

Occurrence of nitrate in Tanzanian groundwater aquifers: A review

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Abstract More than 25 % of Tanzanian depends on groundwater as the main source of water for drinking, irrigation and industrial activities. The current trend of land use may lead to groundwater contamination and thus increasing risks associated with the usage of contaminated water. Nitrate is one of the contaminants resulting largely from anthropogenic activities that may find its way to the aquifers and thus threatening the quality of groundwater. Elevated levels of nitrate in groundwater may lead to human health and environmental problems. The current trend of land use in Tanzania associated with high population growth, poor sanitation facilities and fertilizer usage may lead to nitrate contamination of groundwater. This paper therefore aimed at providing an overview of to what extent human activities have altered the concentration of nitrate in groundwater aquifers in Tanzania. The concentration of nitrate in Tanzanian groundwater is variable with highest values observable in Dar es Salaam (up to 477.6 mg/l), Dodoma (up to 441.1 mg/l), Tanga (above 100 mg/l) and Manyara (180 mg/l). Such high values can be attributed to various human activities including onsite sanitation in urban centres and agricultural activities in rural areas. Furthermore, there are some signs of increasing concentration of nitrate in groundwater with time in some areas in response to increased human activities. However,

reports on levels and trends of nitrate in groundwater in many regions of the country are lacking. For Tanzania to appropriately address the issue of groundwater contamination, a deliberate move to determine nitrate concentration in groundwater is required, as well as protection of recharge basins and improvement of onsite sanitation systems.

Keywords Groundwater contamination · Human activities · Nitrate concentration · Tanzania

Introduction

Background

Groundwater makes up to over 95 % of the world's available freshwater resources and is the main source of drinking water for a large percentage of the world's population (Bowell et al. 1996; Brindha and Elango 2011). Groundwater can be found in most environments. Its quantity, quality, accessibility and recharge depend primarily on geology, geomorphology, land use and levels of precipitation. Geology and geomorphology play a significant role on storage, transportation and quality of the groundwater, whereas precipitation plays a significant role on the groundwater recharge (Taylor et al. 2012). Depending on geomorphology and geology of a place, a recharge of 10–50 mm can occur in the area with annual precipitation of less than 500 mm (MacDonald and Calow 2009).

Groundwater is an important source of water supplying more than 25 % of the domestic water consumption in Tanzania (Gössling 2001; JICA 2002). Groundwater offers the affordable source of water because it can be found close

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to the point of demand (MacDonald and Calow 2009; Taylor et al. 2012). It is the main source of water for most rural areas of Tanzania and urban areas of Dodoma, Arusha, Manyara, Simiyu, Singida, Shinyanga and Dar es Salaam regions (Bowell et al. 1996, 1997; Kashaigili 2012) and islands of Unguja, Pemba and Mafia (Gössling 2001; Hansson 2010). Utilisation of groundwater resources in Tanzania has grown fast particularly since 1997 when there was a severe surface water crisis (Mato 2002; Mtoni et al. 2012, 2013). For example, more than 10,000 groundwater supply sources have been developed in Dar es Salaam alone since 1997 (Mjemah et al. 2012; Mtoni et al. 2013). However, the quality of groundwater in different aquifers in the country remains poorly understood. Therefore, this calls for a deliberate move to determine the trends and occurrence of various contaminants in the groundwater in order to be able to establish the best groundwater management strategies.

The usefulness of groundwater resources, however, is being compromised by contamination due to natural and human activities (Nkotagu 1996a, b; Tredoux et al. 2000; Reynolds-Vargas et al. 2006). Groundwater quality degradation has been widely reported from both urban and rural areas in developed and developing countries. It is often the cause of an increasing freshwater scarcity, increasing water supply costs and a growing human health hazard (Foster et al. 1999). The sources of groundwater contamination can be categorised into natural or anthropogenic sources (Jiang et al. 2009). Natural sources of contamination include contamination due to water–soil interaction during percolation where water dissolves and/or elute some soluble material from rocks/soil (Carol et al. 2012; Ghiglieri et al. 2012; Rajesh et al. 2012). For example, in Tanzania more than 30 % of all water sources have fluoride concentrations greater than 1.50 mg/l the maximum allowable concentration in drinking water recommended by WHO (Kaseva 2006). Additionally, human activities may exacerbate groundwater contamination by escalating the rate of slow occurring natural processes. For example, mining activities facilitate acid rock drainage which may result into groundwater with low pH and high levels of trace elements (Baird 1995).

Potential anthropogenic source of groundwater contamination is domestic sewage especially onsite sanitation systems like pit latrines, cesspits and soak away pits (Nkotagu 1996a; Tredoux et al. 2000; Reynolds-Vargas et al. 2006; Kiptum and Ndambuki 2012). Other sources include industrial effluents, leachate from solid waste dumpsites, leakage from fuel filling stations, automobile and repair garages, industrial workshops and agriculture (Eckhardt and Stackelberg 1995; Goulding 2000; Jalali 2005; Srinivasamoorthy et al. 2009). Contaminants resulting from human activities include biological (like virus,

bacteria, fungi, protozoa and helminths) and physico-chemical (nutrients, heavy metals and salts).

Contamination of groundwater with nitrate is a global problem. High levels of nitrate in groundwater not only may be a good indicator of groundwater contamination but also may lead to human and animal health problems. Information of sources, concentration, spatial and temporal distribution of nitrate in groundwater in Tanzania is uneven and limited; consequently, its quality remains poorly understood. The main objective of this study was to review various studies done in different areas of Tanzania so as to consolidate the existing scattered information on sources, concentration and trends of nitrate concentration in different aquifers. Such consolidated information will help the government to understand areas that require immediate attention/action. In addition, the information will help communities to avoid high-risk zones for further water sources (springs and wells) development and to limit practices that may threaten uncontaminated aquifer. Furthermore, the review will help policy makers and management personnel to use the information for a better groundwater management.

Tanzania: country profile

Location

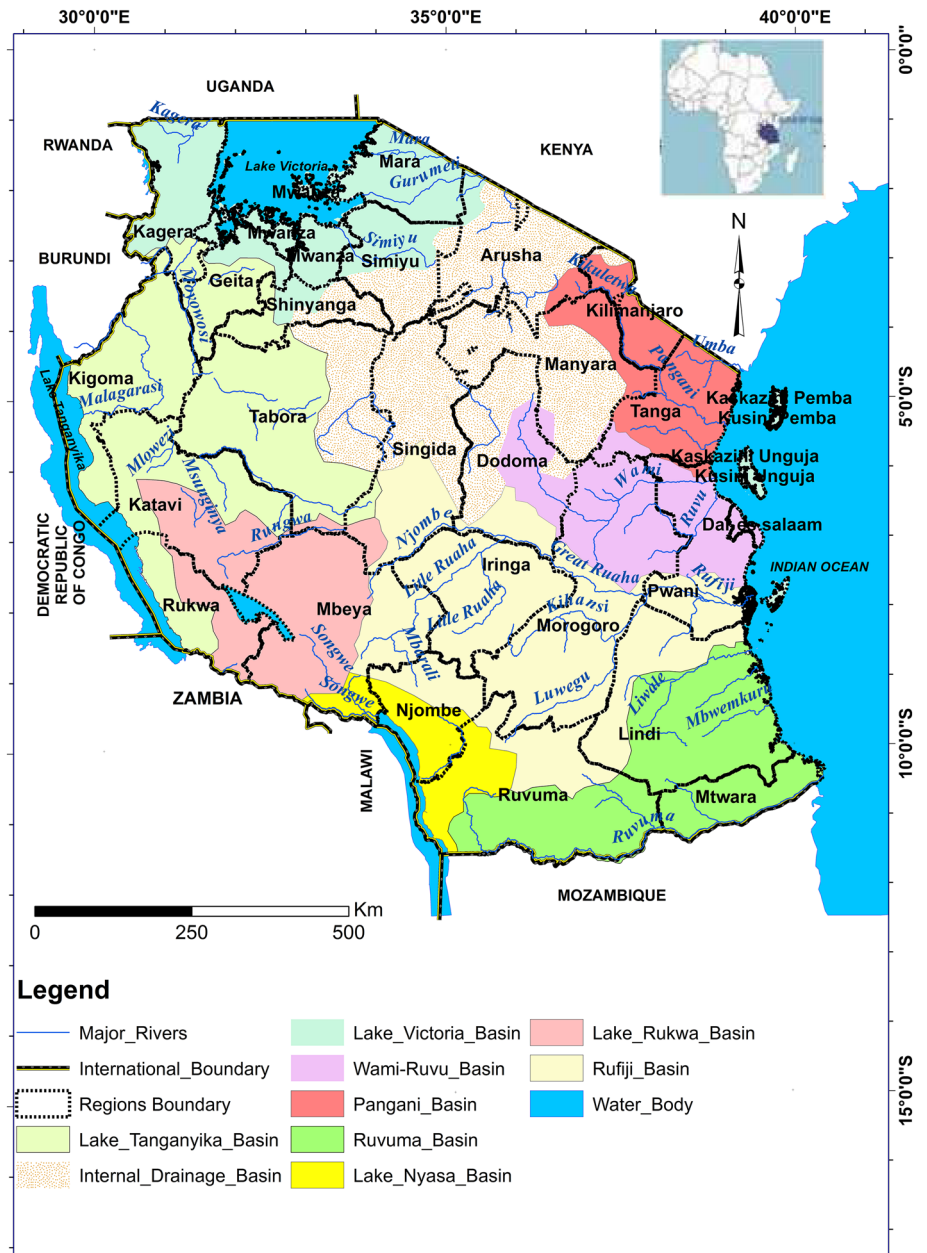
Geographically, Tanzania is located in Eastern Africa between Latitude 1° and 12° South, and Longitude 29° and 41° East (Fig. 1). Tanzania borders with eight countries of Kenya, Uganda, Rwanda, Burundi, Democratic Republic of Congo (DRC), Zambia, Malawi and Mozambique and to the eastern side by Indian Ocean. Landscape changes from East African Great Rift valley, narrow coastal plain, flat to slightly hilly central plateau, savannah landscape, steppe landscape and tropical forest.

