds and vary in type from saline coastal lagoons in West Africa to fresh and brackish water lakes in East Africa (Schuijt 2002). However, ecosystems alone cannot perform the totality of water treatment functions. They cannot filter out all types of toxic substances discharged into water and there is a limit to their capacity. There are tipping points beyond which the negative impacts of contaminant loading to an ecosystem becomes irreversible, hence the need to recognize thresholds and manage ecosystems accordingly.

As previously noted, there are natural limits to the assimilative capacity of wetlands, beyond which they are threatened and can no longer perform a purifying role. Once the concentration of contaminants in run-off reaches critical thresholds, there is a risk of abrupt and irreversible environmental change (Steffen et al. 2015; UN-Water 2017). From this perspective, several degraded wetlands are unable to filter out contaminants in wastewater before its discharge into water bodies. Although natural wetlands are used for wastewater treatment or disposal in some countries such as Uganda, more and more natural wetlands are weakened or diminished due to increasing pollutant loads (Maclean, Boar and Lugo 2011).

The extensive degradation of existing wetlands further highlights the need for protecting remaining natural wetlands through better sanitary practices and improved wastewater management to protect human and ecosystem health. This means more household and industrial wastewater has to be treated before it is discharged into the aquatic ecosystem. This way, the assimilative capacity will not be exceeded and wetlands can continue to play their purifying roles.

3.6 Contaminants of Emerging Concern

Wastewater can be a source of emerging contaminants and can adversely affect the health of aquatic ecosystems and other environmental media. Such emerging contaminants are derived from pharmaceuticals, personal care products, household products, industrial and agricultural chemicals, microplastics and microfibers. Pharmaceutical waste in the environment arises from manufacturing sites, hospital waste, excretion by livestock treated with antibiotics, growth promoting agents and flushing of old and unwanted prescriptions. The increasing occurrence of active pharmaceutical ingredients in aquatic environments adversely affects living organisms on different organizational levels and alters the ecological function of rivers and lakes (Rzymski, Drewek and Klimaszyk 2017).

Household products such as organic waste and detergents, and industrial and agricultural chemicals such as fertilizers, pesticides, biosolids and manures are hazardous waste, mostly released directly into the environment through a range of point and non-point sources. Other sources of hazardous waste include oil exploration and mining activities. Detrimental effects of wastes on aquatic biota are evident at all levels (molecular, cellular, tissue, organ and ecosystem levels), depending on the magnification of the hazardous substance in fresh and marine waters and its accompanying biota, including sediments. For example, at certain concentration levels, substances with endocrine disrupting properties have been shown to impair reproduction in fish and shellfish, raising concerns for their fertility and population survival. Organochlorines have also had impacts on sea birds and marine mammals. Such impacts diminish the services provided by aquatic ecosystems, and consequently the returns derived from them (Greenfacts 2017). The effects of household products on aquatic biota are normally minimal but may accumulate or magnify over time.

Centralized treatment plants receive wastewater through a network of pipes

Box 3.8. Methemoglobinemia

Methemoglobinemia is characterized by reduced ability of the blood to carry oxygen due to reduced levels of normal haemoglobin. Infants are most often affected: they may seem healthy but show signs of blueness around the mouth, hands and feet, hence the common name 'blue baby syndrome'. These children may also have trouble breathing and may also experience vomiting and diarrhoea. In extreme cases, there is marked lethargy, an increase in the production of saliva, loss of consciousness and seizures. Some cases may be fatal.

In the body, nitrates are converted to nitrites. The nitrites react with haemoglobin in the red blood cells to form methaemoglobin, affecting the blood's ability to carry enough oxygen to the cells of the body. Bottle-fed infants less than three months of age are particularly at risk. The haemoglobin of infants is more susceptible and the condition is exacerbated by gastrointestinal infection. Older people may also be at risk because of decreased gastric acid secretion.

Controlling nitrate levels in drinking water sources to below around 50mg/litre is an effective preventive measure (WHO 2013).

