Spatial Nitrate Distribution in the Drinking Water Sources Found in Ethiopia; *Retrospective study*

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Abstract: High levels of nitrate in drinking water can cause methaemoglobinaemia, cancer, hypertension, infant mortality and birth defects. In Ethiopia, there is no comprehensive study that shows level of nitrate in the drinking water sources across the country. The objective of this retrospective study was to investigate the spatial variation of nitrate concentration in the drinking water sources nationally. The study was conducted using the Ethiopian Health and Nutrition Research Institute water quality database from 1993 to 2007. The results in the study indicated that nitrate concentration in the water samples were varied from below 0.00mg/l to 1295.00mg/l throughout the country. The average nitrate concentration in the well water exceeding the WHO guideline was observed in Dire Dewa (104.8mg/l) and exceeding the threshold value were found in Somali (37.0 mg/l), Afar (34.9 mg/l), Harari (26.3 mg/l) and Addis Ababa Regions (20.5mg/l). In the rest region, it was below the threshold value of nitrate. Nitrate in the spring water was below the threshold value except Dire Dewa and Harari regions. Nationally, 15.3 % (n=186) of the wells, 10 % (n = 33) of the springs and 12.4 % (n=21) of the taps had nitrate concentration exceeding the threshold value of 20mg/l and 5.7 % (n = 70) of well water and 2.7 % (n = 9) of spring water samples had nitrate concentrations higher than 50mg/l. Water resources control management can be important at these areas and it needs to apply some actions to reduce or remove nitrate from drinking water.

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1. Introduction

Water is essential for the survival of humans, animals and plants. Contamination of water source with different pollutants may render water sources unsuitable for consumption and put human and animal live as well as the whole environment at a great risk. Nitrate is the most frequently introduced pollutant into the groundwater system. Nitrate in the environment comes from both rural and urban sources (Abdulrahman et al., 2010; Syed and Saadat, 2005). Microbial action in soil or water decomposes wastes containing organic nitrogen into ammonia, which is then oxidized to nitrite and nitrate. Nitrate is the compound predominantly found in groundwater and surface waters. High levels of nitrates in ground and surface water originate mainly from agriculture activities and disposal of human and animal waste (Fields, 2004; Ward *et al.*, 1994). In agricultural areas, nitrogen-based fertilizers are a major source of contamination for shallow groundwater aquifers that provide drinking water (Babiker et al. 2004). Other sources of nitrate contamination are organic animal wastes and contamination from septic sewer systems, landfills, leaky sewage system and gasoline stations (Wakida and Lerner, 2005).

Contamination of drinking water by nitrates is an evolving public health concern since nitrates can undergo endogenous reduction to highly toxic compounds such as; nitrites and nitrosamine (Ward *et al.*, 1994; Chiu and Tsai, 2007). Methemoglobinemia is the primary adverse health effect associated with human exposure to nitrate or nitrite (Deana *et al,* 2010). Acquired methemoglobinemia due to exposure to nitrates in drinking water is considered primarily an issue for infants less than six months old (Deana *et al*, 2010; Ayebo *et al.*, 1997). Pregnant women are also considered vulnerable to the effects from exposure to high levels of nitrate in drinking water (Deana et al, 2010). The second adverse health effect of nitrates in drinking water is the possibility of increased cancer risk (via the bacterial production of N-nitroso compounds), hypertension, increased infant mortality, central nervous system birth defects, diabetes, spontaneous abortions respiratory tract infections and changes to the immune system (Gheisari *et al.*, 2005; Babiker, 2004; Gupta *et al.*, 2000; Ward *et al.*, 1994; Chiu and Tsai, 2007).

Groundwater with nitrate concentration exceeding the threshold of 20 mg/L is considered contaminated as result of human activities (Spalding and Exner, 1993). Recent studies revealed that water contamination with nitrate is globally growing problem due to the high rate of population growth and increasing consumption (Jalali, 2005). In most

European countries, nitrate levels in rivers and ground waters have increased gradually over the last decade mainly as a consequence of large-scale agricultural application of manure and fertilizers, thereby threatening drinking water quality (Stringer, 1988). World Health Organization (WHO) guidelines on the quality of drinking water indicate a maximally admissible nitrate concentration of 50.0 mg nitrate/L (Stringer, 1988; Duijvenbooden, 1989).