Population

From 1968 to 2012, the population of Tanzania has tripled (NBS and Office of Chief Stastitian Zanzibar 2013). Tanzania is sparsely populated with average population density of 51 inhabitants per square kilometre (inh./sq. km) with interregional and urban–rural significant variations (NBS and Office of Chief Stastitian Zanzibar 2013). The population density in Tanzania mainland ranges from 13 to 3,133 inh./sq. km in Lindi and Dar Es Salaam, respectively, while for Tanzania Zanzibar it ranges from 135 to 2,581 inh./sq. km in Kusini Unguja and Mjini Magharibi, respectively (Fig. 2).

For the period of 2002 to 2012, Tanzania had average inter-censal population growth rate of 2.7 % which is higher than estimated world's population growth rate of

Fig. 1 Map of Tanzania, showing location, administration regional boundaries, major rivers and water basins



0.77 % for a period of 2000–2050 (UN 2004). However, there was a significant variation among regions (NBS and Office of Chief Stastitian Zanzibar 2013). Demands for water and threats to water resources are ever increasing owing to population growth and increased development of urban, peri-urban and rural communities.

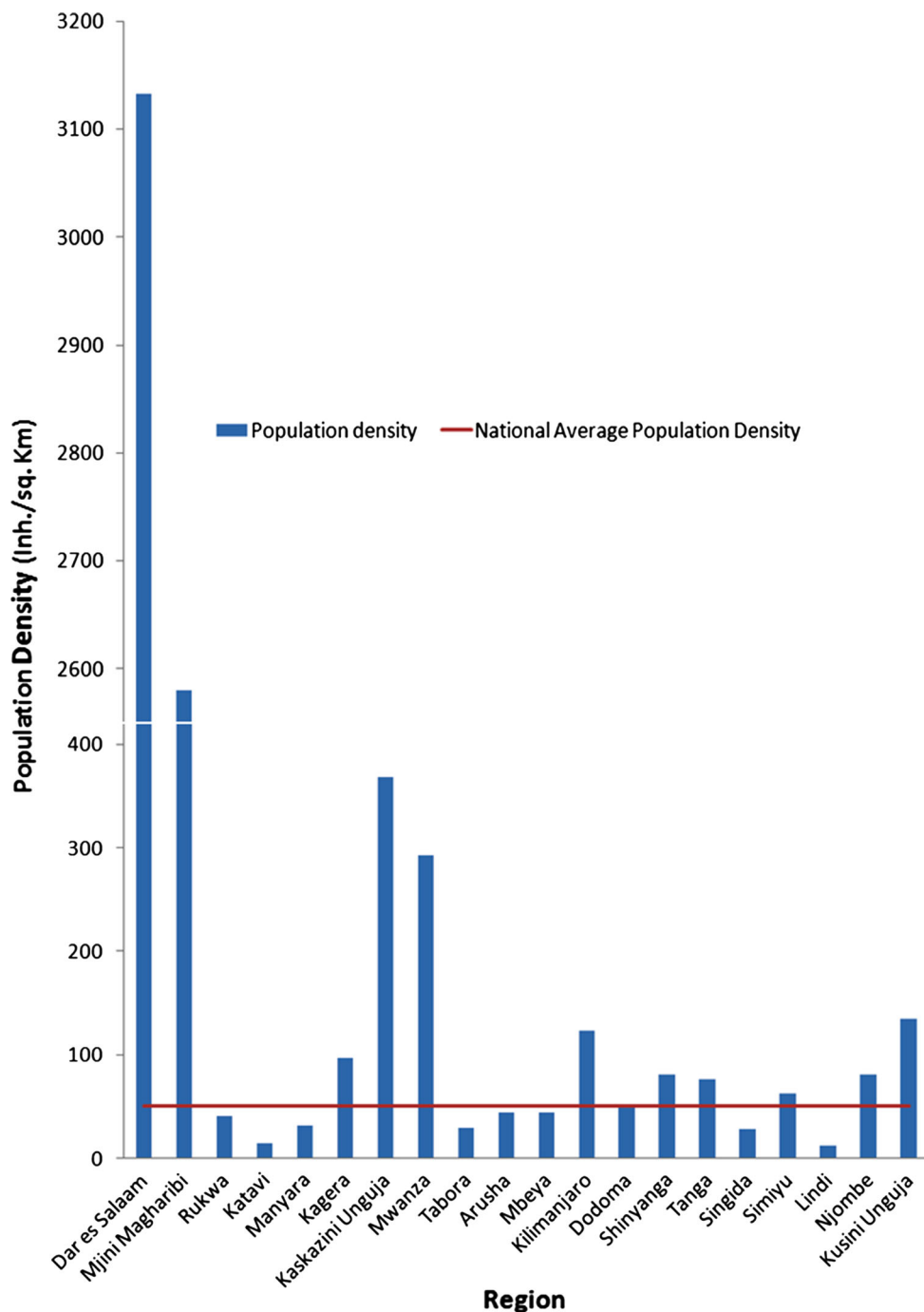
Climate

Tanzania has a tropical climate with regional variations mainly modified by altitude. Temperature varies with seasons and altitude. In the highlands, temperature ranges from below 10 to 30 °C during cold and hot seasons, respectively, while the rest of the country has temperatures

rarely falling lower than 20 °C (McSweeney et al. 2014). Generally, the hottest period extends between November and February (25 to above 31 °C), while the coldest period (15–20 °C) occurs between May and August.

According to Nicholson (1996), Tanzanian climate is controlled by three major air streams and three convergence zones. The air streams include a humid Congo air with westerly and southwesterly flow, north east (NE) monsoon and south east (SE) monsoon. Westerly and southwesterly Congo air is separated by Congo air Boundary. Precipitation is controlled by the position of the Inter-Tropical Convergence Zone (ITCZ), which is relatively a narrow belt of very low pressure that forms near the earth’s equator and monsoon wind pattern. ITCZ

Fig. 2 Population density (inh./sq. km) of some selected regions compared to average national population density (NBS and Office of Chief Stastitian Zanzibar 2013)



changes over the course of the year, migrating southwards through Tanzania in October to December, reaching the south of the country in January and February, and returning northwards in March, April and May (McSweeney et al. 2014). This causes areas around Lake Victoria basin (Nicholson 1996; Basalirwa et al. 1999; Tungaraza et al. 2012; McSweeney et al. 2014), western coast of the Indian Ocean (Sumner 1983; Nicholson 1996; McSweeney et al. 2014) and northern highlands (Nicholson 1996; Basalirwa et al. 1999; McSweeney et al. 2014) to experiences two

distinct wet periods the ‘short’ rains (Vuli) in October to December and the ‘long’ rains (Masika) in March to May. The southern, western and central parts of the country experience one wet season from October to April/May, with central parts being relatively drier and others wet. The annual total rainfall ranges from less than 500 mm in central parts to more than 1,000 mm in wet areas, although the coastal regions and the Islands of Zanzibar and Pemba may receive about 1,500 mm (Sumner 1983; Nicholson 1996; Basalirwa et al. 1999; McSweeney et al. 2014). Such

precipitation may facilitate groundwater recharge significantly if other factors like geology, geomorphology and land cover are good.