There is scientific evidence that many chemicals recognized as emerging pollutants can potentially cause endocrine disruption in humans and aquatic wildlife, causing birth defects and developmental disorders and affecting fertility and reproductive health, even at very low concentrations (Poongothai et al. 2007). They also have the potential to cause cancerous tumours and the development of bacterial pathogen resistance, including multi-drug resistance (UN-Water 2017).

Emerging pollutants are found in varying concentrations in treated and untreated municipal wastewater, industrial effluents and agricultural run-off that seeps into rivers, lakes and coastal waters (UN-Water 2011). They have also been detected in drinking water (Raghav et al. 2013), as conventional wastewater treatment and water purification processes are not effective in removing them. Advanced wastewater treatment technologies (membrane filtration, nanofiltration, ultrafiltration and reverse osmosis) can partially remove some chemicals and pharmaceutically active compounds. However, these treatment technologies are costly and most developing countries cannot afford them (González et al. 2016).

Box 3.9. Hazardous substances

Hazardous substances are chemical substances that are either toxic (poisonous), reactive (capable of producing explosive or toxic gases), corrosive (capable of corroding steel), or ignitable (flammable). If improperly treated or stored, hazardous substances can pollute the environment.

Contamination of water resources by hazardous substances harms living organisms and ecosystems. It harms human health through bioaccumulation, contamination of public water supply and recreational use of contaminated water resources. In higher concentrations, they kill fish and shellfish in the lakes, reservoirs, rivers and ocean waters. The contamination of water and soil can hinder the growth of agricultural products and the contaminants can accumulate in the products.

Agricultural chemicals are one class of hazardous substances that cause contamination. These are organic chemicals that include organochlorine compounds. They are extremely toxic and when humans are exposed to them, they can suffer from internal and neurological diseases. They include many substances that are suspected of being carcinogens or mutagens. Because agricultural chemicals are generally highly soluble, they contaminate the environment by seeping into the ground with rainwater, while those on the ground's surface can be transported into river by rainwater (Engelking 2009).

3.7 Efforts at Reducing Ecosystem Health Risk Through Wastewater Treatment

Ecosystems impacted by discharge of untreated wastewater and human excreta have less capacity to provide a number of important services on which humans rely. In South Africa, it has been reported that more than two-thirds of the wastewater treatment facilities examined did not meet the minimum quality-control standards. In South Africa, fish death as a result of the negative impacts of wastewater on ecosystems has been reported in the Vaal – a major river – and the Vaal Dam, into which untreated sewage is discharged. This highlights the need for wastewater treatment.

Several countries in Africa including Egypt, Morrocco, Namibia, South Africa and Tunisia are relatively advanced as regards practising wastewater reuse or having wastewater treatment plants that produce safe effluent (Bahri, Drechsel and Brissaud 2008). Wastewater has been reclaimed for potable use in Windhoek, Namibia (Box 3.12). However, in many other countries on the continent, urban wastewater is either untreated or partially treated before discharge into water bodies. This is due to a lack of – or simply partially functioning – WWTPs.

It has been estimated that 90 per cent of untreated wastewater in Africa is released directly into rivers, lakes and oceans (UN-Water 2017). Challenges facing the WWTPs include insufficient technical capacity to cope with increased wastewater load due to population increase, pollution load variation caused by uncontrolled discharge into the sewage network and power cuts where treatment processes require energy (Nikiema et al. 2011). The most significant challenge is funding wastewater treatment plants. In developed countries, a lot of money is invested in wastewater treatment and in designing and building systems for wastewater collection. However, this is not the case for many African countries because collection and treatment of wastewater is less prioritized and obtaining funding is also a challenge (Grayson 2013).

Fish death as a result of the negative impacts of wastewater on ecosystems

3.8 Ecosystem Health Risk Reduction and SDG 6

3.8.1. Use of value-recovery technologies or principles

If regarded as a resource, wastewater can be treated, recycled and reused to minimize its adverse effect on the ecosystem and the health of humans. This will result in improved water quality by drastically reducing the proportion of hazardous chemicals and materials that end up in the water bodies, thus contributing towards achieving SDG 6: ensuring availability and sustainable management of water and sanitation for all.

