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Review

Another decade of water quality assessment studies in Tanzania: Status, challenges and future prospects

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Increased population pressure and environmental stressors have amplified research on water quality both locally and globally. In Tanzania, water quality assessment is a mature discipline, with an over four-decade history. In this article, studies on water quality assessment in Tanzania from 2006 through 2016 are reviewed. The approach used is to scan selected publications to gather data and information on types and concentration levels of contaminants measured in surface and ground waters; their status, trends and potential health risks. The aim is to establish research gaps that call for further investigations and factors that hinder such efforts so as to provide insight that can facilitate future studies. Significant outputs were found in terms of study focuses and investigated locations. Lack of analytical facilities, complexity in the interpretation of toxicological data and data management practices represent major setbacks, while land-use practices, sea water intrusion, climate change and biogeochemical features continue to the scale-up threat on surface and ground water quality in the country. It is pragmatic that there is still a gap in research on such subjects as effects of climate change; effects of mixed toxicity of chemicals; risk characterization; analysis of emerging contaminants of concern and development of remediation plans for specific contamination problems. Some strategies towards ameliorating the challenges are suggested. The study puts forwards some recommendations, including the establishment of a National Water Quality Assessment Programme that will provide central water quality descriptions of the nation water resources.

Key words: Water quality assessment, contamination status, analytical challenges, Tanzania.

INTRODUCTION

Assessment of the quality of surface and ground waters has remained one of the major interests of environmentalists, scientists, policy makers and regulatory authorities, locally, regionally and globally. Poor water quality is directly associated with inadequate water supply, health risks and effects to aquatic life (Tiwari et al., 2017; Tiwari et al., 2016; Mahato et al., 2016; Myers, 2015). Water quality assessment is the overall process of evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and

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its suitability for intended uses (Chapman, 1996). The aim is to define the condition of the water so as to provide the basis for detecting trends and to provide information enabling the establishment of the cause-effect relationship. It involves a programmed process of sampling, measurement and subsequent recording or signaling, or both, of various water characteristics, often with the aim of assessing conformity to specified standards (WHO, 2004). The activities can be differentiated as long-term, short-term and continuous.

A complete assessment of water quality is based on three components, namely hydrology, biology and physico-chemical. The hydrological aspect deals with how the water movement through its endless circulation affects its quality. Water is studied as an element of the landscape together with its interaction with the environment. It seeks to explain the water balance in terms of flow, direction, discharge, time and space (Jing et al., 2017). The biological aspect deals with the presence of microbial organisms and water-borne pathogens. It aims at achieving a water quality standard that will not harm aquatic organism and is safe for human consumption. This can be carried out in terms of the response of individual species or biological communities to changes in their environment. The physico-chemical aspect of water, normally measured by suitable analytical methods, studies the physical and chemical characteristic of water that is determined by different factors such as climatic conditions, the local geology of the area, soil cover, land use practices and others (Gordalla, 2011). Comprehensive water quality assessment is, therefore, a complex endeavor and involves multiple factors, for example, determination of the hydrological, biological and physicochemical characteristics can be carried out in the field or in the laboratory using varieties of methods and combinations of methods to produce a wide range of data. The key elements include preliminary surveys; field sampling; shipment of samples; analysis of targeted chemical and biological species; determination of other key variables; data analysis and data interpretation.

Globally, water quality assessment has a long history; in the earlier decades, systematic water quality assessment was only known in the industrialized countries, where the main water quality issue of concern was feacal as well as metal pollution (Jing et al., 2017; Tiwari et al., 2015). The assessment was therefore mostly on the biological aspect and was solely for the purpose of diseases prevention (Trudgill et al., 1999). However, with modern discoveries, technological advancements and realization of new concerns, there have been significant changes, new developments and paradigm shifts. Water quality assessment is now a well-known body of knowledge and includes aspects of preservation of the entire systems, together with the diverse groups of endangered species of natural or pristine conditions making up the whole aquatic ecosystem. This paper is based on thorough review of publications, including research papers, government reports from various departments and consultancy reports. The aim is to develop a comprehensive picture and provide an overview of the status, new developments and existing challenges so as to put forward some recommendations.