Hydrogeology

Geologically, Tanzania is studded by rocks that range in age from Precambrian to present (Howard 2011; Kashaigili 2012). These are grouped into hard formations (igneous and metamorphic rocks) and soft formation (sediments and sedimentary rocks). The ratio of soft to hard formation is approximated to be 1:3 (Kongola 2004). The hard formations of Tanzania include the Greenstone belt, Ubendian, Karagwe Ankolean, Bukoba, Usagaran and Mozambique systems. The greenstone belt of Tanzania is the oldest, forming the Tanzania Craton composed of Dodoman, Nyanzian and Kavirondian systems being intruded by granitoids. These formations host significant amount of groundwater mainly through fractures from the shallow depth (<40 m) to deep depth (>100 m) (Kashaigili 2012). Also, the Ubendian, Karagwe Ankolean, Bukoba, Usagaran and Mozambique systems, generally metamorphosed to high grade, host significant amount of groundwater through fractures. In these formations, the quality of groundwater has been affected significantly by the geology of the areas. For instance, there is high fluoride content in groundwater in Arusha, Manyara and Kilimanjaro regions due to dissolution of fluoride from fluoride bearing rocks of igneous origin (Ghiglieri et al. 2012).

The soft formations of Tanzania include the Mesozoic to Cenozoic sediments in the coastal areas, inland basins (mainly karoo sediments), rift valley sediments together with recent volcanic and fluvial sediments (Kashaigili 2012). Due to their primary porosity, sedimentary rocks are potential for accumulation of appreciable groundwater resource (Fetter 2001). Groundwater in the inland basins and rift system is controlled by both lithologies and structures; in some parts, the water quality is affected by the geology of the areas as in hard formations. Biogenic sedimentary deposits in the coastal and inland basins, e.g. Minjingu phosphate deposits formed during Pleistocene age probably, are the natural source of nitrate in the groundwater. However, their contributions to nitrate contamination in Tanzanian groundwater have not been established. The large part of the coastal sediments is affected by salinity. However, there are some areas with fresh groundwater, being hosted in sands, silts and fractured limestone.

Generally, groundwater storage in Tanzanian aquifers approximates 5,250 km³ (MacDonald et al. 2012). Nevertheless, the water yielding capacity of Tanzanian geological formations depends on their interstices and voids spaces. The quantitative information on potential of Tanzanian aquifer systems to yield groundwater is uneven and

generally limited. Boreholes drilled for domestic water supplies indicate variable yields. Variable yields have been reported in boreholes drilled at different places of the country ranging from <5 to >100 m³/h and averaging 11 m³/h (Baumann et al. 2005). An exceptionally high yield of about 460 m³/h was recorded in some boreholes in the Dodoma (Baumann et al. 2005).

The major source of groundwater in the aquifers of Tanzania is rainfall (Nkotagu 1996c; Rwebugisa 2008; Mjemah et al. 2011). In Tanzania, studies on the groundwater recharge potentials are limited. In Dodoma, where average rainfall is about 500 mm/year, recharge rate range from 5 to 10 mm/year, averaging to 1.3 % of the annual rainfall (Rwebugisa 2008). On the other hand, the recharge in the Quaternary sand aquifer of Dar es Salaam ranged from 0 to 570 mm/year and averaging at 240.7 mm/year for a period 1971–2006 (Mjemah et al. 2011). The amounts of groundwater in the aquifers are balanced with groundwater abstraction, base flow to rivers and discharge into the lakes and Indian Ocean.

Land use

Owing to population growth and human development, a significant amount of land has been converted from natural forests to settlements or agricultural land (Masanja 2003; Malugu 2007; Yanda and Munishi 2007; Kashaigili and Majaliwa 2010; Sheuya 2010; Mdemu et al. 2012). For example, due to population growth radius of built-up area in Dar es Salaam City expanded from 2 km in 1945 to 32 km northwards, 20–28 km westwards and 14 km southwards in 2002 (Sheuya 2010). In other parts of the country, for example, Malagarasi River catchment in Lake Tanganyika Basin there have been significant changes in land use where areas with settlements and cultivation have increased annually by 1.05 % from 1984 to 2001 (Kashaigili and Majaliwa 2010). Similarly, land-use changes, from natural land to agricultural land and settlements particularly in the peri-urban areas, are on increase at an alarming rate in almost all urban centres in Tanzania (Kombe 2005). Such land uses in most cases have negative impact on the quality and quantity of the groundwater (Foster et al. 1999; Cronin et al. 2007).

Hydrology and water resources management in Tanzania

Tanzania Mainland has nine major drainage basins that are used as water resources management regimes (Fig. 1). Such basins include Lake Victoria, Pangani, Ruvu/Wami, Rufiji, Ruvuma and southern Coast, Lake Nyasa, Lake Tanganyika, internal drainage and Lake Rukwa basins. Within these river basins, there are several major rivers including Pangani, Wami, Ruvu, Rufiji, Mbwemkuru,

Lukuledi, Malagarasi, Kagera and Ruvuma (Fig. 1). Also, great East African lakes, namely Lake Nyasa to the south, Lake Victoria in the north and Tanganyika to the west are found within these basins (Fig. 1). These rivers and other large water bodies are sources of water for various purposes such as irrigation, hydropower generation, industrial and domestic uses.

Access to safe drinking water in Tanzania is more pronounced in urban areas compared to rural areas. About 74 % of urban households have access to safe drinking water as compared to about 40 % of their rural counterparts (NBS and Office of Chief Statistician Zanzibar 2013). Thus, about 26 and 60 % of urban and rural populations, respectively, consume water of unknown quality. Water resources management in the drainage basins (Fig. 1) is undertaken by the Basin Water Office which is under the Basin Water Board (United Republic of Tanzania 2008). Borders of each basin have been described by the Ministry of Water (United Republic of Tanzania 2008).

Nitrate concentration in groundwater

Nitrogen in the form of NO_3^- , NO_2^- , NH_3^+ and organic nitrogen is one of the most common contaminants which may be found in the groundwater (Tredoux et al. 2000; Orebiyi et al. 2010). Nitrate is a compound of nitrogen that may occur naturally in very low concentrations in the groundwater. It is normally a stable compound especially in oxygen-rich environments. Nitrate is very soluble in water and is readily leached from soils dominated by permanent negative charges or soils with moderate to high pH, without being influenced by adsorption and precipitation reactions. Nitrate can persist in groundwater for decades and accumulate to high levels as more nitrogen is applied to the land surface every year. Waters containing more than 50 mg/l of nitrate can lead to human and animal health problems (WHO 2007; Gatseva and Argirova 2008). Discharge of nitrate contaminated groundwater to water bodies with low nitrate concentrations may result in eutrophication (Spalding and Exner 1993). The presence of nitrate at elevated concentration in the groundwater may be an indirect indicator of the presence of other contaminants derived from human activities (Reynolds-Vargas et al. 2006). A full understanding of the natural concentration, possible sources and biogeochemical transformation of nitrate is required for a successful groundwater management strategy.

Background concentration of nitrate in groundwater

Determining the degree of nitrate contamination in the groundwater is difficult without a clear understanding of

background concentrations present. Background concentrations of nitrate in different aquifers vary depending on geological formations and current and past vegetation cover (ECETOC 1988; Foster et al. 1999; West 2001; Limbrick 2003; Wendland et al. 2005). Natural sources of nitrate in the groundwater include leaching and oxidation of nitrogenous compounds incorporated in rocks (Holloway and Dahlgren 2002) and fixation by leguminous plants and microorganisms (Edmunds and Smedley 1996). According to Holloway and Dahlgren (2002), rock nitrogenous compound concentrations range from trace levels to above 200 mg-N/kg in granites and may exceed 1,000 mg-N/kg in some sedimentary and meta-sedimentary rocks. In many aquifers, background concentration of nitrate is less than 1 mg/l (West 2001; Wendland et al. 2005). However, due to variation in geochemical and historical vegetation cover, higher background concentrations have been reported elsewhere (Burkart and Kolpin 1993; Eckhardt and Stackelberg 1995; Mueller 1995; Foster et al. 1999; Limbrick 2003). Such background concentration of nitrate may reach as high as 10 mg/l (Lawrence 1983; ECETOC 1988; Nishikawa et al. 2003; Panno et al. 2006).

In Tanzania, the background concentration of nitrate in the groundwater remains poorly understood. However, the limited data collected from various aquifers in undisturbed areas particularly protected areas, uncultivated areas and deep aquifers in Tanzania indicate a nitrate concentration of less than 2.5 mg/l (Rwebugisa 2008; Mckenzie et al. 2010; GITEC and WEMA 2011; Bakari et al. 2012). For example, Rwebugisa (2008) reported that nitrate was not detected even in shallow wells located in protected areas in Makutupora sub-basin in the Internal Drainage Basin. In addition, background concentration of nitrate in groundwater in Zanzibar is not well known although 5.0 mg/l have been considered as an indication of influence from sewage (Hansson 2010). Because background nitrate concentration in different aquifer systems in Tanzania remains poorly understood, the background nitrate concentration of 10 mg/l as used by Lawrence (1983), ECETOC (1988), Nishikawa et al. (2003) and Panno et al. (2006) was adopted in this review. Nevertheless, because the geology, climate and land use differ from one place to another, water basin-specific background concentration needs to be established.