In Ethiopia, the dominant source of drinking water used to supply major urban and rural communities is from wells and springs (Gebrekidan and Samuel, 2011). Although there are no systematic and comprehensive water quality assessment programs in the country, there are increasing indications of water contamination problems in some parts of the country. The major causes of this contamination could be soil erosion, domestic waste from urban and rural areas and industrial wastes. However, information on the water quality of Ethiopia is very scant. This paper examines the concentration of nitrate in the well water, spring water and tape water which were collected and analysed from different regions of Ethiopia.

2. Material and Methods

2.1. Country description

Ethiopia lies in the north-eastern part of the Horn of Africa between 3^0N and 15^0N latitudes and 33^0 E and 48^0E longitudes. The country is landlocked and is surrounded by Djibouti to the east, Somalia to the southeast, Kenya to the south, Sudan to the west, and Eritrea to the north and northeast. It has a total area of 1,127,127 km2. Ethiopia is a country with great geographical diversity, with a topography ranging from 4550 metres above sea level to 110 metres below.

Administratively Ethiopia consists of nine regions – Afar, Amhara, Benshangul-Gumuz, Gambella, Harari, Oromia, Somali, Tigray and the Southern Nations, Nationalities and Peoples Region (SNNPR) and two administrative councils (Addis Ababa and Dire Dawa). Each regional state is subdivided into zones and *woredas*.

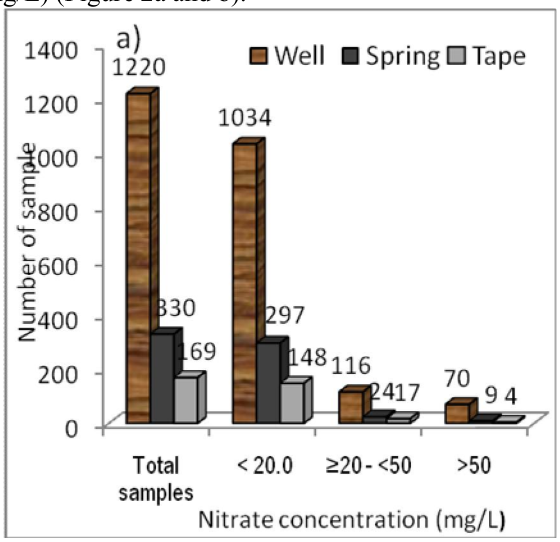
Figure 1. Map of Ethiopia and the nine regional states

2.2. Sample collection and analysis:

This retrospective study of Nitrate was conducted using the Ethiopian Health and Nutrition Research Institute water quality database. The water samples were collected by Environmental health professional using plastic container. The nitrate concentration in the water sample was measured using the phenoldisulfonic acid method according to water and wastewater analysis (APHA, 1965). Nitrate test results data between 1993 to 2007 organized and analyzed using excel. The total numbers of the water samples assessed were 1719 and from this 1220 were from well water, 330 from spring and the remaining 169 were from tape water. The concentration of nitrate in the water samples were compared with WHO guideline.

3. Results and Discussion

Nitrate concentration in the water samples varied from less than 0.00mg/l to the maximum of 1295.00mg/l throughout the country. The samples were classified into three groups based on their nitrate concentrations. These included the following; low (<20 mg/L), medium (≥20 to <50 mg/L) and high (>50 mg/L) (Figure 2a and b).



Nitrate concentration in the low class indicates samples with a low risk for human or environment. The medium class involves samples with nitrate concentration high enough to indicate the influence of human activities (Spalding and Exner, 1993; Mutewekil *et al.,* 2008). About 15.3 % of the wells water samples (n=186), 10 % of the springs water samples (n = 33) and 12.4 % of the tap water samples (n=21) had nitrate concentration higher than 20mg/L, the threshold value of anthropogenic source. Nitrate concentrations in the high class exceed the WHO drinking water recommendation guideline (WHO, 1993). 5.7 % of well water samples (n = 70), 2.7 % of spring water samples (n = 9) and 2.4 % of the tap water samples (n = 4) had nitrate concentrations higher than 50mg/l, the maximum acceptable nitrate concentration for drinking water (the national guideline). This information is further broken down by region (Table 1 and 2). Moreover, the areas which have high nitrate concentration above the national and WHO standard are summarized in Table 3.

