Low Cost Sanitation and its impact on Quality of Groundwater in Addis Ababa

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Abstract

Addis Ababa the capital city of Ethiopia is home to over 2.7 million people, and has an area of about 530.14 km^2. One of the challenges faced by the city administration is the provision of clean water to the residents. Recent attempts to address this shortage have mainly focused on abstraction of groundwater. On the other hand the city's sanitation service coverage is considered to be low, with a majority of the population relying on pit latrines. It is considered that the human waste from the proliferation of pit latrines in the city may have increased contamination of groundwater resource. Boreholes in the city were assessed for the presence of two chemicals, nitrate and chloride commonly found in human waste. These chemicals are considered to be indicators of fecal contamination. Maps of the level of these chemicals indicate the spatial extent of contamination is high in the city center around the minor aquifer areas. The major aquifer area displays a relatively low contamination.

Key words

Addis Ababa, low cost Sanitation, pit latrines, contaminants, contamination, groundwater, nitrate, chloride,

Introduction

Poor sanitation service has been one of the major problems in Addis Ababa. The first attempt to address this problem appears to have been undertaken in the 1920s when the sanitation inspection section was established under the municipal police. A notice of cleanliness and health was also issued in 1927, and in 1928 the *Yetsidat Zebegna* or sanitation guards were set up to ensure environmental sanitation when residents started cleaning dirt and burying it. Public latrines were also instituted in the same year (Assen, 1987)**,** (Pankhurst, 1987).

The first recorded sewage disposal system for the city of Addis Ababa (combined for storm and domestic waste) is also reported to be the one constructed by the Italians in the 1930s (BCEOM, 1970). Since then provision of sewerage services has only attracted a cursory attention with the first suggestion proposed in 1959 (Girma, 2004). In 1970 a study proposed increasing sewerage service coverage up to 10% of the city's population, but this was later abandoned in lieu of addressing the more pressing water shortage (BCEOM, 1970).

Sanitation services coverage

Approximately 75% of the population of the city of Addis Ababa utilizes pit latrines as the main form of human waste disposal (CSA, 2005). About 24.4 % is considered to have no form of sanitation service,

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while only 0.6% of the population use flush toilets connected to a sewer system. Currently only a portion of the sewage collected by this system is believed to reach the treatment plant. The balance is considered to be leaking into water courses due to maintenance problems such as pumping failures and blocked pipes (DHV, 2003).

The pit latrine therefore remains as the main workhorse of sanitation service provision in the city. In spite of the wide spread use however, the number of pit latrines and their spatial distribution is not accurately known. A 1993 study suggests that there were 175,000 'septic tanks' (pit latrines) in the city whose population was at that time estimated to be 1,459,000 (Tesfaye, Zereu, & Abdella, 2002).

The 1994 national census also records that of all the 374,742 urban housing units in the city, 168,732 used shared pit latrines and 67,895 housing units had a private pit latrine. In contrast, 89,508 units had no toilet; whereas 30,113 and 14,815 units had private and shared flush toilets respectively. 3,679 housing units were classified as 'not stated' (CSA, 1999). Of these housing units, 338,640 units had no bathing facility and only 14,746 and 14,612 units had a private bath tub and private shower, respectively.

A study in 2003 also cites that of the total housing units 74.1% have toilets with private and communal facilities. The rest (24.9%) do not have any facilities and use open fields to defecate. This, it is estimated, pollutes the environment at a rate of 200 tones of fresh fecal matter and 600 tones of fresh urine per day (BCEOM, SEURECA, & Tropics, 2003).

The 2004 Welfare Monitoring Survey found that the highest number of household pit latrine usage was 74.3%, at Addis Ababa, with the next urban centre (the city of Dire-Dawa) at 64.5% (CSA, 2005). Girma (2004) reports that on average 34 people share the same pit latrine, with 50-60% of households in the densely populated areas using shared pit latrines.

In 2007 a total of 3,197,496 m^3 of liquid waste from pit latrines is reported to have been collected and disposed of by vacuum trucks in the city of Addis Ababa (MoI, 2007). This waste is subsequently taken to the two treatment plants at the periphery of the city. These plants were initially designed for 50,000 people (BCEOM & Consult, 1992) and a sewage flow of 7,600 cubic meters (Tamiru *et al*, 2005). Berhnau (October 2002) reports that 40% of liquid waste in the treatment plant is discharged into the Small Akaki River, and

eventually into the nearby Aba Samuel lake.