STUDY AREA

Geographical setting and climatic condition

Tanzania is one of the East African countries, located between Latitude 1° and 12° south and Longitude 29° and 41° east. It is bordered by Kenya and Uganda on the north; Mozambique, Zambia and Malawi on the south; Rwanda, Burundi and Democratic Republic of Congo on the west and by the the Indian Ocean on the east. It has a total area of about 945,000 km^2, of which about 886,000 km^2 is land that includes three major coastal islands of Mafia, Pemba, and Zanzibar and a coastline that is about 800 km long; and 59,000 km^2 is surface water. The country's landscape is characterized by a wide variety of topography, including large freshwater and salt water bodies, the East African Great Rift valley, narrow coastal plains, savannah landscape, steppe landscape and tropical forests. The northeast part of the country is mountainous and includes Mount Meru, Mount Kilimanjaro, and the Usambara and Pare mountain ranges. The eastern part is the coastal strip that is rich in biodiversity, including mangrove swamps.

The Tanzanian climate is mainly tropical but varies widely according to topography. Temperatures rarely fall lower than 20°C except in the highlands and may reach above 31°C during the hottest periods of the year in some parts. The country has seasonal rainfalls where the north and east part experience two distinct wet periods; the short rains "Vuli" in October to December and the long rains "Masika" from March to May; while the southern, western, and central parts of the country experience one wet season that continues October through to April or May. Figure 1 is the map of Tanzania showing climatic classification.

Water resources

Tanzania has abundant surface and groundwater resources, including wetlands, natural streams, rivers and lakes, including nine water basins. Among the Tanzanian water basins are the Rufiji River Basin (177,000 Km^2) which is the largest, followed by Ruvuma (53,330 Km^2) and Pangani (43,650 Km^2). Others are Wami-Ruvu, Lake Tanganyika, Lake Victoria, Lake Nyasa, Lake Rukwa and the internal drainage basin. Figure 2 is the map of Tanzania showing the major water bodies. Tanzania

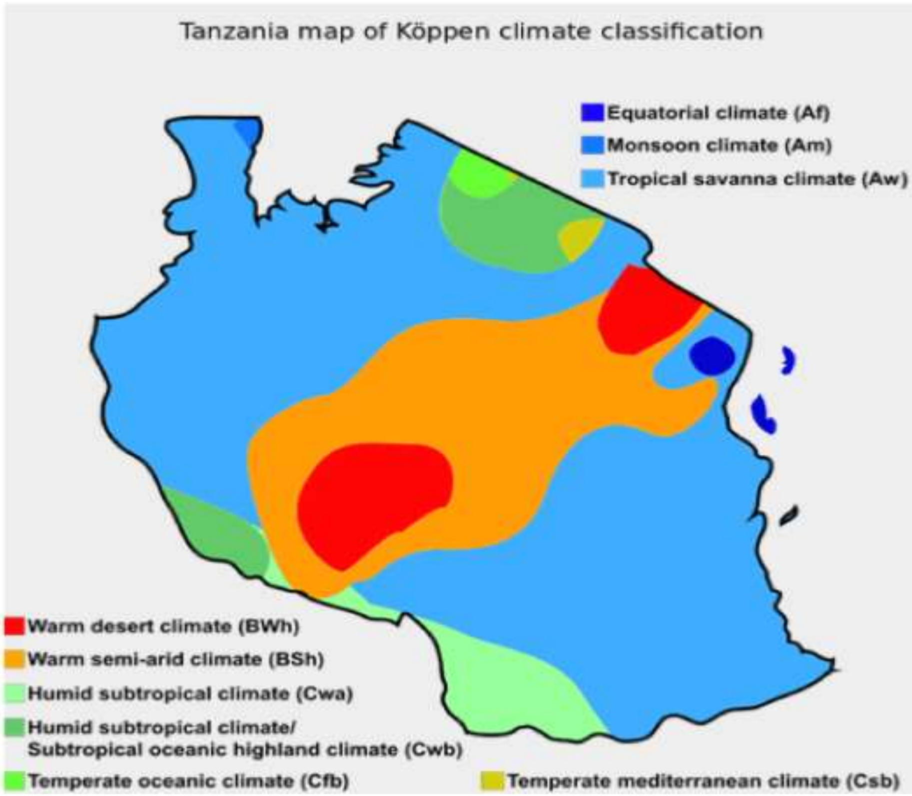

Figure 1. Climatic classification of Tanzania. Source: Ali Zifan (Enhanced, modified, and vectorized). - Derived from World Koppen Classification.svg., CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=47085579.

shares all the great lakes in east Africa with the neighboring countries, these including Lake Victoria, Lake Tanganyika and Lake Nyasa/Malawi. Additionally, the country shares major trans-boundary rivers with the neighbors including rivers Kagera and Mara (Kimaro, 2010).