Well managed wetlands have the capacity to absorb some pollutants

Table 3.3. Opportunities and challenges associated with source-separated domestic wastewater

Waste stream	Opportunities	Challenges
Urine	Nutrient recovery (nitrogen, phosphorus, potassium)	Heavy to transport mechanically: risk of precipitation and clogging when transported in pipes; ammonia evaporation and odour
Faecal matter	Energy (biogas) production; soil amendment	Small volumes produced per person; transport and logistics may be difficult; high pathogen levels; odour
Blackwater (flush water, urine and faeces) or brownwater (flush water and faeces with no urine)	Energy (biogas) production; nutrient recovery; soil amendment; will flow under gravity	Amount of water affects transport (clogging) and energy production value; pathogens; odour
Greywater (water used in shower, bath, handwashing, dishwashing and laundry)	Heat recovery; water recovery	Treatment required to prevent regrowth of bacteria; generation of parallel products (sludge and foam); impact of salinity and chemicals on soils; source separation; pathogens; odour
Faecal sludge (sludge collected in on-site systems, containing excreta and possibly other waste)	Soil amendment; fuel source	Collection and transport; identifying institutions responsible for management; pathogens; odour

Source: Adapted from Tilley (2013).

There are different options available to reduce wastewater contamination. Wastewater can be reduced in volume and can also be treated to remove pathogens and pollutants that make it hazardous. Additionally, it can become a source of energy, plant nutrients and other agricultural inputs, as well as a source of water and many other valuable resources, bringing sizeable economic, social and environmental benefits, as inferred from Table 3.3.

