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Nitrate pollution of Neogene alluvium aquifer in Morogoro municipality, Tanzania

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ABSTRACT

Concern over nitrate pollution of groundwater in integrated water quality management has been growing recently. The levels of nitrate in wells from septic tanks and urban agriculture with nitrogen fertilizers application may increase the potential groundwater pollution by nitrate. The purpose of this study was to determine the concentrations and spatial distribution of nitrate (NO_3^-) in groundwater in Morogoro municipality. Groundwater samples were collected from 20 wells during wet season period in March-April 2010 in 6 wards namely Kihonda, Mji Mpya, Mafisa, Saba Saba, Boma and Kilakala. The spectrophotometer was used to measure the NO_3^- concentration in water samples. The minimum and maximum nitrate levels were 1.4 and 32.5 mg/L respectively in the wards studied with an average of 7.76 mg/L. These results showed that all of the groundwater samples have NO_3^- concentration below the Tanzania Bureau of Standards upper limit value and World Health Organization guideline of 75 mg/l and 50 mg/l respectively. Also, the level of nitrate concentration tends to decrease with depth for most of the places due to the anoxic condition that is available at the higher depth which facilitates the utilization of nitrate by anaerobic microorganisms.

Keywords: Nitrate levels, shallow wells, pollution, urban environment.

INTRODUCTION

Groundwater is a natural resource with both ecological and economic value which is of vital importance for sustaining life, health, agriculture and the integrity of ecosystems. Groundwater quality may be impacted by changes in overlying land use such as industrial development, agricultural activity and wastewater generation. The contaminants for which epidemiological studies have suggested a risk associated with their presence in potable water include arsenic, fluoride, lead, nitrate, pesticides, hydrocarbons and chlorinated hydrocarbons (Orebiyi et al., 2010). The most common contaminant identified in groundwater is dissolved nitrogen in the form of nitrate (NO_3^-). It is well known that serious and occasionally fatal poisonings in infants have occurred following ingestion of well waters which contain more than 50 mg/l NO_3^- (WHO, 2007). Nitrate has been linked with gastric and oesophageal cancer, because of the reaction of nitrate with amines in the diet-forming carcinogenic nitrosamines. Further risks exist for pregnant women and for patients with gastric medical conditions, and with hemoglobinopathy (Gatseva and Argirova, 2008). Despite the World Health Organization's guidelines (WHO, 2007) for drinking water quality, nitrate levels in groundwater have been increasing over recent decades in most countries (Razowska-Jaworek and Sadurski, 2005; Barbooti et al., 2010; Jiban Singh et al., 2010).

In Africa, scarcity and water pollution constitute a major challenge for sustainable water resources management (Tredoux and Talma, 2006). In Tanzania, the government has passed a new Water Supply and Sanitation Act (URT, 2009) with a view to give effect to the National Water Policy (URT, 2002). The main aim of this law is to ensure the rights of every Tanzanian to have access to efficient, effective and sustainable water supply and sanitation services for all purposes by taking into account among others, protection and conservation of water resources and development and promotion of public health and sanitation. Though little studies of nitrate pollution have been done on a local scale in Tanzania (Mjemah, 2007; Kassenga and Mbuligwe, 2009), there is limited groundwater monitoring data to help manage the resource on a regional scale. The objective of this study was to determine the levels and spatial distribution of nitrate in wells at Morogoro municipality.

MATERIALS AND METHODS

Geological and hydrogeological settings

The geology of the study area is composed of two geological units; the Precambrian Basement Complex, and the Neogene. The Precambrian basement known as Usagaran system covers a vast area in the basin, where the study area is located. It is the fundamental rock in the Uluguru Mountains and composed of high grade metamorphic rocks essentially granulites, gneisses and amphibolites of various compositions. In some places, these rocks are intercalated with marbles. The Neogene formation is composed of thick deposits of red soil occurring in the north-west of Morogoro Town; in the extreme north-west is the edge of the ‘mbuga’ soils and alluvium of the Wami Flats (not shown in the map since it is outside the study area). Generally, the Neogene formation is the one forming the major aquifers with potential water in the study area though its thickness in the study area is about 50 m. The study area is crossed in the centre by Morogoro River and Ngerengere River, which both are originated from Uluguru Mountains as shown in Figure 1.