Studies indicate that the contribution of ground water potential to total water resources is not well documented (Kashaigili, 2010). Groundwater resources are mainly used in the form of shallow wells for domestic purposes over a wide part of the country, mainly rural areas. They are also commonly used in the peri-urban suburbs where there is no distribution network and in places with unreliable supply. Most boreholes are located in the internal drainage basin. However, there have been concerns that the rapid increase in the use of shallow wells may lead to an increased risk of groundwater contamination from pit latrines in such locations (Kashaigili, 2010).

Tanzanian is among the African countries with a high rate of population growth, its population is said to have quadrupled in the last 50 years (World Bank, 2014). The Tanzanian population was estimated at more than 51 million in 2016 (UNSD, 2017). The country depends on its surface and ground water resources for the provision of clean water, food and other livelihood resources to the population. Apart from that the surface water resources in Tanzania are contributing to the tourism sector, agriculture, power generation and industry. They are also essential as habitats for aquatic plants and animals. However, like most developing countries, the economic activities in industry, energy production, mining, agriculture and livestock keeping depend largely on these resources, exerting much pressure on them, including possible contamination by different kinds of micro-contaminants (Ngoye and Machiwa, 2004; Mtanga and Machiwa, 2007; Hellar-Kihampa, 2011).

Potential stressors of water quality

Among the key aspects that researchers put into considerations when planning for water quality assessment are what parameters to monitor, where to monitor and when to monitor. In studying the anthropogenic influences on water quality, researchers have been able to link different contaminants to specific categories of land-uses. For example, agricultural land-use, including

Figure 2. Map of Tanzania, showing location, administration regional boundaries, major rivers and water basins (Source: Elisante and Muzuka, 2015).

croplands, horticulture, gardening and livestock keeping, has been linked to the high concentration of nutrients (N, P), pesticide residues and enrichment of some major elements (Cl, Na, Ca, Mg) (Brodie and Mitchell, 2005). Urban land-use, including commercial, residential and transportation activities, has been associated with elevated concentrations of trace-elements (As, Cu, Cr, Zn, Cd, Mn, Pb, Ni and V) and enrichment of nutrients (NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, SO_4^{2-}) both in water and sediment (Fitzpatrick, 2007). Mining and smelting activities have been linked to heavy metal pollution, especially As, Hg, Zn and Pb (Mataba el at., 2016).

Studies have shown that in the Sub-Saharan Africa countries including Tanzania, water contamination is caused by a number of stressors, including land-use practices. It has further been indicated that the extent of water contamination might be compounded by pressures from structural adjustment programmes launched in response to economic crises, over-exploitation of natural resources, lack of state control and lack of proper enforcement of environmental regulations (Nyenje et al., 2010).

According to the National Environmental Policy of Tanzania (NEP), the major environmental challenges of Tanzania include lack of accessible, good quality water for both urban and rural inhabitants; pollution; loss of wildlife habitats and biodiversity. Others are deterioration of aquatic systems and loss of land-cover. The National Environmental Policy further stipulates that the productivity of lake, river, coastal and marine waters in the country are threatened by pollution and poor management. Human activities in towns and the country-sides are said to have affected the health of many surface water bodies, and lowered the productivity of the environment in general (NEP, 1997).

Both surface and ground waters are under a threat of contamination from different sources of stressors, including agricultural activities, industrial activities, transportation, mining, urban settlements and even rural settlements. Agriculture is the main land use sector in the country. It is estimated that more than 13 million hectares of land are being cultivated. This is however only 33% of the total arable land in the country (Tanzania Agriculture, 2017). Among the main food crops in Tanzania are maize, sorghum, millet, rice, wheat, beans, cassava, potatoes and bananas, whereas main cash crops include coffee, sisal, cashew nut, tea, cotton and tobacco. At one point in history, Tanzania was the largest producer of sisal in the world. Agricultural products also contribute largely to the country's foreign exchange in terms of cash crop exports. Owing to this, the use of agrochemicals in Tanzania is widespread.