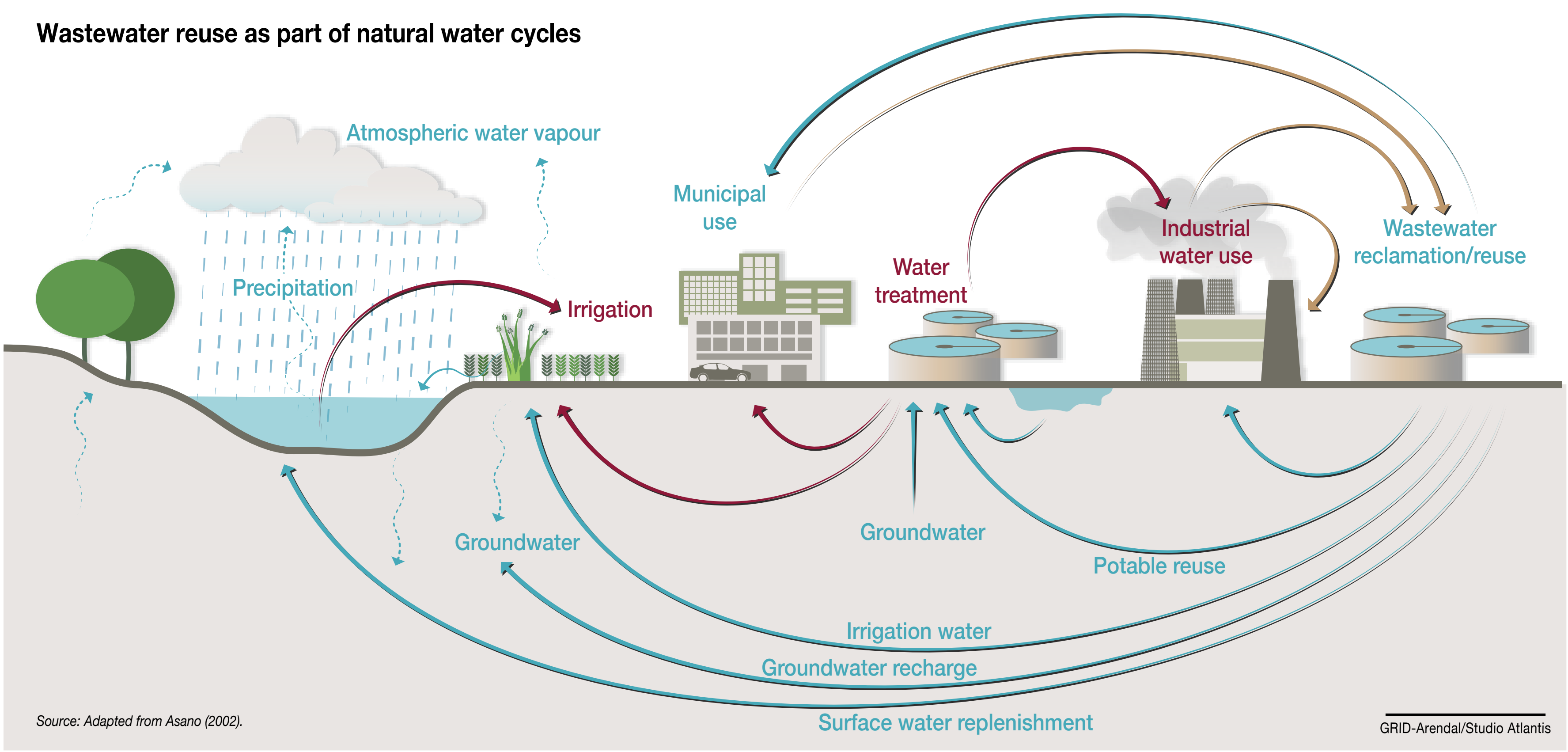

Figure 3.11. Wastewater reuse as part of natural water cycles

3.8.2. Managed aquifer recharge through wastewater reinjection: The case of Atlantis, South Africa

The South African model of storm water and wastewater injection into aquifers provides an opportunity for other African countries to adopt this technology. Indirect recycling of storm water and treated wastewater for potable purposes has formed an integral part of the Atlantis Water Resource Management Scheme for the past 30 years (Bugan et al. 2016). This augments the limited natural groundwater supplies along the semiarid west coast, north of Cape Town. Figure 3.13 shows the sequence of operations of the Atlantis Water Resources Management Scheme.

The Atlantis model is based on artificial groundwater recharge as a water management tool for bulk water supply in southern Africa. This involves management of large volumes of storm water from urban areas aimed at controlling impacts on surface water. Managed aquifer recharge ensured the sustainability of the Atlantis groundwater supply over more than two decades and will continue to play a key role. Indirect recycling of storm water and treated domestic wastewater via the aquifer as a means to augment supplies has been adopted by the public. The various processes for wastewater treatment of the Atlantis Water Resources Management Scheme are shown in Box 3.11. The groundwater scheme provides a cost-effective water supply option when coupled with strict management of the resource.

Wastewater reclaimed for use in agriculture

Box 3.10. Wastewater reclamation for potable use in Windhoek, Namibia

Windhoek in Namibia is home to the world's longest operational wastewater reclamation plant. The scheme has been in operation since 1968 and was previously known as the Goreangab Water Reclamation Plant (GWRP). Prior to this, reuse of sewage effluent in Namibia had only been considered for supply to power stations, an idea which was never implemented. An integrated number of factors led the water utility in Windhoek to seek other alternatives to meet water demand. These factors included rising population growth, a significant decline in annual rainfall and increased evapotranspiration. With the lack of perennial rivers in Windhoek and the impractical costs of water transportation from other regions, wastewater effluent was again considered, but this time for potable purposes. The GWRP was commissioned to implement a solution and after rigorous pilot testing (1960–1968), in 1968, secondary treated sewage effluent was reclaimed, blended with dam water and added directly into the city's water supply to meet up to 12 percent of the daily demand (Van 2016).