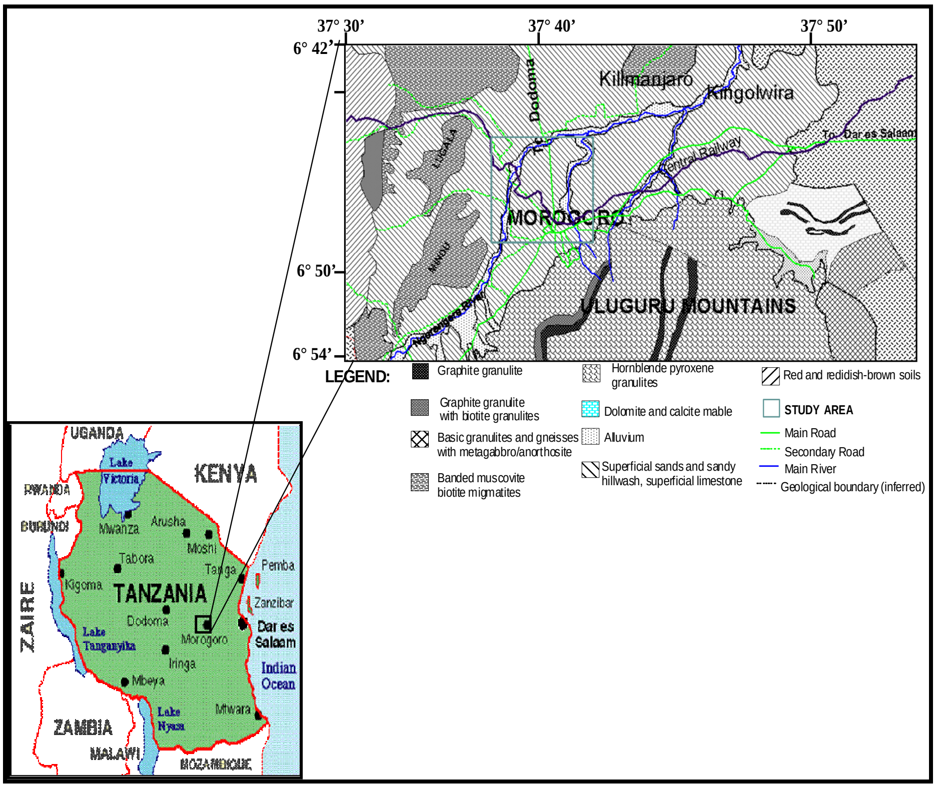

Figure 1: Morogoro geological map showing study area (Sampson, 1961).

Sample collection and analysis

Groundwater samples were collected from the 20 water wells in Morogoro municipality (Figure 2). The water samples were collected once a month for each well during rain season in March and April 2010. Groundwater samples were transport to laboratory with ice bag and examined immediately. Most of the groundwater samples were collected from wells inside or close to residential and commercial areas; these wells were used mainly for potable supply, washing, and irrigation. Water samples were analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS) and nitrate (NO_3^-) as described in the Standard Methods (2005). The pH and EC were measured in situ using pH and EC-meter. The TDS was analysed by TDS meter and nitrate analysis was done using Spectrophotometer analytical method in the laboratory of Morogoro Urban Water Supply and Sewerage Authority (MORUWASA). However, the spectrophotometric method with phenol disulphonic acid was used to analyze NO_3^- when salinity was too high for NO_3^- to be detected in a diluted sample. The information on groundwater use and screen depth was respectively obtained through communications with well owners and well lithology data.