Studies conducted in various agricultural locations in the country revealed environmental contamination due to pesticide residues (Kishimba et. al., 2003). For example, the sugarcane plantations at Arusha Chini in Kilimanjaro region which have been operational since the early 1940s are one of the largest and oldest users of pesticides in the country (Mtambo and Katundu, 1996), with an over sixty years history of pesticide use. Analysis of surface waters collected close to the plantations has revealed contamination by different types of pesticide residues (Hellar and Kishimba, 2005). The country has also been a long time the chief producing area for the famous Arabica Coffee and flowers for export, both of them chemically intensive (Msogoya and Maerere, 2006). Studies have further established that pesticide management practices in the country, including storage, disposal of empty containers and disposal of obsolete pesticides are generally poor (Mwema and Sharp, 2016). This increases the risk of surface and ground waters contamination by pesticide and their residues. In other parts of the country such as the Lake Victoria basin, non-point source pollution from agricultural practices and unplanned urban settlements were found to affect the quality of water bodies (Machiwa, 2003).

Livestock keeping is another activity that poses contamination threat in the country, especially in the locations where households keep large numbers of cattle, goats and sometimes sheep. There some large concentration of pastoral communities, who are nomadic and depend on livestock for their livelihoods, moving constantly in search of water and pasture. Altogether, livestock keeping has been linked to the inputs of chemical species to the water sources worldwide (Hellar-Kihampa et al., 2013a).

Discharge of industrial effluents is another serious environmental issue of concern. The existing industrial activities, especially in main towns, include textile and garments, soap and detergents, agro-industries such as sugar, sisal, vegetable oil/fat refineries, dairies, breweries, cotton ginneries, distilleries, coffee processing; fruit canning and tanneries. Other important industries include paper and plastic production, fertilizer, cement, metal works, timber and bottled water production. Most of these industries are relatively small, but may cause pollution of surface and ground waters due to the large organic load and the use of some chemicals such as dyes. It has also been reported that at some locations, freshwater bodies are used as points of disposal for domestic wastes, including outlets of municipal waste water, a practice associated with pollutant loading into water (Mwegoha and Kihampa, 2010). Environmental challenges associated with wastewater management especially in urban centers in the country arise from haphazard and unplanned expansions of towns and cities, while municipal authorities or other utility service providers have limited resources. This has been indicated as a contributor to pollution of surface waters and deterioration of environmental quality (Kihampa et al., 2016).

Another potential source of contamination in Tanzania is mining activities. The country is rich in mineral deposits which include gold, diamond and tanzanite. Others include tin, phosphate and limestone. In some locations, there are uncontrolled mining activities that are considered as significant environmental risks due to the likelihood of contamination of freshwater systems, especially from toxic metals and poor sanitation of the mining camps (Macfarlane and Mitchell, 2003). Studies conducted close to the mining sites indicate different degrees of contamination by toxic metals and dispersion in environmental matrices including Hg and As, for example, the Mugusu and Rwamagaza artisanal mines in the Lake Victoria goldfields (Ikingura et al., 2006).

REVIEW OF WATER QUALITY ASSESSMENT STUDIES IN TANZANIA 2006 TO 2016

Study approach and objectives

The earliest records found in respect of water quality research in Tanzania were from the early 1970s (Mohamed, 2003), including those by Steinbach (1974). In the decade that followed, more water quality assessment studies were carried out in the country, including those by Mashauri and Mayo (1989); Kandoro (1997) and Mohamed (1997). Other studies conducted in the more recent past include those by Machiwa (2000), Ikingura and Akagi (2003), Kishimba et al. (2003), Ngoye and Machiwa (2004), among others.