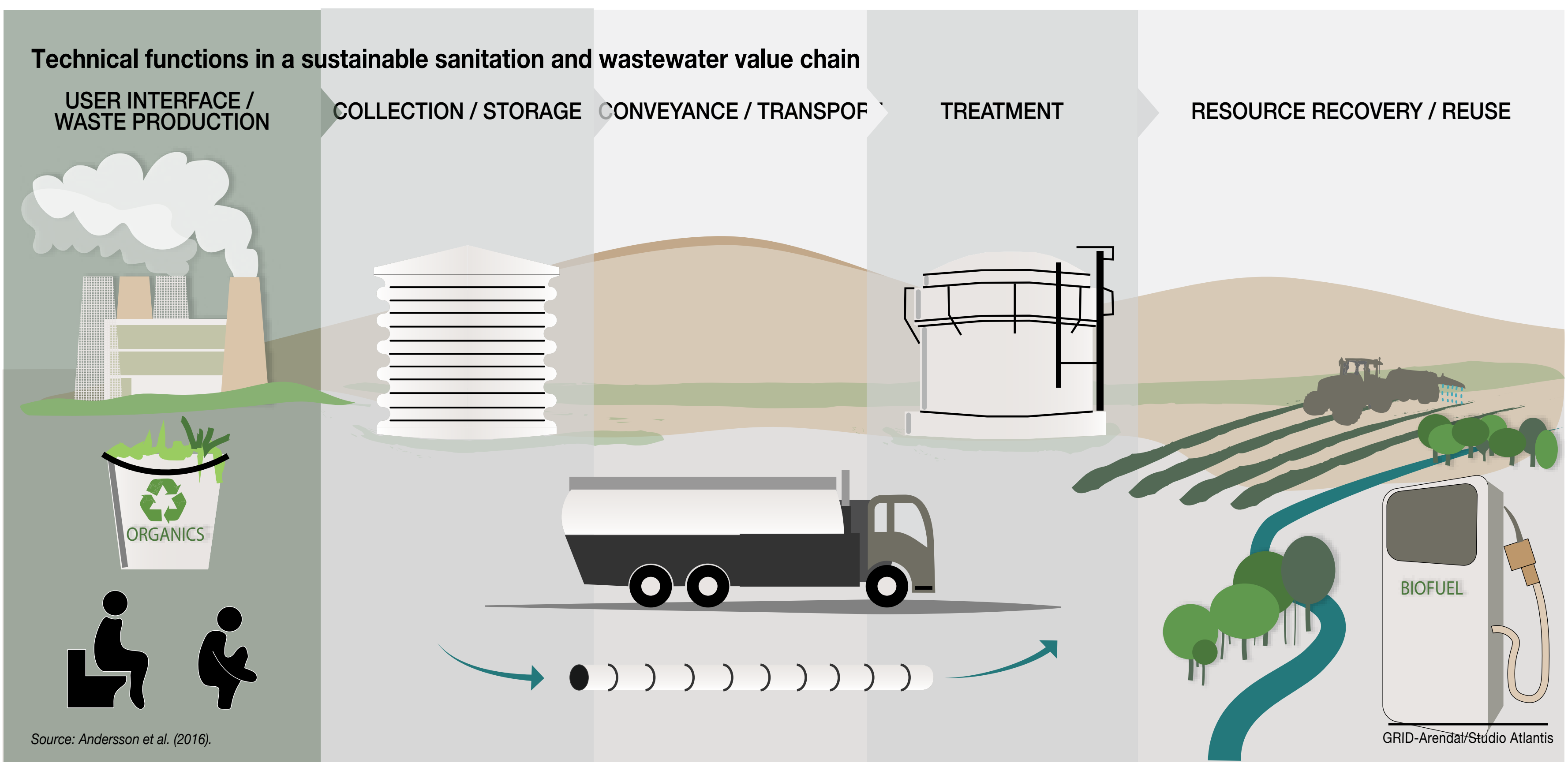

Figure 3.12. Technical functions in a sustainable sanitation and wastewater value chain

Box 3.11. Storm and wastewater recharge of the aquifer in Atlantis, South Africa

The large volumes of storm water run-off that would be generated after urbanization and the associated hardening of surfaces was seen as a valuable water source for augmenting water supplies and it prompted the construction of a storm water collection system. This consists of 12 detention and retention basins and the necessary interconnecting pipelines with peak flow reduction features. The storm water system at Atlantis was designed with the flexibility to control water flows of differing salinity and to collect the best quality water for infiltration into the aquifer.