Sources of nitrate in the groundwater

Nitrate leaching to groundwater is related to hydrogeological conditions, land use and soil type (Oenema et al. 2005). Intensive agriculture, domestic and industrial wastes disposal and atmospheric nitrogen contamination are considered to be the main sources of nitrate contamination in the groundwater (Goldberg 1989). Major sources of nitrate

in urban aquifers are related to wastewater disposal (onsite systems particularly pit latrines and leaky sewers), solid waste disposal (dumpsites) and industrial activities (Bowell et al. 1997; Tredoux et al. 2000; Wakida and Lerner 2005; Mjemah et al. 2011; Mtoni et al. 2012). Human excreta introduces about 5 kg of nitrogen to the environment per year per capita (Lewis et al. 1980).

Agriculture is the main source of nitrate in groundwater from rural areas due to application of organic and inorganic fertilisers (Jalali 2005; Ju et al. 2006; Reynolds-Vargas et al. 2006; Srinivasamoorthy et al. 2009; Divya and Belagali 2012; Dragon 2012). Expansion of agricultural activities will be associated with increased use of fertilisers and pesticides. For example, although the use of fertilizer is quite low in Tanzania compared to other countries, it has been rising in recent years. The use of fertilizers increased from about 120,000 metric tons in 2005/06 to 263,000 metric tons for the year 2009/10 (International Fertilizer Development Centre 2012). In such an increase, urea and diammonium phosphate (DAP) accounted for about half the total volume of 2010, NPK fertilizer which is mainly composed by nitrogen, phosphorus and potassium, consistently accounted for another 21 % of the total, while calcium ammonium nitrate (CAN) accounted for approximately 9 %. Such fertilizers contain nitrogenous compounds which may be oxidised in the soil to nitrate and then leached to the aquifer. Furthermore, due to ambitious agricultural sector development plan (Kilimo Kwanza), the application of fertilizers is expected to rise from 263,000 to 574,000 metric tons in 2015 (International Fertilizer Development Centre 2012).

Nitrate from such sources can be introduced into groundwater systems by infiltration. Following periods of heavy rainfall, nitrate flushing can increase concentrations in both surface water and groundwater. Shallow aquifers are most susceptible to nitrate contamination as well as to other types of man-made contaminants. However, shallow aquifers far from human activities and in areas distant from the recharge zone may contain very low nitrate concentration.

Nitrate contamination in Tanzanian groundwater

Study approach

This paper consolidates information on nitrate concentrations and trends in groundwater from selected areas in different drainage basins in Tanzania. Data and information on spatial distribution, trends and concentrations of nitrate in groundwater at regional and local scales were gathered from previous studies. Previous studies on groundwater quality were limited to areas depending on the groundwater as the source of water supply and areas with poor water

supply; therefore, groundwater sources are exploited to supplement shortage in water supply. The islands of Unguja and Pemba (Hansson 2010) and areas located in the Internal Drainage Basin mostly depends on the groundwater as the source of water supply (Kashaigili 2012), while some parts of Pangani basin, Wami/Ruvu basin and Lake Tanganyika basin use groundwater to supplement surface water supply (USFS 2009; GITEC and WEMA 2011; Mtoni 2013).

Nitrate concentrations in the groundwater (mg/l as nitrate) were compared to a background concentration of 10 mg/l and WHO maximum allowable concentration (50 mg/l). The spatial distribution of nitrate was determined by plotting the relative concentration of nitrate on the map of Tanzania using ArcGIS 10 software. In addition, attempt to study a temporal trend of nitrate concentration in the groundwater was limited by the availability of continuous data.

Concentration and spatial distribution of nitrate in groundwater

Concentration of nitrate in groundwater in the Internal Drainage Basin

The Internal Drainage Basin is described by rivers/streams draining into a group of inland water bodies (lakes) that are located around the north-central part of the country. The Internal Drainage Basin runs southward from the border with Kenya to central Tanzania (Fig. 1). Groundwater is the main source of water for drinking, irrigation and industrial activities particularly in Singida (Bowell et al. 1997), Manyara (Bowell et al. 1997), Shinyanga (Bowell et al. 1997; Policy and Operations Evaluation Department (IOB) 2007), Arusha (Bowell et al. 1996, 1997; Pittalis 2010) and Dodoma (Nkotagu 1996a, b; Rwebugisa 2008) regions. Bowell et al. (1997) reported high nitrate concentration region reaching 180 mg/l which positively correlated significantly with coliform counts of the groundwater samples collected from Manyara and Arusha. Such high nitrate concentration associated with positive correlation with coliform counts reflects contamination originating from human and animal faecal matters.

The study by Nkotagu (1996a) showed that nitrate concentrations in groundwater samples collected from Hombolo sub-basin in Dodoma District (Fig. 3) ranged from 0.01 to 449.1 mg/l with a median of 52.8 mg/l. 50 % of the samples had nitrate concentration higher than the maximum concentration recommended for drinking water by WHO (2007), while 76 % of the samples had nitrate concentrations above background concentration of 10 mg/l. Such data indicate that about 76 % of the water samples were contaminated by nitrate resulting from human

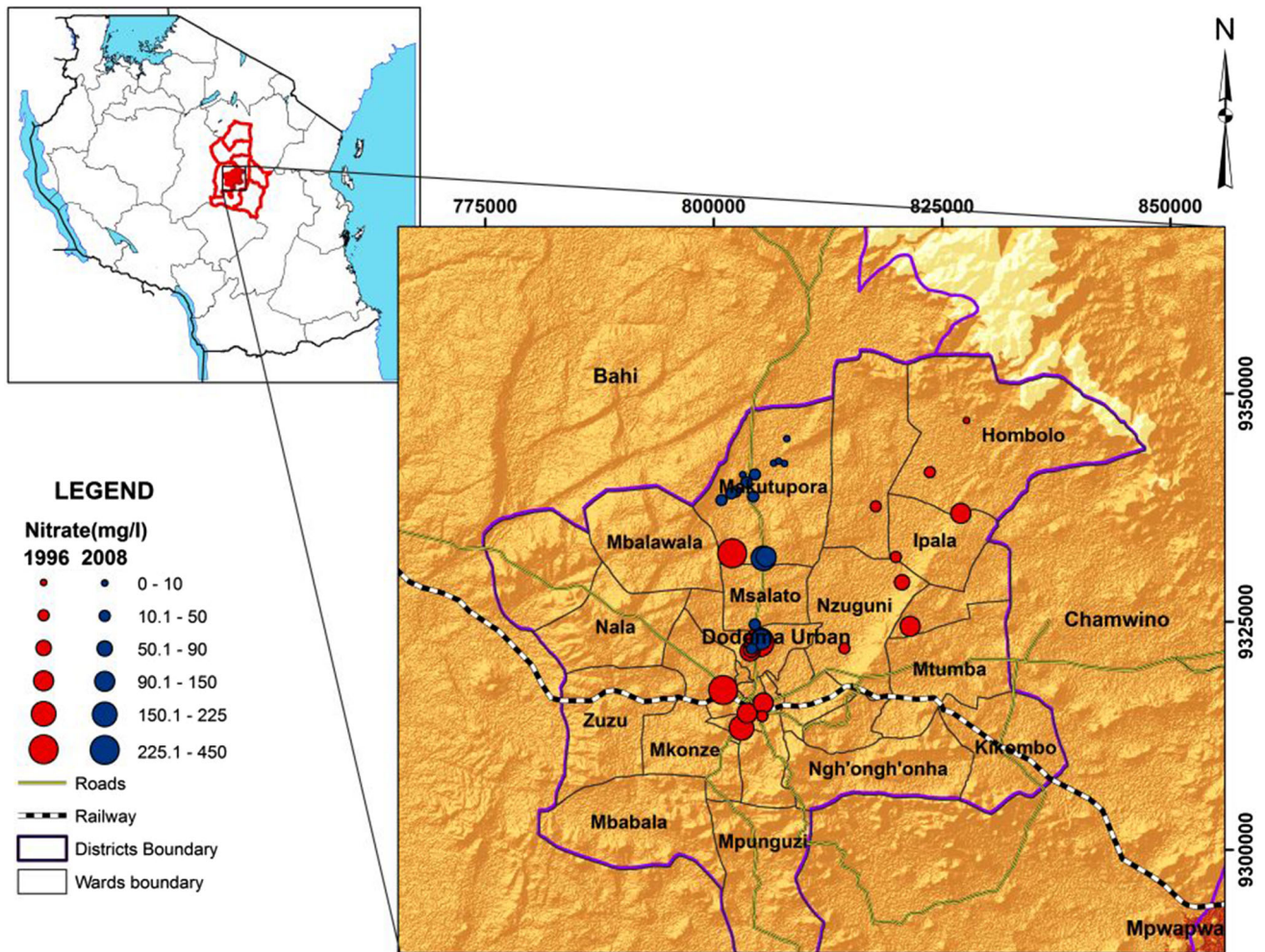


Fig. 3 Distribution of nitrate (mg/l) in groundwater in Dodoma District (source of data Rwebugisa 2008; Nkotagu 1996a)

activities specifically onsite sanitation (particularly pit latrines) and animal manure since the area is occupied by pastoralists, and there is no or insignificant application of industrial fertilizers. The significant negative correlation between nitrate concentration and pH was observed owing to mineralisation and nitrification of organic nitrogen from animal manure and/or human wastes in either the aquifer or unsaturated zone (Nkotagu 1996a).