The 2006 to 2016 decade is characterized by increased public awareness of environmental protection and concerns over public health. This is evidenced by the increase in the number of documented studies that investigated the quality of different types of water in the country, probably due to increased awareness on water quality issues, and also increased the availability of modern technologies for water quality assessment. For example, it was during this decade that Tanzania established its own water quality standards through the Tanzania Bureau of Standards (TBS, 2008). Some review articles have been written on the subject, including that by Byrceson et al. (1990) which featured the East African Region by Mohamed (2003) which featured studies conducted between late 1970s to late 1990s and by Elisante and Muzuka (2015) which featured occurrence of nitrate in ground water aquifers, among others. However, no review has been done on studies conducted in the most recent decade (2006 to 2016).

Findings from different studies

Some of the water quality assessment studies conducted in the country within the specified decade (2006 – 2016) are summarized in Table 1. The information includes types of parameters measured and types of water sampled; locations where the studies were conducted and summary of the key findings obtained.

The summary in Table 1 shows that researchers investigated different types of water in various locations to assess levels of toxic metals, inorganic contaminants, nutrients, bacteria, organic matter and physic-chemical parameters, among others. In all these studies, quality of water was found to be affected by different stressors related to human activities. For instance, the study by Mataba et al. (2016) investigated the distribution of trace elements in the aquatic ecosystem of the Thigithe River, the main community source of water for human and livestock consumption in over 15 villages of Ingwe division close to the Mara Gold Mine in Mara Region, north Tanzania. It was found that water was contaminated by the trace elements As, Cd, Co, Cr, Cu, Hg, Ni, Pb and Zn, even though their concentrations were below or near the detection limits.

The study by Mihale (2015) assessed levels of nitrogeneous (ammonia, nitrite and nitrate) and phosphate compounds in the Great Ruaha River water in response to natural and human pressures. High levels of ammonia and nitrite were observed in some locations with indications of the influence of land cover, land use, soil type and groundwater level. Phosphate levels were also high with indications of anthropogenic influences such as fertilizer applications. Nitrogen (N) and phosphorus (P) are essential for the growth of plants and animals, for this reason they are often identified as nutrients. However, when in excess concentrations in natural waters, the two may lead to what is known as ‘nutrients pollution’. This is among the leading causes of water degradation in rivers and lakes, both in the developed and developing the world (Leone et al., 2009).

Kihampa et al. (2016) found high levels of dissolved solids, nutrients, and toxic metals in urban rivers receiving treated industrial wastewaters in Dares Salaam city. It was revealed that poorly treated wastewaters contributed into contaminating the receiving waters. This was again observed in Kilimanjaro Municipality where treated wastewater used for fish raring was still contaminated with toxic metals Cd, Cr, Cu and Pb in levels that exceeded the TBS limits for metals in reclaimed wastewater used for aquaculture (Tarimo and Hellar-Kihampa, 2016). This indicates that the national standards for effluents discharge into rivers and streams are not enforced

The study by Hellar-Kihampa et al. (2013a, b, 2014) analysed a number of micro-contaminants, including toxic metals, inorganic ions, nutrients, pesticide residues and organic contaminants in the main Pangani River and its tributaries to determine the impacts of natural and anthropogenic influences. The results indicated a low level of contamination of river water by various diffuse sources, including applications of agro-chemicals in agricultural fields and livestock keeping. Although concentrations or organic contaminants detected are rather low, their mere presence in the water body is of particular environmental concern due to their persistent, toxic and bioaccumulative nature. Their lipophilic tendency, hydrophobicity and low chemical and biological degradation rates cause them to have high levels of

Table 1. Some water quality assessment studies in Tanzania 2006 - 2016.