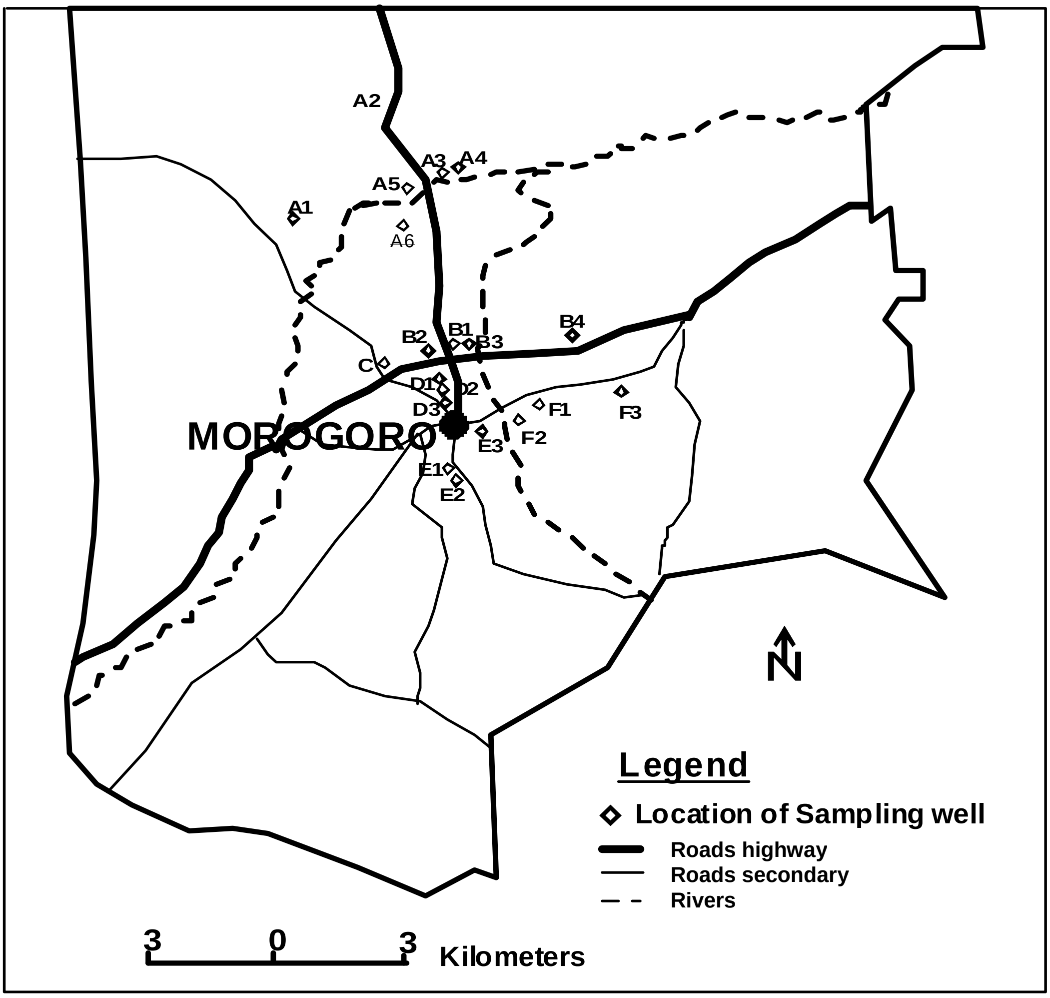

Figure 2: Location of groundwater sampling at Morogoro municipality.

RESULTS AND DISCUSSION

Table 1 shows the results of chemical constituents, pH, EC, TDS and nitrate concentrations of groundwater samples from 20 wells in Morogoro municipality. The depths of the wells are also shown in Table 1.

PH

Measurement of pH is one of the most important and frequently used tests in water chemistry which related to the concentration of hydrogen ions in solution (Reeve, 2002). Table 1 shows the pH values obtained from this study area which ranged from 7.0 to 8.65. According to the TBS (2005) lower and upper limits for quality of drinking water are 6.5 and 9.2 respectively. The results from the present study show that the observed pH can slightly increase the solubility of metal and precipitate heavy metal as hydroxides hence increase their groundwater contamination. Also, the weathering of minerals, such as limestone or dolomite, by water becomes more rapid with a decrease in pH (Reeve, 2002) which was not expected in this area. At low concentrations of hydrogen ions and low ionic strengths, which are typical of unpolluted environmental samples, the hydrogen ion activity is approximately equivalent to the hydrogen ion concentration. The biological effect of a change in pH can most easily be seen by the sensitivity of freshwater species to acid conditions. Lethal effects of pH on aquatic life occur below pH 4.5 and above pH 9.5 (WHO, 2007).

Total dissolved solids

The substance remaining after evaporation and drying of a water sample is termed the “residue”. The filterable residue is the Total Suspended Solids (TDS) which is a measure of the amount of dissolved material in the water column reported in milligrams per litre (mg/L). The most important aspect of TDS with respect to drinking water quality is its effect on clarity and taste. Also, the total amount of dissolved solids in groundwater is estimated by measuring the EC of the water, and this is often used as a rough indication of natural groundwater quality (Reeve, 2002). From this study, the values of TDS range from 332-2670 mg/L with an average of 1112.7 mg/L (Table 1). Differences in TDS were also observed in some closely-spaced wells (Figure 2) and this is attributed either to the depth of the well or to interconnection with higher, more saline, strata. Contamination from external sources can also be an additional factor. The observed TDS levels are below the recommended limit for drinking water supplies. The palatability of drinking water with a TDS level less than 500 mg/L is generally considered to be good. Drinking water supplies with TDS levels greater than 1200 mg/L are unpalatable to most consumers (WHO, 2007). The principal constituents that contribute to elevated filterable residue values are usually dissolved salts such as calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulphate and nitrate. High concentrations of TDS limit the suitability of water as a drinking source and irrigation supply (Razowska-Jaworek and Sadurski 2005).