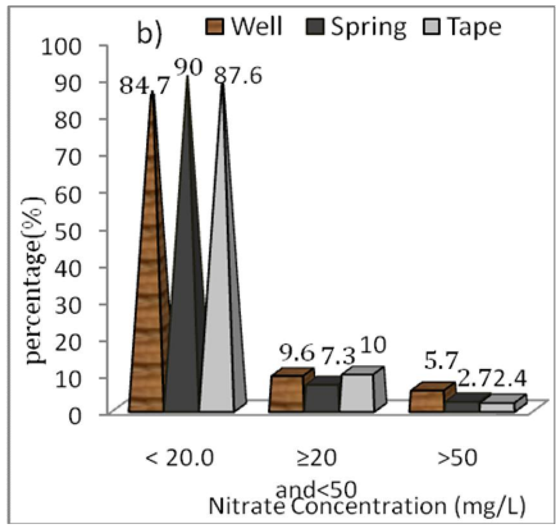


Figure 2. a) Number of samples with different concentration of nitrate; b) Percentage of samples with different concentration of nitrate

Table 1. Nitrate and nitrite concentration in well waters collected from different regions

Region	Total *NO.	Nitrate concentration (mg/L)								Nitrite	
		≥20 - <50		>50mg/L		≤0.00mg/L		Mean value	Max. value	>3mg/L	
		*No.	(%)	*No.	(%)	*No.				*No.	(%)
Afar	106	10	9.4	11	10.4	12	11.3	34.9	294.5	7	6.6
Addis Ababa	189	33	17.4	20	10.6	20	10.6	20.5	327.3	3	1.5
Amhara	121	9	7.4	8	6.6	12	9.9	11.3	166	3	2.4
Benishangul	46	0	0	3	6.5	21	45.7	14.2	409	0	0
Dire Dawa	19	4	21	12	70.6	-	-	104.8	271.6	0	0
Gambela	12	1	8.3	0	0	6	50	3.4	40	0	0
Oromia	568	36	6.3	6	1.1	119	20.9	6.09	114.3	8	1.4
SNNPR	54	0	0	0	0	17	31.5	2.72	1.41	0	0
Somali	22	2	9.1	4	18.2	6	27.3	37	376.6	2	9
Tigray	72	17	23.6	4	5.6	9	12.5	19	235	7	9.7
Harari	12	4	33.3	2	16.7	1	8.3	26.3	79.14	0	0

*No. = Number of samples

Table 2. Nitrate concentration in spring and tape water collected from different regions

Region	Nitrate concentration in spring water						Nitrate conc. in tape water			
	Total *No.	No. sample ≥20 - <50 (mg/l)	No. sample >50 (mg/l)	≤0.00 (mg/L)	Mean value (mg/l)	Max. value (mg/l)	Total *No.	*No. > 50 (mg/l)	Mean value (mg/l)	Max. value (mg/l)
Afar	8	0	0	1	2.3	2.66	7	0	6.7	17.7
Addis Ababa	11	1	0	2	12.3	69.6	65	0	1.6	4.9
Amhara	57	7	3	11	12.6	98.4	3	0	0.3	0.9
Benishangul	3	0	0	1	0.24	0.36	0	–	–	–
Dire Dawa	4	2	1	1	49.4	126.8	0	–	–	–
Oromia	126	7	1	30	6.5	314.5	48	0	3.6	26.4
SNNPR	40	1	1	17	5.1	61	5	0	2.1	5.12
Tigray	19	5	0	2	14	38.3	4	0	0.7	2.2
Harari	4	0	1	-	58.4	260	5	0	21.3	36.7

*No. = Number of samples

Table 3. Woreda/village which have high concentration of Nitrate in their water sources

Region	Zone	Woreda/ village	Sample source	NO_3^- (mg/l)
Afar	Zone-1: Dubty, Asayita, Middle Awash, Elidar, Afambo, Hamiltole,Handeg, Geyreni and Gilifega		well	256.4
Amhara	N/Gonder	Debremariam spring/Azezo	spring	51.6
	N/ Shewa	Eyerusalem, Gozie, Kecheni	well	83.3
	Wagimra (Sekota)	Kative, Kitibe	Spring	77
		Beleka, Ekmetsekue, Selessia, Tsebiyo cherkose	well	92.4
Benishanguel	Dabatie (pawie)		well	193.6
Oromia	E/ Shewa: Metahara, Debrezeit, and Akaki		well	72.9
Somali	Jijiga: Jijiga, Jerere valley(KebriBeyah)		well	97.4
Tigraye	Kilte-Awlaelo(E/zone), Sheraso town, Chekentemy, Mai Daga / Axum, Mekele		well	112.8