Location	Water type	Parameter	Status	Reference
Thigithe River (North Mara Gold Mine)	Surface water	Trace elements	High levels of As and Hg in downstream site where artisanal mining is performed	Mataba et al. (2016)
Maji ya Chai River, Arusha	Surface water	Natural organic matter	Water quality influenced by precipitation and humic substances	Aschermann et al. (2016)
Dares Salaam City	Wastewater discharged into river systems	Nutrients and toxic metals	Poorly treated industrial effluents contaminate urban rivers with nutrients and toxic metals	Kihampa et al. (2016)
Mount Meru,	Ground water	Stable isotope compositions of nitrogen-nitrate and oxygen-nitrate and concentration of nutrients	80% of all water sources had nitrate concentration higher than background concentration of 10 mg/l	Elisante and Muzuka (2016a)
		Total coliform (TC), faecal coliform (FC), *Escherichia coli* (*E. coli*) and faecal streptococci (FS)	Ground water sources contaminated by bacteria due to the positioning of pit latrines, inoculation of microbes by exposed buckets and inefficiency of the casing material.	Elisante and Muzuka (2016b)
Great Ruaha River	Surface water	Nitrogen and phosphorus	High levels of ammonia and nitrite in some locations associated with anthropogenic activities	Mihale (2015)
Kilimanjaro Municipality	Wastewater	Toxic metals, nitrogen, and faecal coliforms	Concentrations of toxic metals in water released into the environment exceeded WHO limits	Tarimo and Hellar-Kihampa (2016)
Dares Salaam City	Ground water	Inorganic ions	Water quality influenced by seawater intrusion and anthropogenic inputs	Sappa et al. (2015)
Pangani River Basin	Surface water	Toxic metals	The presence of low levels of metal contaminants with concentration patterns indicating anthropogenic inputs.	Hellar-Kihampa et al. (2014)
Msimbazi River, Dares Salaam	Surface water	Industrial pollutants	Levels of Cr exceeding the Who and TBS standards.	Mwenda (2014)
Kinondoni District, Dares Salaam	Groundwater	fecal and total coliform bacteria	water samples from boreholes were contaminated with bacteria in quantities higher than the TBS limit	Kiangi (2014)
Pangani River Basin		Nutrients and inorganic ions	Inputs of nutrients (N-compounds) from human activities; levels of inorganic ions mostly indicate natural sources	Hellar-Kihampa et al. (2013a)
		Organic contaminants	Water samples contaminated by organochlorine pesticide residues from historical agricultural applications.	Hellar-Kihampa et al. (2013b)
South-eastern Tanzania	Surface water and groundwater	Isotopes and major ions	Elevated NO_3^- concentrations in a few shallow aquifer samples imply sewage infiltration from domestic wastewater.	Bakari et al. (2013)

Table 1. Cont.

Temeke District, Dares Salaam	Drinking water	Physico-chemical parameters	Significantly high levels of chloride exceeding the allowable WHO limit	Napacho and Manyele (2010)
Inter-tidal areas of Dares Salaam			Polycyclic aromatic hydrocarbon (PAH) contamination of surface sediments and oysters	Gaspare et al. (2009)
Mzinga Creek and Ras Dege, Dares Salaam	Mangrove ecosystem	Toxic metals	Low levels of Cd, Cr, Cu, Hg, Pb and Zn in water, suspended particulate matter and oysters. Contributed by industrial and agricultural activities and transportation activities in the nearby Dar es Salaam port	Mtanga and Machiwa (2007)

accumulation in the environment and long-term implication to the ecosystems (Minh et al., 2007).

Kiangi (2014) investigated the quality of domestic water obtained from boreholes in some wards of Kinondoni District in Dares Salaam, focusing on fecal and total coliform bacteria and some physic-chemical water quality parameters and compared them to the WHO guidelines and TBS standards. The obtained results indicated that the water samples from boreholes were contaminated with bacteria in population higher than the TBS and WHO limits. Napacho and Manyele (2010) investigated the quality of drinking water from different sources in Temeke District in Dares Salaam. The sources examined included tap water, river water and well water (deep and shallow wells). The study revealed that some of the physico-chemical parameters in water samples did not meet the permissible World Health Organization (WHO) and the Tanzania Bureau of Standards (TBS) levels. Chloride levels were found to be significantly higher than the allowable WHO limit.

CHALLENGES AND FUTURE PROSPECTS

Challenges

Analytical instruments

In water quality assessment studies, analytical chemistry plays a significant role especially in the analysis of samples; however, this often requires the use of expensive equipment. In most cases, sophisticated analytical research instruments and methods with very low detection limits are needed in order to detect most micro-contaminants in environmental samples. In recent decades, some robust and reliable methods that allow multiple analyses of samples have replaced the rudimentary, labour-intensive and time-consuming methods (Filella, 2013). Modern methods for measuring trace amounts of contaminants in the water are based on application of analytical techniques such as gas chromatography-mass spectrometry (GC-MS), high-performance liquid chromatography (HPLC), inductively coupled plasma-mass spectrometry (ICP-MS), ion chromatography (IC) and advanced liquid chromatography-tandem mass spectrometry (LC-MS^2), hydride generation atomic absorption spectrometry (HG-AAS) among others.