Electrical conductivity

The ability of water to conduct an electric current is known as conductivity or specific conductance, and depends on the concentration of dissolved metals and other dissolved materials (ions) in solution (Reeve, 2002). Conductivity is measured in milisiemens per meter (1 mS/m = 10 µS/cm). The EC measurement was made in the field immediately after water sampling, because conductivity changes with storage time and is also temperature-dependent. The spatial distribution of electrical conductivity (EC) from analysed groundwater samples across the study area is shown in Figure 3. Kihonda (ward A) depicted higher EC due to higher TDS and possibly salinity. The EC values ranged from 661 to 5350 µS/cm with an average of 2214.45 µS/cm (Table 1). The conductivity of natural waters is found to vary between 50 and 1500 µS/cm and generally EC is < 500 µS/cm except for areas very near to the Ocean were EC > 1500 µS/cm or even up to 5000 µS/cm because of the possible occurrence of coastal salinization (Reeve, 2002). In this study EC was well correlated with total dissolved solid (r^2= 0.99) from analysed groundwater samples across the area as shown in Figure 4. It is often possible to establish a correlation between conductivity and dissolved solids for a specific body of water [dissolved solids = conductivity x 0.55 to 0.9 (the factor most often used is 0.7)]. The variation of the empirical factor, from 0.55 to 0.9, depends on the ionic components in solution and on the temperature of measurement (Reeve, 2002).

Groundwater nitrate concentration

The nitrate concentrations of groundwater in 20 wells that were sampled in Morogoro municipality are shown in Table 1. The minimum and maximum nitrate levels were 1.4 and 32.5 mg/L respectively with an average of 7.76 mg/L. The spatial distribution of NO_3^- from analysed groundwater samples across the study area is shown in Figure 3. The low concentration of NO_3^- in the area indicates the least anthropogenic sources of pollution. However, vegetables are the main urban agricultural activities in the Municipal which farmers use inorganic N-fertilizers (and organic manure) that can result in groundwater contamination in vulnerable hydrogeologic settings. In comparison, wards A, B, C, D, E, and F show different mean in nitrate contents, 3.0, 3.8, 15.2, 3.1 and 14 8 mg/l respectively. Of the six wards, the highest average nitrate concentration in groundwater was observed in ward D, followed by ward F, B, E and A. The observed NO_3^- levels are lower than the Tanzania Bureau of Standard (TBS) upper permissible limit value and World Health Organization (WHO) guideline of 75 and 50 mg/L respectively (TBS, 2005; WHO, 2007) respectively.

Variation of nitrate concentration with well depth

Figure 5 shows the variation of NO_3^- concentration with depth. It can be observed from the graph that the trend of NO_3^- is decreasing with depth, though there are some deep wells with high NO_3^-, however, this can be due to the multiple screens. The decrease of NO_3^- observed in the shallow wells as the depth increases is related to the anoxic condition. In anoxic condition, organic carbon tends to be oxidized preferentially by the electron acceptor that supplies most energy to the micro-organisms, namely oxygen. With an excess of organic carbon, aerobic bacteria use dissolved oxygen until it is depleted. Once oxygen concentrations are depleted, which mostly occurs in the deep aquifer, reduction of other electron acceptors (such as NO_3^-) becomes energetically favourable. Once oxygen is consumed, denitrifying-bacteria use nitrate as an electron acceptor; when the nitrate is depleted, reduction reactions proceed through manganese and then iron oxides.

Table 1: Physico-chemical parameters of groundwater samples from Morogoro municipality.