Water Wells Inventory in Addis Ababa

In spite of the significant role groundwater sources are playing in meeting the demands of the city, the exact number of wells is not known. A number of inventories carried previously have attempted to compile well data. It appears that these inventories were carried out, more for the purpose of documentation rather than for groundwater resource management purposes. An inventory in the 1970s records a total of 175 deep wells, some in use and some abandoned, with the oldest one on record, drilled near the old airport in 1937(BCEOM, 1970). The inventory indicated that, of the 146 wells located within Addis Ababa the average yield for 87 of them was 2.6 liters per second. On the other hand of the 29 wells located in the Akaki-Kaliti area, 24 of them had an average yield of 3.5 liters per second.

A study by AESL (1984) cites an inventory that recorded the existence of 572 hand dug wells and 93 springs in the city, including 175 deep wells. Although groundwater did contribute significantly to the water demands of the city, the study
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concludes it was not managed appropriately. It was reported that limited local geological information existed and that borehole log correlation with geologic features was questionable.

Vernier et al (1985) also cite an inventory where approximately 600 dug wells and more than 100 springs were identified, of which most were in use. More than 150 wells were drilled since the 1940s. A study by AAWSSA and SEURECA cited by Berhanu (2002) records a total of 275 wells in the city with a recommendation for drilling 146 new boreholes.

A 2004 inventory by AG Consult records at least 1200 boreholes, within 200 kms of the environs of the city. Inventories are still ongoing and a 2005 inventory has revealed that there were at least, 1037 water points in and around Addis Ababa. Of these 925 were boreholes with variable depth, 34 of shallow depth and 78 springs. Of the total number of only 22% have borehole log information. Eighty four percent of these water points were used for domestic water supply while 14% were used for industrial purposes. (WWD&SE, 2007). Fig. 1 below shows the distribution of wells and springs over the areas of the city.
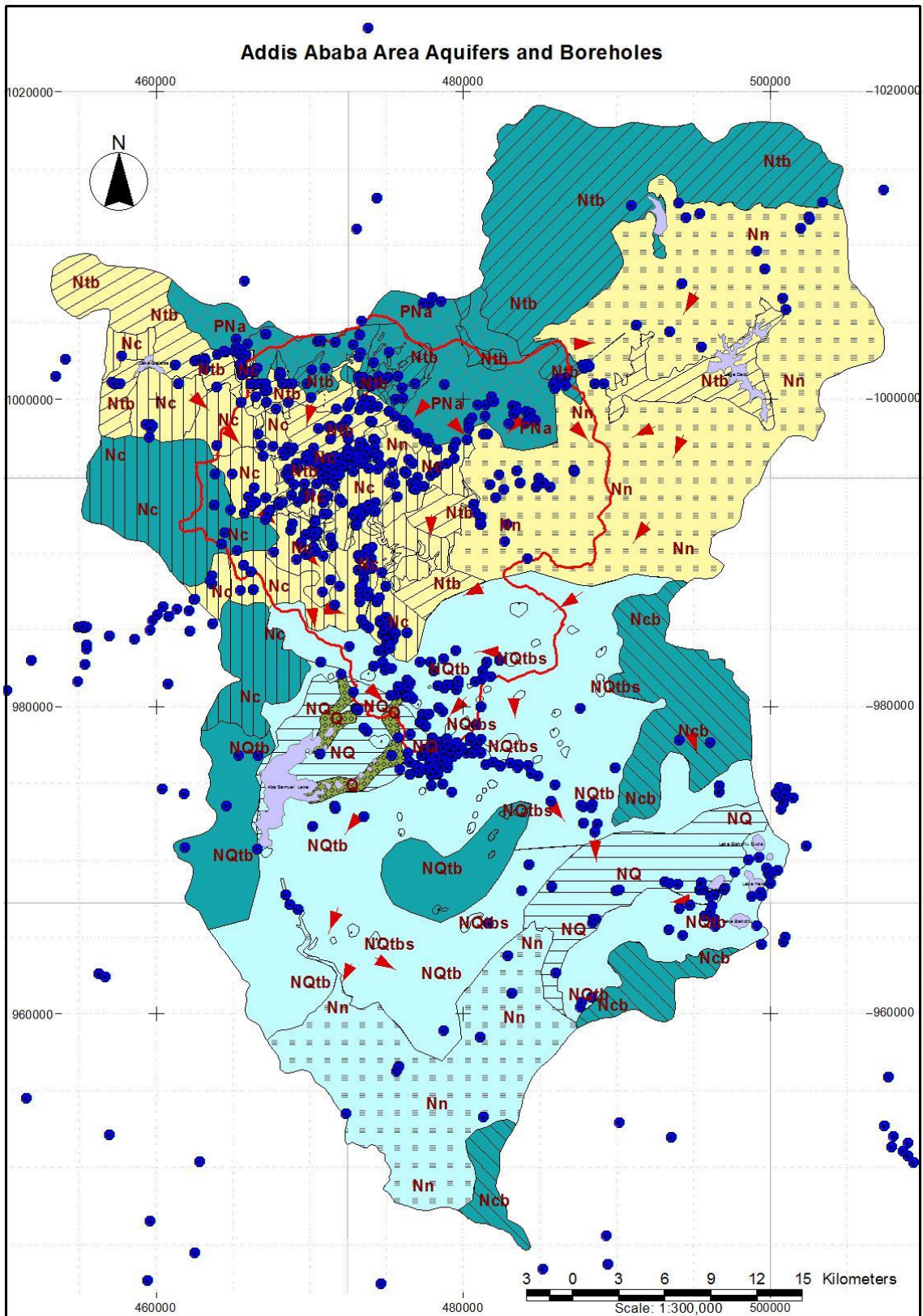
Fig. 1 Addis Ababa area aquifers and boreholes distribution (Adapted from AG Consult)