Rwebugisa (2008) reported nitrate concentration ranging from 0.0 to 150 mg/l and median of 20 mg/l in groundwater samples collected from Makutupora, Msalato and Dodoma urban centre (Fig. 3). 18 % of the groundwater samples had nitrate concentration higher than the maximum concentration recommended for drinking water by WHO (2007), while 55 % of the samples had nitrate concentrations above background concentration of 10 mg/l. It was noted that the concentration of nitrate in protected areas (Makutupora) was low compared to the other areas (Fig. 3) where it ranged from 0.9 to 32 mg/l below the maximum concentration recommended for drinking water

by WHO. Such low nitrate concentration in the groundwater samples collected from Makutupora where boreholes supplying water to Dodoma municipality and surrounding villages are located probably was a result of prohibition of human activities around the area.

Figure 4 presents the spatial distribution of nitrate concentration in Arusha region which partly covers Internal Drainage Basin (northern of Mount Meru) and Pangani Basin (South of Mt. Meru). Pittalis (2010) reported elevated nitrate concentration ranging from below detection to 72 mg/l in groundwater samples collected from Ngarenanyuki and Oldoinyo Sambu wards (Fig. 4) in 2007 with median of 24 mg/l. 7 % of the groundwater samples had nitrate concentration higher than the maximum concentration recommended for drinking water by WHO (2007), while 93 % of the samples had nitrate concentrations above background concentration of 10 mg/l. The elevated nitrate concentration in water sample collected from Ngarenanyuki and Oldoinyo Sambu probably indicates contamination mainly caused by agricultural activities.

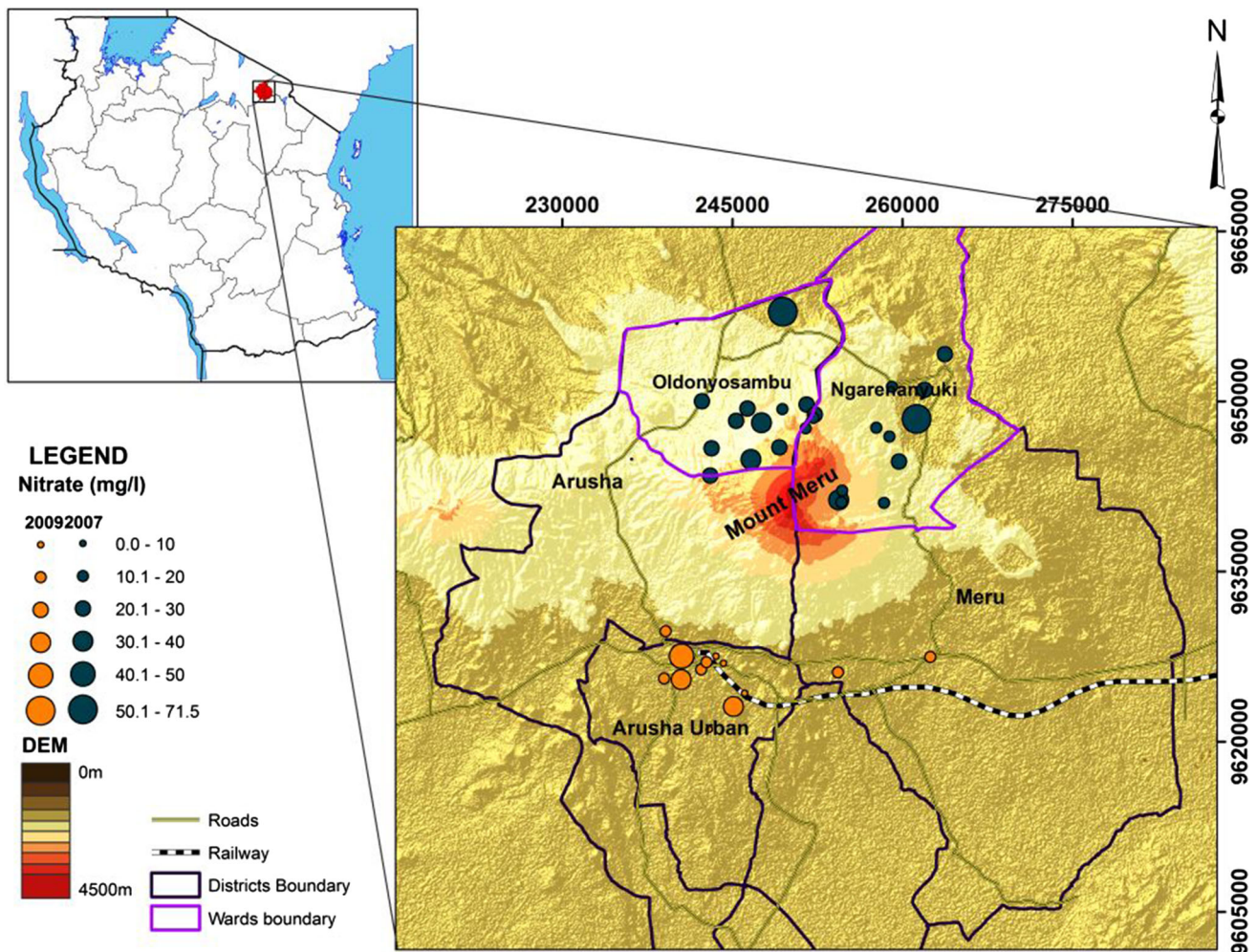


Fig. 4 Spatial distribution of nitrate (mg/l) in groundwater in part of Arusha region around Mount Meru (source of data Pittalis 2010; GITEC and WEMA 2011)

Concentration of nitrate in groundwater in the Pangani Basin

The Pangani Basin is located in the north-eastern Tanzania between latitude $3^{\circ}03'S$ and $5^{\circ}59'S$ and longitude $36^{\circ}23'E$ and $39^{\circ}13'E$ with an area of about $53,600 \text{ km}^2$ (Fig. 1). Seventeen administrative districts of Arusha, Manyara, Kilimanjaro and Tanga regions are within the Pangani River Basin. The basin is composed of five sub-catchments, namely Pangani, Zigi, Uмба, Mkulumuzi and Msangazi with main rivers draining to the Indian Ocean. Pangani River which is the largest river in the basin has two main tributaries, i.e. Ruvu and Kikuletwa which meet at Nyumba ya Mungu Dam. Major water use activities include hydropower production, small- and large-scale irrigation, and domestic and industrial water needs.

Elevated nitrate concentrations in groundwater in Pangani Basin have been reported by many authors (Mckenzie et al. 2010; Howell et al. 1997; GITEC and WEMA 2011).

For example, Mckenzie et al. (2010) reported groundwater nitrate concentration ranging from below detection limits in undisturbed areas to 11.8 mg/l in cultivated areas around Mount Kilimanjaro. Furthermore, GITEC and WEMA (2011) reported nitrate concentration ranging between 4 and 47 mg/l and median of 11 mg/l in groundwater samples collected from southern part of Mount Meru in Arusha municipality (Fig. 4). All groundwater samples had nitrate concentration less than the maximum concentration recommended for drinking water by WHO (2007), while 60 % of the samples had nitrate concentrations above background concentration of 10 mg/l . Elevated nitrate concentration was observed within Arusha municipality (Fig. 4) probably originating from onsite sanitation facilities particularly pit latrines.