Initially, all wastewater was treated in a single wastewater treatment plant and all the treated effluent was used for artificial recharge. In 1986, this practice was discontinued due to water quality considerations and separate treatment plants were constructed for domestic and industrial wastewater treatment. These came online in the mid-1990s. The domestic wastewater undergoes full secondary treatment with nitrification-denitrification steps (anaerobic-anoxic-aerobic). The effluent from the secondary settling tanks is polished in a series of maturation ponds (see Figure 3.14 below). The maturation pond effluent is blended with the urban storm water run-off before discharge into the main recharge basins.

Source: Tredoux et al. (2009).

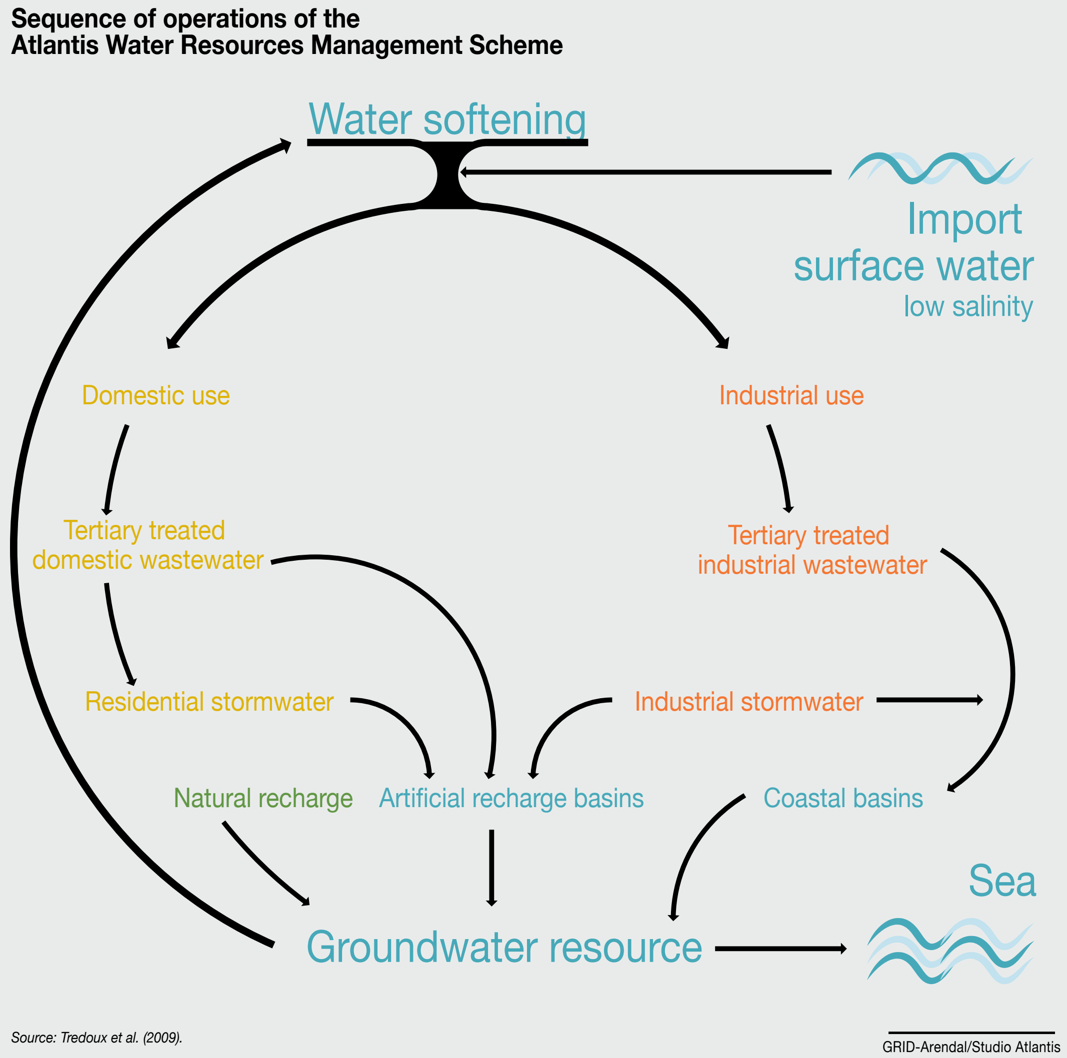

Figure 3.13. Sequence of operations of the Atlantis Water Resources Management Scheme