Other advanced tools for water quality studies include the use of remote sensing and real-time monitoring, for example, to assess the impacts of human activities, land-cover, water clarity, algal bloom, some optically related water quality characteristics and spatial and temporal information about fundamental environmental dynamics. There are also some advanced data-transfer technologies that allow continuous monitoring and capture changes as they occur. In terms of microbiological aspects, for example, authors in developed countries are now employing “Microbial Source Tracking” which is an advanced technology that identifies source-specific fecal pollution in environmental waters from different hosts such as humans, livestock, and wildlife (Younos and Parece, 2015).

In a developing country such as Tanzania, purchasing and maintaining analytical instruments is surrounded by many problems, including funding and expertise for operating and servicing the instruments. Without sufficient investment in scientific equipment, technical capacity becomes one of the major limiting factors for effective water quality assessment (Öman et al., 2006). For example, among the cited studies in Table 1 that employed such techniques, most were made possible by using resources from developed countries laboratories (Mataba et al., 2016; Mihale, 2015; Hellar-Kihampa et al., 2013a, b, 2014). With increased technological development and the introduction of new products for human, animal and agricultural use such as pharmaceuticals and personal care products, the range of chemical components that need to be sought in environmental samples at trace levels also increases. The lack of appropriate techniques for analysing such contaminants, whose numbers are constantly increasing, is of particular concern. Further to that, the analytical methods require solvents, reagents and standards such as certified reference materials and internal standards for quality control and assurance purposes.

Interpretation of results

Another challenge is the complexity of interpretation of the toxicological data. In most cases, data from the local environment are compared to regulation aspects or standards of other countries such as the European Union and the US EPA. However, studies suggest that there might be lots of differences between the local environment and the environments where the standards were first established. For example, the standard test species used to test toxicity may not be those existing in the local environment; the sizes of the water bodies assumed in the exposure modeling might be different due to climate, e.g. rainfalls in the tropical climate tend to be much heavier and thus runoffs become much heavier and more often. Other important considerations are estimates of sedimentation rates which are actually significantly higher in the tropical surface waters. As one step, the Tanzania Bureau of Standards has set quality standards for assessing the suitability of different categories of water. However, there is still a lack of national standards for some beneficial water uses such as agriculture, recreational and wildlife. Currently, researchers are using some international guidelines such as those of the WHO.

Most of the cited studies were concerned with establishing concentration levels of different micro-contaminants in a location and suggesting their possible sources. The spatial and temporal variations of water quality parameters were indicated to be influenced by multiple-factors, including several upstream stressors acting together. However, proving the cause-effect relationship or exact contributions of different diffuse sources to the overall contamination for regulation purposes has been a challenge, while aspects such as detection of long-term trends, effects of mixed toxicity of contaminants and assessment of exact risks to aquatic organisms were left to chance. The reasons for this scenario are reported to include inadequate analytical tools, funds, and human resources.

Data management

The government of Tanzania established a specific ministry responsible for water in the early 1970s. The ministry has contributed in management and development of water quality monitoring and assessment programs, although there has generally been more priority in monitoring water quantity as compared to water quality (Hawkins and Gillespie, 2010). Data that identify contaminants and characterize their sources are not readily available, while pollution control capacity is still inadequate. The only reliable source of primary data is from detailed periodic surveys of particular water bodies conducted by specialist programmes or donor-sponsored projects such as Pangani River Basin and Lake Victoria Environmental Management Project (Hawkins and Gillespie, 2010). In most other cases, monitoring data have been irregular and reports in the public domain on water quality difficult to get. Generally, a water quality database for the nation's water is not available. Most of the cited studies were coordinated by individuals/ research groups in training and research institutions and are only published in research journals. Availability of useful and updated information of interest to professionals and stakeholders is still a challenge. The National Water Quality Management and Pollution Control Strategy document (Hawkins and Gillespie, 2010) gives some important recommendations for management of water quality data that if followed, will provide more focused and improved data management.