In Tanga region (Fig. 5), nitrate concentration in groundwater ranged between 0 and 747 mg/l with a median of 9 mg/l (GITEC and WEMA 2011). Fourteen percent of groundwater samples mostly from sources located in urban

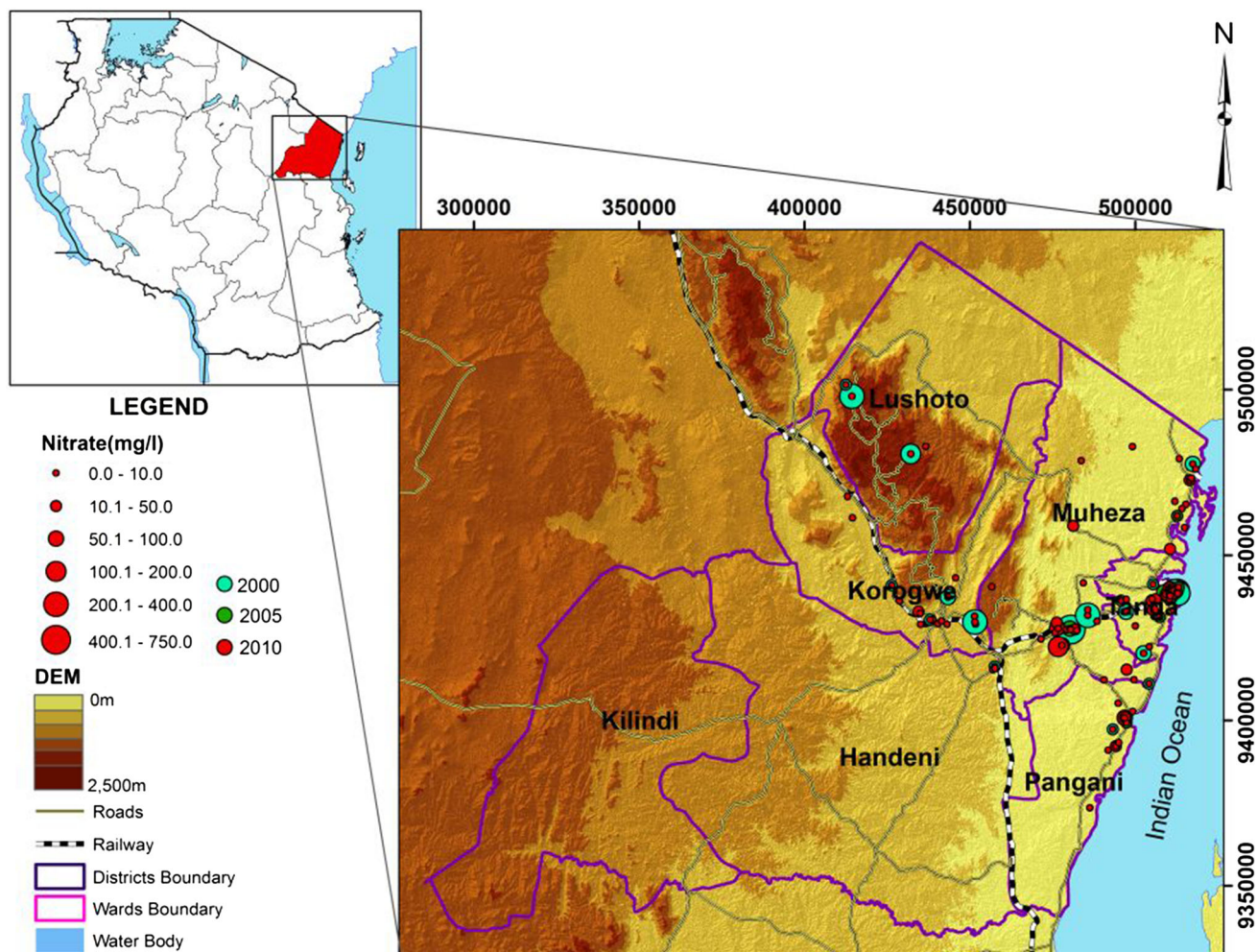


Fig. 5 Spatial distribution of nitrate (mg/l) in groundwater in part of Tanga region (GITEC and WEMA 2011)

areas had nitrate concentration higher than the maximum concentration recommended for drinking water by WHO (2007). Additionally, 45 % of the samples had nitrate concentrations above background concentration of 10 mg/l. Elevated nitrate concentration was observed in urban areas of Lushoto, Tanga and Korogwe (Fig. 5). Such elevated nitrate concentrations were associated with onsite sanitation facilities particularly pit latrines (GITEC and WEMA 2011).

Concentration of nitrate in groundwater in the Wami–Ruvu Basin

Wami/Ruvu basin consists of two main river systems, the Wami and the Ruvu and some small coastal rivers (e.g. Msimbazi, Kizinga and Mzinga rivers) in the south of Dar es Salaam (Fig. 1). The Wami–Ruvu Basin is one of the four basins that drain into the Indian Ocean. Wami–Ruvu Basin covers parts of Dodoma, Morogoro, Tanga, Coast and Dar es Salaam regions (Fig. 1). Dar es Salaam City, which is the highly populated urban area in Tanzania,

receives piped water from Ruvu and Mzinga rivers. However, due to increasing water demand, poor infrastructures, and deteriorating quality and quantity of river water, surface water supply from Ruvu and Mzinga rivers does not suffice the water requirements for Dar es Salaam City (Mtoni 2013). To supplement surface water, significant number of wells and boreholes has been developed by different organizations and individuals in Dar es Salaam (Mato 2002; Bakari et al. 2012; Mjemah et al. 2012; Mtoni et al. 2013) and Morogoro (Kibona et al. 2011).

Spatial distribution of nitrate observed at different time in the groundwater in Dar es Salaam is presented in Fig. 6. Nitrate concentration showed a decreasing trend as one moves from the city centre to periphery especially to western direction owing to decreasing population density. Nitrate concentration in groundwater of Dar es Salaam ranged from below detection limit to more than 445 mg/l (Mato 2002; Mjemah 2007; Napacho and Manyele 2010; Dejager 2011; Bakari et al. 2012; De Witte 2012; Mtoni et al. 2013) with highest observable at Mbagala (Bakari

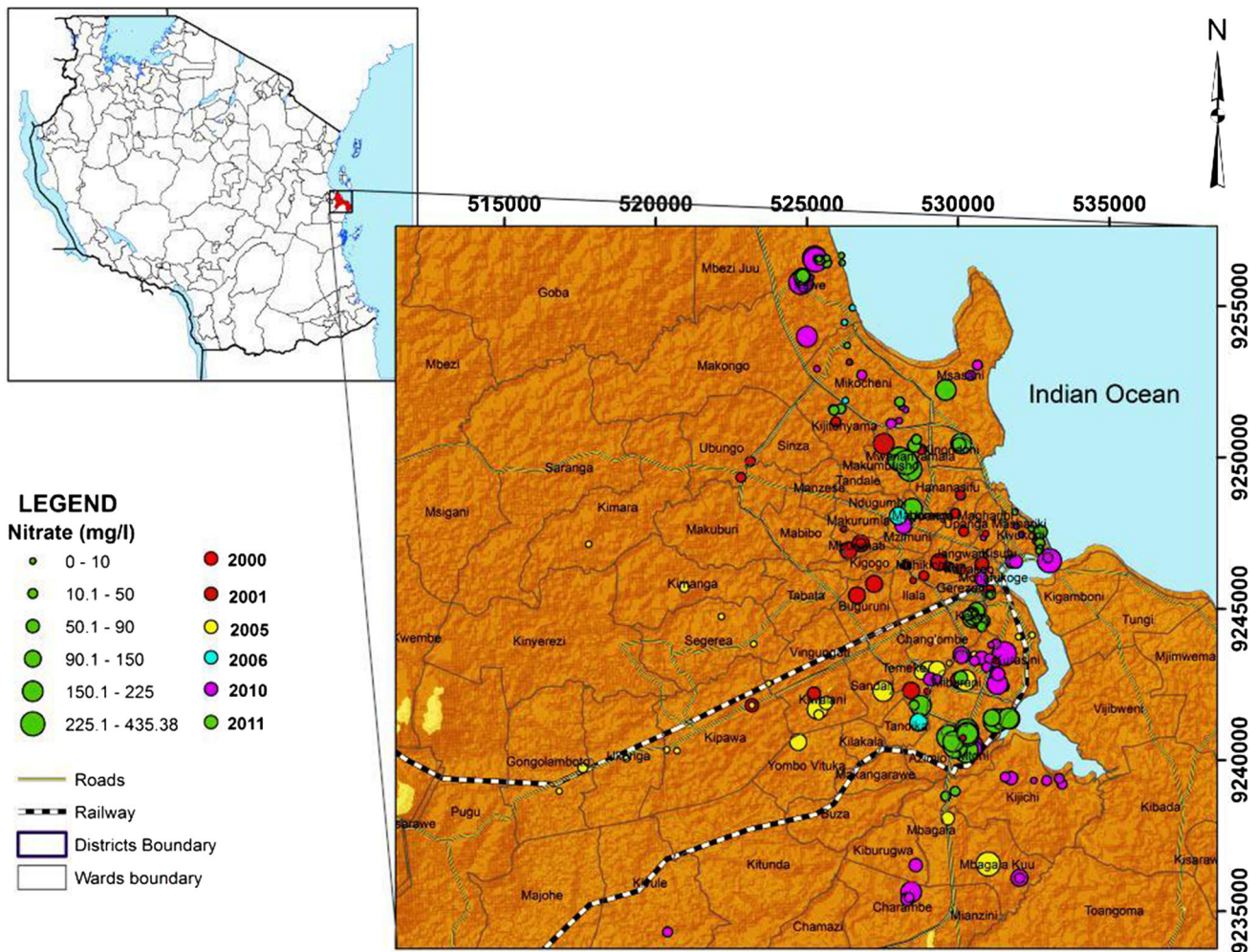


Fig. 6 Spatial distribution of nitrate (mg/l) in groundwater in some parts of Dar es Salaam City (Mato 2002; Mjemah 2007; Mtoni 2013)