Area	Well Code	Depth	pH	EC	TDS	Av. NO_3^- Conc.
		M		µS/Cm	mg/L	mg/L
Kihonda	A1	40	8.53	5350	2670	15.3
Kihonda	A2	61	8.17	4070	2030	2
Kihonda	A3	55	8.65	1004	506	5
Kihonda	A4	65	8.2	996	498	2
Kihonda	A5	52	8.49	4300	2149	4.3
Kihonda	A6	63	8.21	4600	2294	2.7
Mafisa	B1	55	7.94	1660	827	4.2
Mafisa	B2	65	7.75	897	451	2.2

Mafisa	B3	50	7.32	3930	1980	7.5
Mafisa	B4	52	7.27	2300	1150	1.4
Saba Saba	C	35	7.4	2730	1360	22.5
Mji Mpya	D1	45	7.2	1799	906	14.1
Mji Mpya	D2	33	7	2520	1307	21.8
Mji Mpya	D3	48	7.8	1052	527	9.8
Boma	E1	60	7.2	812	406	3.9
Boma	E2	65	7.4	661	332	2.3
Boma	E3	58	7.2	1263	640	3.2
Kilakala	F1	52	7.2	1524	778	2.8
Kilakala	F2	37	7	1627	835	32.5
Kilakala	F3	48.5	7.2	1194	608	9

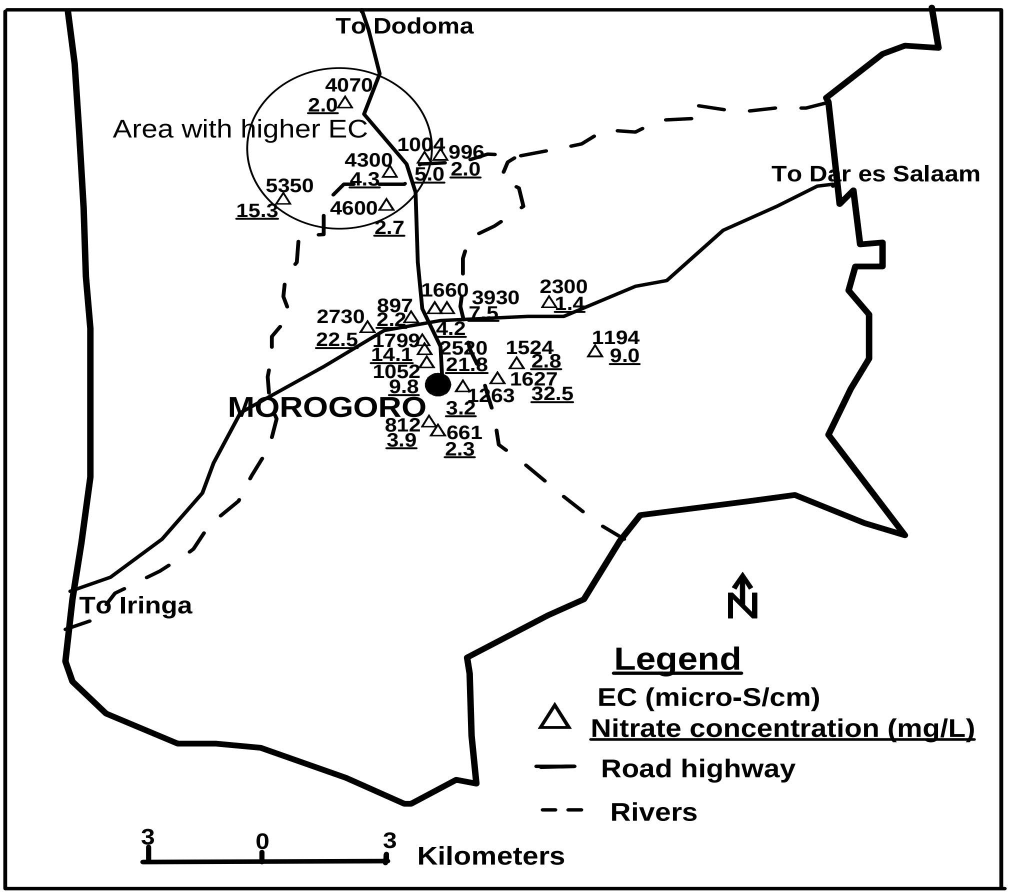

Figure 3: The EC (measured at 25 °C in µS/cm) and NO_3^- concentration (mg/L) of groundwater in Morogoro municipality.