In Afar region, 106 well water, 8 spring and 7 tap water samples were collected and analyzed. The maximum and average nitrate concentrations detected were 294.5 and 34.9, 2.3 and 2.66, and 6.7 and 17.7 mg/L as NO_3^-, for well, spring and tape water, respectively (Table 1 and 2). Nitrate concentration in the spring and tape water samples was very low. Nitrate concentration in all the spring and tape water samples were complying with the national and WHO standard of nitrate. However, the average concentration of nitrate in all the well water samples was above the threshold value of nitrate. Moreover, 19.8% of samples (n=21) had nitrate concentration above the threshold value of 20mg/L of anthropogenic and 10.4 % of samples (n=11) were above the national standard. The nitrite concentration of 6.6% of the sample (n=7) was also above 3mg/l which is the national and WHO standard of nitrite (3mg/l). Water samples, which had high concentration of nitrate, were collected from Dubty, Assaita, Middle Awash, Elidar, Afambo, Hamiltole, Handeg, Geyreni and Gilifega village (Table 3). All these villages are located in the lower valley of the Awash River. In the Lower Awash Valley, salinity problems and evapotranspiration are very high throughout the area (Taddesse *et al., undated*). For example, Potential evapotranspiration (PET) at Dupti is 2348 mm which is over ten times the average annual rainfall (Taddesse *et al., undated*). Study indicated that in the saline groundwater, evaporation may increase nitrate concentration in the ground water (Piromleart, 1995). This could be one of possible factors for high concentration of nitrate. The other possible factors could be the intensive agricultural activities in the region. Large- scale irrigated farming is common on the floodplain in the lower valley. More than 62500 hectare of land is cultivated using irrigation (Taddesse *et al., undated*).

In Addis Ababa, 189 well water, 11 spring water and 65 tape water samples were collected from all part of the city. The concentration of nitrate in the tape water were very low in all the samples with an average value of 1.6mg/L and nitrate in all the sample were with in the national standard. The mean value and maximum value of spring water samples were 12.3mg/l and 69.6 mg/l, respectively. One spring water sample only did not comply with the standard.

However, nitrate concentrations were high in the well water samples. The average value of nitrate concentration was 20.5mg/l, which is above the threshold value, and maximum value detected was 327.3 mg/L. Out of 189 well samples, 28% of the samples (n=53) were above the threshold and nitrate concentration in 10.6 % of the samples (n=20) exceed the national standard. The high nitrate levels are likely caused by a lack of proper sewers and other waste disposal facility. The majority of the households (75%) in Addis make use of a pit latrines discharging to open drains and about 15% have flush toilets and septic tanks, these likewise often discharging to open drains (Alemayehu *et al.,* 2009; AAWSSA, 2008). According to Yates (1985) improperly used septic tanks can be still the largest contributors of wastewater to the subsurface water. On the other hand, twenty samples (10.6%) had nitrate concentration below 0.00mg/l and all these samples were collected from the foot of Entoto Mountains. Nitrate contamination Addis Ababa aquifer is well documented in different studies (Taye**,** 1998; UN, 1989).

One hundred twenty one well water and fifty seven spring water samples were collected and analyzed from different parts of Amhara region. The average and maximum value of nitrate concentration were 11.3 and 166mgl/L for well water, and 12.6 and 98.4 mg/l for spring water (Table 1 and 2). Nitrate concentrations above the national standard were detected in 6.6 % of the well water samples (n=8) and 5.2 % of the spring water samples (n=3). Nitrite concentration was also high in 2.4 % of well samples (n = 3). Nitrate concentration above the national standards was detected in some areas of three zone in Amhara region (Table 3). In Wagimra zone, spring water from Kative and Kitibe, and well water from Beleka, Ekmetseku Selessia and Tsebiyo cherkose had nitrate concentrations which exceed 50mg/L. One spring water from North Gonder (Azezo) had also concentration of nitrate above the standard. On the other hand, in North Shewa zone only well water from Eyerusalem, Gozie and Kecheni had nitrate concentration above the standard (Table 3).

In Benishangul region, 46 well water and 54-spring water samples were analyzed. The average and maximum value of nitrate detected were 14.2 and 409, and 0.24 and 0.36mg/l for the well and spring, respectively (Table 1 and 2). Twenty one samples (45.7 %) had nitrate concentration below 0.00mg/L. On the other hand, water samples from three wells (6.5%) exceeded the maximum nitrate contamination levels allowed in drinking water. These water samples were collected from Metekel zone at Pawie (Table 3).