et al. 2012). Highest recorded nitrate concentration in Chang’ombe, Mtoni, city centre and Kawe were 318, 213, 424 and 435 mg/l, respectively (Fig. 6). Elevated concentration of nitrate was observed in both shallow and deep wells with shallow wells having the highest concentration relative to that of deep wells (Mtoni et al. 2013). Generally, 32 % of groundwater samples collected in Dar es Salaam from 2000 to 2011 had nitrate concentration higher than the maximum concentration recommended for drinking water by WHO (2007). Furthermore, 60 % of the samples had nitrate concentrations above background concentration of 10 mg/l. Elevated concentration of nitrate in the groundwater samples collected from the city centre was associated with the leakage of untreated sewage owing to the lack of rehabilitation of ageing sewage system (Mtoni et al. 2013). On the other hand, such elevated concentration was the result of the presence of high to very high density of septic tanks and pit latrines, respectively, in areas not connected to sewage pipe like Kawe, Mbagala, Chang’ombe and Mtoni (Mato 2002; Mjemah 2007; Napacho and Manyele

2010; Bakari et al. 2012; Mtoni et al. 2013). This is a serious problem because in Dar es Salaam City, groundwater consumption is increasing at an alarming rate due to dwindling of water supply services (Mtoni et al. 2013).

According to Kibona et al. (2011), nitrate concentrations of groundwater within the Morogoro municipality ranged from 1.4 to 32.5 mg/l where wells that are less than 40 m deep had higher values. Almost 25 % of reported wells had nitrate concentration above 10 mg/l. Kilakala, the most densely populated area, had highest nitrate concentration relative to other areas (Fig. 7).

Concentration of nitrate in groundwater in the Lake Tanganyika Basin

Lake Tanganyika Basin is situated in the western part of the country. The basin covers a total of 239,000 km² from Tanzania, Rwanda, Burundi, Democratic Republic of Congo and Zambia (Fig. 1). Almost 60 % of the total runoff to Lake Tanganyika is from Tanzanian side. In the

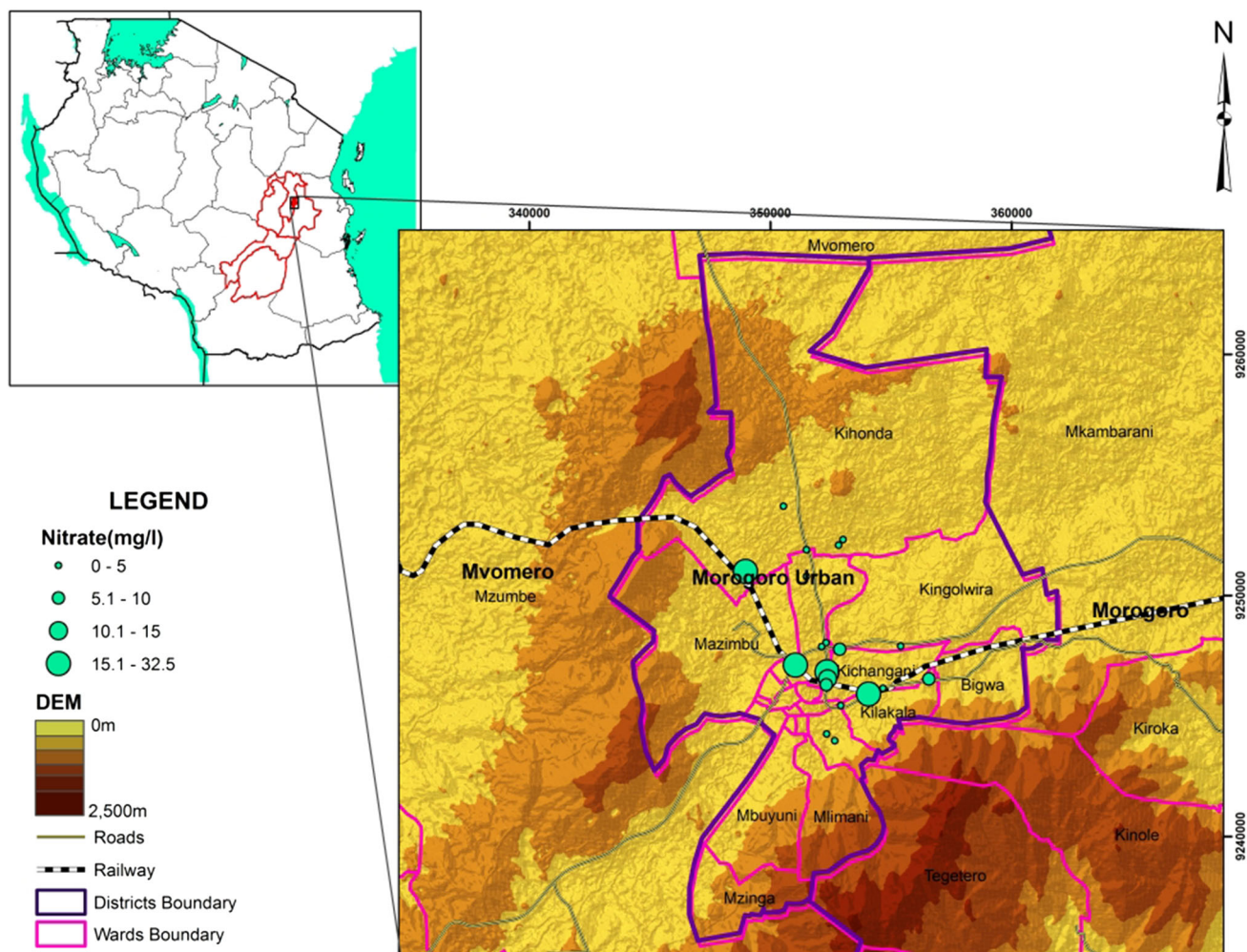


Fig. 7 Spatial distribution of nitrate (mg/l) in groundwater within the Morogoro municipality (Kibona et al. 2011)

Tanzanian side, agriculture and livestock keeping are the main economic activities (United Republic of Tanzania 2008; Jørgensen et al. 2006). USFS (2009) reported elevated levels of nitrate in the groundwater above background concentration of 10 mg/l ranging from below detection limit to 94.2 mg/l in Tabora, which indicates groundwater contamination. Such elevated levels of nitrate concentration in groundwater are probably caused by agricultural activities.

Concentration of nitrate in groundwater Zanzibar

Information on the levels of nitrate and ammonia in groundwater, which is the main source of drinking water in Zanzibar, is scarce (Gössling 2001; Hansson 2010). A few of the reported works showed that the levels of nitrate are not higher than 10 mg/l (Hansson 2010). Although the reported nitrate concentrations values in drinking water are

below the toxic level, they are, however, higher than the proposed background concentration for Zanzibar of 5.0 mg/l (Hansson 2010). This could be a signal of anthropogenic contamination, and if immediate actions are not taken, the levels could increase abruptly parallel to the increase in human population. Onsite sanitation facilities (most households use pit latrines while most hotels use soak-pits) are the main source of nitrate (Hansson 2010). There is a high positive correlation between nitrate and ammonia concentration which may indicate that it is very likely that the ammonia and the nitrate come from the same source (Hansson 2010).

Variation of Nitrate concentration with depth

Variation of nitrate concentration with depth depends on the land use, climate, hydrogeology, biological composition and physicochemical properties of the area. Mtoni

(2013) reported a decreasing trend of nitrate concentration in groundwater as the depth of the well increased. It was observed that nitrate concentration increased from below 10 m reaching a maximum at between 15 and 20 m deep then decreasing. Furthermore, Kibona et al. (2011) observed a significant negative correlation ($r = -0.8734$, $p < 0.01$) between nitrate concentration and well depth where highest concentration of nitrate (32.5 mg/l) was observed in wells of less than 35 m deep decreasing gradually to 1.4 mg/l at a depth of 65 m. The decrease in nitrate concentration with depth can be attributed to the anoxic condition common in deep wells. In anoxic condition, nitrate will be the electron acceptor of choice, hence easily reduced. With little or no oxygen, microorganisms use nitrate as an electron acceptor to oxidise organic carbon. In doing so, nitrate concentration is lowered or depleted.