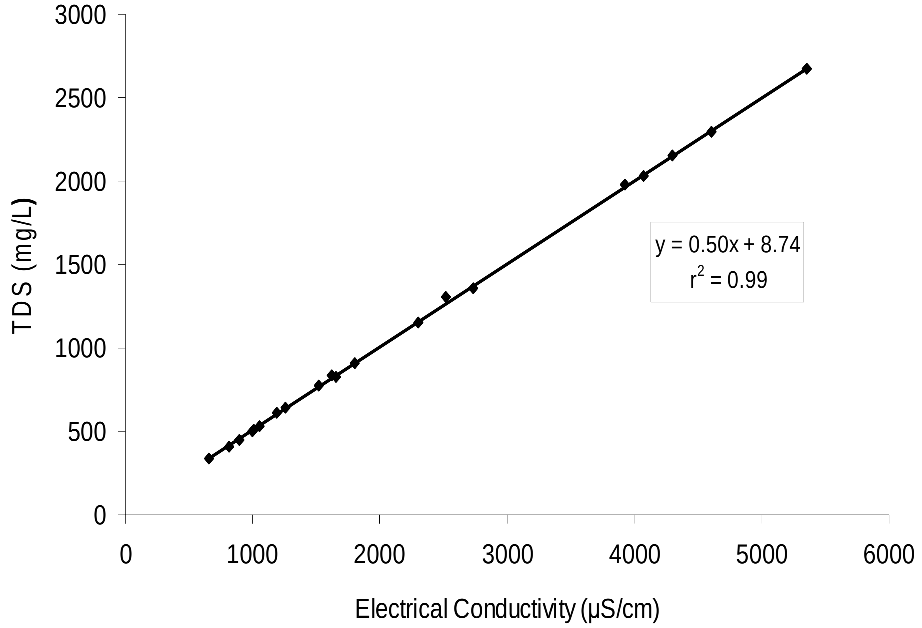

Figure 4: The correlation between EC and TDS of the aquifer at Morogoro municipality.

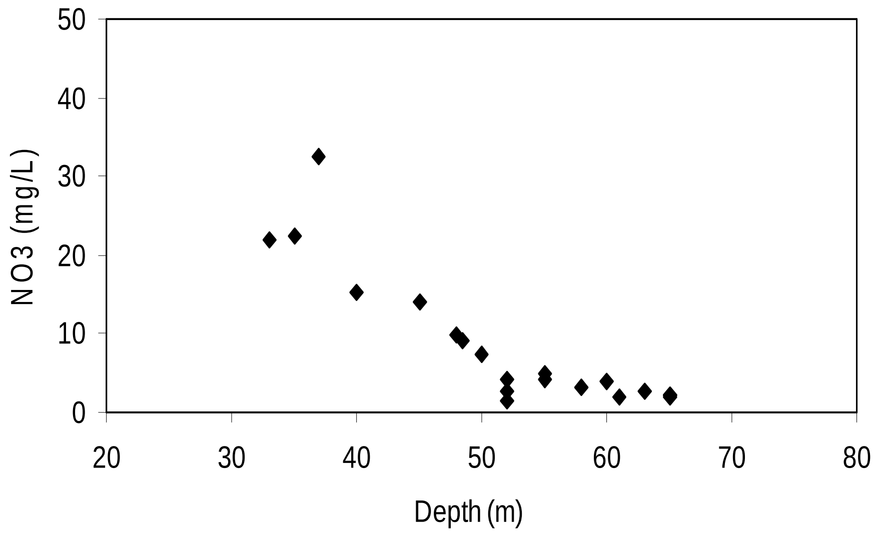

Figure 5: The variation of NO_3^- concentration with depth.

Conclusion

The objective of this study was to assess the groundwater pollution of nitrate in Morogoro municipality. The magnitude of the pollution in this area depends on human activities, including agriculture and livestock breeding. The results show that high nitrate concentration occurred mainly in wells with depths less than 41 m. However, all groundwater samples in the selected wards have nitrate concentration below the TBS standard and WHO guideline. The high nitrate concentration in the study site is contributed by large volumes of wastewater from septic tanks. Although groundwater is not only commonly used as drinking water in Morogoro municipality, nitrate in groundwater remains a critical issue associated with mass transport, waterway transformation, and interactions of surface-groundwater. The Ministry of Health, Ministry of Water and irrigation, and the National Environment Management Council (NEMC) should work very closely to enforce appropriate pieces of legislation in order to ensure protection of groundwater resources. All wastewater should be treated before being discharged into the environment. Further study of all major ions for ionic balance and their seasonal variations are needed to better judge the reliability of the chemical analysis.

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