Future prospects

The observed trends in technological advancement, economic forces, population dynamics and climate change in the country are likely to introduce more significant and long-lasting environmental stressors that impact both quality and quantity of freshwaters. It is obvious that the coming decades will witness growing need for water quality assessment more than in the past. Such assessments will also require increased parameters than were considered in the past, and therefore a requirement for more advanced tools and techniques. There are almost no studies on emerging contaminants of concern such as pharmaceuticals and personal care products; although such contaminants are no longer termed as 'contaminants of emerging concerns' in developed countries because their determination in the environment is well published. Further to that, studies on persistent organic contaminants are relatively few, probably due to the challenge of analytical instruments, because generally studies that measured organic contaminants in environmental samples in the country are still rare.

Tanzania is a large country and rich in water resources, the documented studies only give a glimpse of their trends and status. The general knowledge in terms of quality of the large part of water resources in the country is highly spatial as there are still many important water resources that are yet to be systematically investigated. The baseline levels of micro-contaminants in most major

Tanzanian rivers are still unknown, and drainage basin-based studies on water and sediment chemistry are hardly available. The reviewed studies focused on water pollution with concern on concentration levels of contaminants, while aspects of ecosystem health; ecological risk evaluation and water ecology restoration were not well addressed. There were also fewer researches on groundwater quality. More studies on effects of climate changes will also be required because the subject is still not well addressed. Furthermore, according to the WHO, the greatest concerns in water for human consumption are a microbial risk. Current developments indicate that there might be some changes in assessment of biological water quality parameters. Traditionally, measuring of total coliforms and *Escherichia coli* bacterial has been the most common way of assessing biological quality of water for human consumption, however, of recent there have been some concerns by international water analysts on whether reliance on total coliforms and *E. coli* only as biological indicators is sufficient to ensure microbial water quality (Bari and Yeasmin, 2014). There are some considerations on the need to adopt a more holistic approach to assessing biological water quality. Future studies will, therefore, need to focus on these subjects, among others.

In this modern era, it is important to undertake sample pretreatment techniques which fulfill the requirements of environmental protection. It is also clearly necessary that water sampling and analysis is done by observing standard quality assurance and control protocols, including precision of analytical results and determination of baseline levels. Future needs, therefore, include the establishment of laboratories certified by the International Standards Organization (ISO) and training of staff to strengthen analytical and human resource capacity.

CONCLUSIONS AND RECOMMENDATIONS

Surface and ground water resources in Tanzania are major sources of supply for domestic, agricultural, industrial and hydropower generation. At the same time, there have been increased sources of stressors that threaten the water quality, where the main potential contamination hazards are well known. In the period between 2006 and 2016, significant research efforts have been devoted to water quality assessment in the country, with research aspects ranging from toxic metals, nutrients, pesticide residues, organic contaminants, organic matter, inorganic contaminants, isotopes, major ions and physico-chemical parameters and microbiological contaminants. Their concentration levels and distribution patterns vary widely from one area to another, depending on different factors such as types of the chemicals, input pathways, and climatic conditions. Generally, the reviewed studies indicate alteration of the natural characteristics of water due to natural and anthropogenic sources.

Monitoring and assessment of the quality of freshwater as a necessary resource is an important venture that requires significant research efforts to be deployed. Deliberate efforts should be made to enable availability of modern analytical tools; continuous measurement techniques that can enable testing when needed; event sampling that record impact of specific events such as floods and spills as they occur; automated sampling methods and analytical tools that may do a rapid assessment of water quality and detect any abrupt changes. It is important to have a special focus on groundwater since it is likely to be the key resource in Tanzania mainly due to the changing climate. There is a need of carefully managing it to make full benefit of its potential, including protecting its quality.

This study recommends the establishment of national water quality assessment program that will provide up to date water quality conditions for the large part of the national water recourses. This can be done through coordinated programs to collect data, interpret results and communicate findings to small teams of individuals/researchers familiar with the study area so as to make the best use of available resources. Other recommendations that this article puts forward are strict application of legal and administrative tools such as ‘polluter-pays’ principle; formation of networks for water quality monitoring and assessment to ensure that there is no duplication of work and efforts in collecting, analyzing, and storing water-quality data; commitment of financial resources by the Government for such efforts; establishment of reliable and accessible data base and communicating the water quality data to different stakeholders, including the general public, in a form that is accessible and suitable to needs of the different groups.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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