Trends in nitrate concentrations in the groundwater in Tanzania

The degree of nitrate contamination in groundwater is mainly a function of past and present land use. Trends in nitrate concentration in the groundwater require long-term records of a particular aquifer. However, in Tanzania such records are missing, and there is a discontinuity of the information. For example, nitrate concentration in some wells/boreholes in Makutupora Dodoma increased from natural concentration of 0.1–10 mg/l in 1983 to above 100 mg/l in 2004 (Rwebugisa 2008). Furthermore, the average concentration of nitrate in protected Makutupora well field have been gradually increasing from an average of 0.85 mg/l in 1983 to an average of 31.87 mg/l in 2004 (Fig. 8). Similar trends can be derived from few studies conducted in Dar es Salaam. The study conducted by Mato (2002) in Dar es Salaam in 2001/02 reported high values of nitrates concentration in groundwater of up to 151 mg/l. About 5 years later, Mjemah (2007) reported a maximum value of nitrate of 421 mg/l 2005/06. Furthermore, Mtoni et al. (2012) and Bakari et al. (2012) reported 435.4 and 445 mg/l, respectively, in Dar es Salaam in 2010/11. The trend indicates that the concentration of nitrate in groundwater in Dar es Salaam is increasing with time although this observation cannot be conclusive because the values indicated above may not be of samples from the same boreholes.

Specifically, some few wells in Dar es Salaam exhibited significant changes in nitrate concentration with time (Fig. 9; Table 1). The data from such studies indicate an increase in nitrate with time (Table 1). Such an increase in nitrate concentration in the groundwater in Dar es Salaam

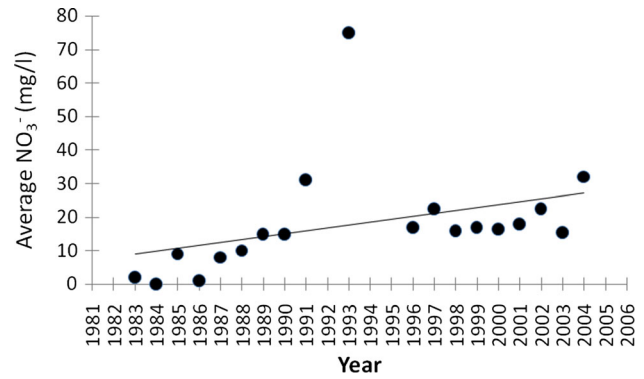


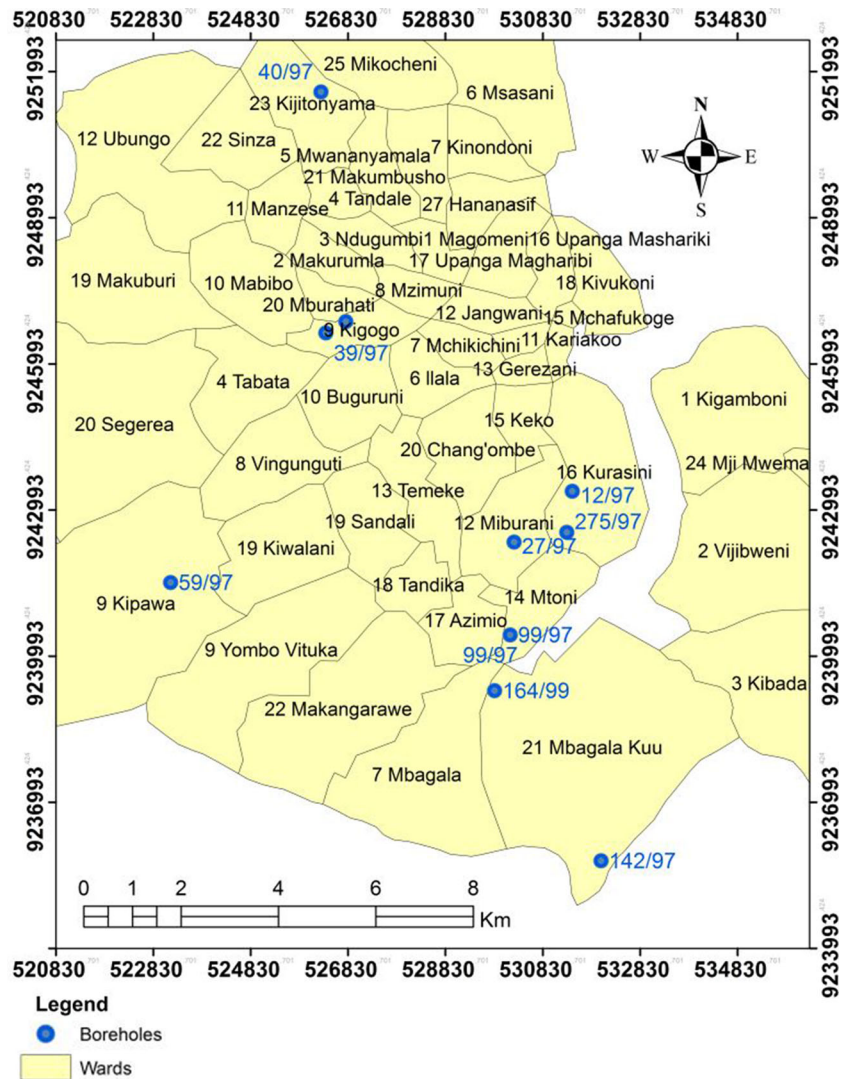
Fig. 8 Trends of average nitrate concentration (mg/l) in groundwater from MakutuporaB from 1983 to 2004 [source Rwebugisa (2008)]

Table 1 Boreholes displaying increasing or decreasing trends of nitrate concentrations (mg/l) in Dar es Salaam, Tanzania

| Borehole no. | NO ₃ ⁻ (mg/l) | Time of collection | References |
|--------------|-------------------------------------|--------------------|----------------------------|
| 66/98 | 18.3 | 2000 | Mato (2002) |
| | 97.7 | 2001 | Mato (2002) |
| 27/97 | 108.0 | 2001 | Mato (2002) |
| | 167.2 | 2005 | Mjemah (2007) |
| 12/97 | 1.6 | 2001 | Mato (2002) |
| | 78.2 | 2005 | Mjemah (2007) |
| 164/99 | 55.5 | 2001 | Mato (2002) |
| | 78.7 | 2005 | Mjemah (2007) |
| 275/97 | 19.9 | 2001 | Mato (2002) |
| | 53.4 | 2010 | Dejager (2011) |
| 99/98 | 1.4 | 2000 | Mato (2002) |
| | 36.6 | 2001 | Mato (2002) |
| 142/98 | 9.0 | 2005 | Mjemah (2007) |
| | 42.9 | 2010 | Napacho and Manyele (2010) |
| 39/98 | 14.6 | 2000 | Mato (2002) |
| | 97.7 | 2001 | Mato (2002) |
| 59/97 | 62.2 | 2001 | Mato (2002) |
| | 0.5 | 2005 | Mjemah (2007) |

was probably caused by population increase, which leads to increase in onsite sanitation facilities particularly pit latrines. However, significant decreases in nitrate concentration have been observed in some wells/boreholes. For example, nitrate concentration in borehole number 59/97 (Fig. 9) in Dar es Salaam decreased significantly from 2001 to 2005 (Table 1). Also, Rwebugisa (2008) reported decrease in nitrate concentration in some wells in Makutupora well field due to efforts to protect the well field area from impacts of human activities associated with shifting of people to other areas.

Fig. 9 Map showing locations of boreholes (Table 1) (with increasing or decreasing trends in nitrate mg/l)



Conclusion

Concentration of nitrate in groundwater in many parts of Tanzania is above the background level of 10 mg/l and in some places exceeds WHO maximum recommended levels for drinking water. Highest values were observed in urban areas of Dar es Salaam, Dodoma and Tanga where the concentration of nitrate in some aquifers was higher than 400 mg/l. Nitrate concentration in internal basin is high particularly in Hombolo sub-basin, Dodoma, where the values of nitrate concentration are as high as 449 mg/l. Similarly, high concentration of nitrate (445 mg/l) was observed within the city of Dar es Salaam. High nitrate concentrations in groundwater samples from urban areas like Arusha, Dar es Salaam, Dodoma and Tanga most likely result from contamination from sanitation systems particularly pit latrines. Generally, in urban areas, concentration of nitrate in groundwater samples decreased as one moved from densely populated areas to sparsely

populated areas probably due to decreasing density of sanitation facilities. In rural settings, elevated nitrate concentration in the groundwater probably was contributed by excessive use of fertilisers (inorganic fertilizers and animal manure). Coverage of reported nitrate values in groundwater is unevenly distributed with large part of the country lacking reported nitrate values. This calls for deliberate move to determine nitrate concentration in groundwater throughout the country so as to establish background levels of nitrate and build-up database for future use and reference. Multiple potential sources of nitrate were observed which calls for further research to trace the source of nitrate so as to ascertain the actual source of nitrate. Immediate measures are required to stop the current trend of groundwater contamination through protection of recharge basins and improve onsite sanitation systems.

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