The numbers of well, spring and tape water samples collected from different parts of the Oromia region were 568, 126 and 48, respectively (Table 1 and 2). The average and maximum value of nitrate concentration in the samples were 6.09 and 114.3 mg/l for well water, 6.5 and 314 mg/l for spring water, and 3.6 and 26.4 mg/L for tape water samples, respectively (Table 1 and 2). Out of 568 well samples, 20.9% of samples (n=119) and 23.8% of spring samples (n=30) had nitrate concentration below 0.00mg/L. On the other hand, nitrate concentration in 0.8% of the spring and 1.1% of the well samples (n = 6) were above the national standard. From the well water samples, 1.4 % of the samples (n=8) had also nitrite concentration above 3mg/L (above the standard). Well waters from Metehara, Akaki and Debreziet had average nitrate concentration of 72.9 mg/L which is above the acceptable level (Table 3). The high concentration of nitrate in East Shewa zone could be attributed to both agricultural practice and sewage discharge.

In Dire Dewa region, 19 well water and 4 spring water samples were analyzed. The average and maximum value of nitrate concentrations detected were 104.8 and 271.6mg/l, and 49.4 and 126.8 mg/l, for well and spring water, respectively (Table 1 and 2). Water samples from 18 of these wells (94.7%) had nitrate concentration above the threshold value of nitrate. Nitrate concentration in 12 well samples (70.6%) and 1 spring sample exceed the WHO and national standard. Well water samples from Harari region had nitrate concentration ranged between 0.00 and 79.14 mg/L, with an average of 26.3mg/l which is above the threshold value for nitrate. Out of the total samples, two samples (16.7%) had nitrate concentration that exceeds 50mg/L, the maximum acceptable level.

Twenty two and twelve well water samples were analyzed from Somali and Gambela region, respectively. In Somali region, the average nitrate concentration was 37mg/L which is above the maximum threshold value and the maximum value detected was 376.6mg/L. Nitrate concentration in 18.2% of the sample (n=4) exceed the national standard. The high value of nitrate was associated with human actives. However, in Gambele region, both the average value (3.46mg/L) and the maximum value (40mg/L) were within the national standard. The high concentration of nitrate in the groundwater resource of Dire Dewa, Harari and Somali region could be caused by factors similar to those causing nitrate problems in Addis Ababa.

In SNNRP region, 54-well water, 40-spring water and 5-tape water samples were analyzed. The concentration of nitrate in water samples from all wells were detected very low which had an average value of 1.41mg/L and a maximum value of 2.72 mg/L. One sample from the spring water had nitrate concentrations which exceed the maximum allowed levels for drinking water.

In Tigray region, 72 well water, 19 spring and 4 tape water samples were analyzed. The average and maximum nitrate concentrations detected were 19 and 235, 14 and 38.3, and 0.7 and 2.2 mg/L as NO_3^-, for well, spring and tape water, respectively (Table 1 and 2). All spring and tape water samples were comply with national standard of nitrate. However, nitrate concentrations in 21 well water samples exceed the threshold value of nitrate and 4 samples were above the national standard. The high levels nitrate were recorded in the water sample collected from Kilte-Awlaelo (E/zone), Sheraso town, Chekentemy, Mai Daga / Axum and Mekele (Table 3). Tekle *et al* (2004) assessed nitrate pollution in Aynalem and Mekele groundwater sources of drinking water for Mekelle city. It was reported that nitrate levels in the downstream wells of Mekele had above 50mg/l. The reported possible sources of nitrate are animal feedlots and municipal wastes. NEDECO (1998) had also reported high nitrate concentrations in polluted wells around large towns such as Mekele, Indasilase and Shiraro (NEDCO, 1998).

4. Conclusion

The result of this study indicated that nitrate concentration in the water samples varied from below 0.00mg/l to 1295.00mg/. Nationally, 15.3 % (n=186) of the wells, 10 % (n = 33) of the springs and 12.4 % (n=21) of the taps had nitrate concentration exceeding the threshold value of 20mg/l and 5.7 % (n = 70) of well water and 2.7 %(n = 9) of spring water samples had nitrate concentrations higher than 50mg/l. The highest concentration of nitrate were found in the water samples collected from Dire Dewa, Harari, Afar and some water samples collected from Addis Ababa, Amhara, Oromia, Tigary and Somali regions. On the other hand, the highest compliance was recorded in SNNRP, Gambela and Benishangul region. Water resources control management can be important at these areas and it needs to apply some actions to reduce or remove nitrate from drinking water.

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