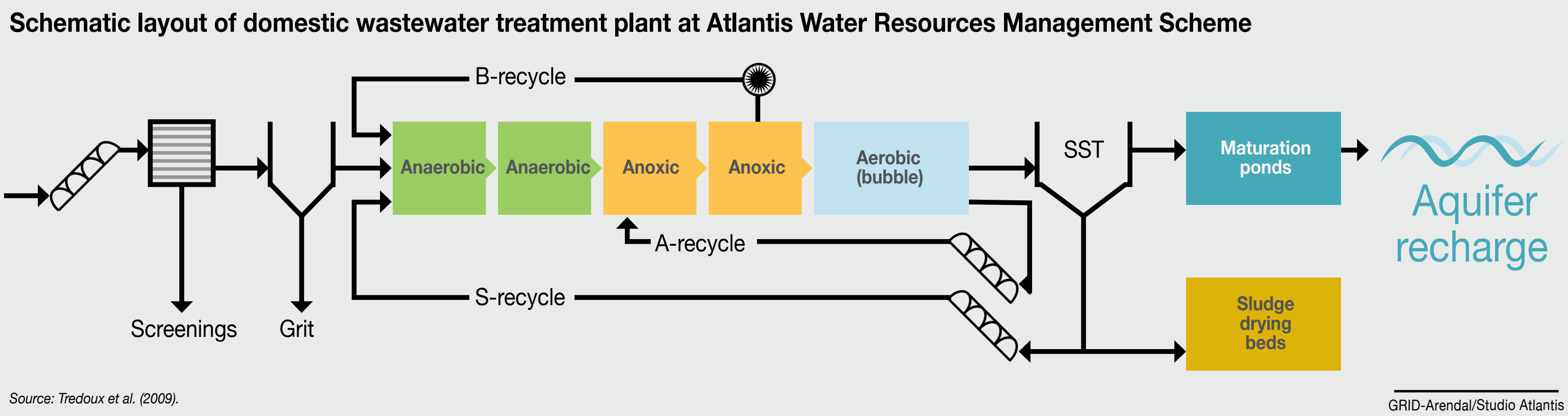

Figure 3.14. Schematic layout of domestic wastewater treatment plant at Atlantis

3.9 Conclusion

Ecosystems provide types of essential services that are necessary to maintain optimal ecosystem health, including provisioning, regulating, supporting, and cultural (Millennium Ecosystem Assessment 2005). Although wastewater is an important source of essential nutrients for plants, many environmental, sanitary and health risks are also associated with the use of wastewater for crop irrigation due to the presence of toxic contaminants and microbes (Khalid et al. 2018).

Wastewater management – or lack of it – has a direct impact on the biological diversity of aquatic ecosystems. It can disrupt the integrity of these ecosystems by negatively affecting their capacity to provide ecosystem services. This underscores the need for its treatment and reuse. Wastewater is an important resource that can be used to recharge aquifers and reduce water scarcity. However, it contains components that have negative effects on ecosystems.

Wastewater treatment will make a substantial difference to the health of key ecosystems, including rivers, lakes, soil, groundwater and wetlands. Substantial investment is needed to help improve the health of ecosystems on the African continent to protect the important ecosystem services they provide. If regarded as a resource, wastewater can be treated, recycled and reused to minimize its adverse effect on the ecosystem and the health of humans. This will result in improved water quality by drastically reducing the proportion of hazardous chemicals and materials that end up in the water bodies; thus contributing to achieving SDG 6: ensuring availability and sustainable management of water and sanitation for all. The integration of wastewater into the natural water cycle should be encouraged and more resources should be invested into WWTPs and into the protection of freshwater ecosystems such as wetlands.

A healthy ecosystem can provide for both wildlife and people