Sanitation and Health

The Ministry of health reports that up to 60% of the current disease burden in Ethiopia is attributable to poor sanitation. Some 250,000 children die each year (FMoH, 2005) and 15% of total deaths among the population of children under five is attributed to diarrhea. Unsanitary conditions in smaller urban areas have also been cited as being the cause of infections in both children and adults (Abera et al, 2006) (Girum, 2005). Tadesse and Beyene (2009) report of A. lumbricoides and T. trichiura infections as being prevalent in urban areas including Addis Ababa, which have been attributed to high population density and poor sanitary conditions. This finding is quoted to be consistent with an earlier study by Lemma (1968) cited in the same study.

Another study by (Worku & Solomon, 2007) in Jimma town also suggested the prevalence of *Ascaris lumbricoides* ova as an indicator of poor sanitation and hygiene. This was attributed to irregularities in water supply where residents were forced to use alternative sources which exposed them to infections. A separate study by Amare *et al.,* (2007) also confirmed the high prevalence of intestinal parasitosis and attributed it to poor personal and environmental

sanitation. Poor sanitation practices have also been cited as being a serious health risk in Mekelle town another urban centre in the north of Ethiopia (Kinfe & Abera, 2007). Pathogenic organisms including bacteria, viruses and parasites may therefore pose health threats, as a result of contamination of water resources by human waste.

An assessment of water supply and sanitation sector in the country also cites many of the health problems in Ethiopia as related to unsafe and inadequate water supply and unhygienic waste management including that of human excreta (DHV, 2003). This appears to be a long standing problem. Teka (1991) suggests 50% of the health problems in Ethiopia as being related to improper sanitation while, Mesfin (2003,) suggest a figure of 80 %. Current estimates put 75% of all health problems in the country as 'preventable communicable diseases and under nutrition' (Abebe et al, 2008). Regardless of the difference in these figures, there appears to be a general consensus about the seriousness of sanitation related health problems in Ethiopia.

The Ethiopian Environmental Authority (EPA) also admits that 'serious deficiencies in Sanitation services and the inadequacy of sewerage infrastructure and

random defecation in urban areas have created a dangerous health and environmental problems'. The rivers and streams in urban areas are so polluted that they have become 'main sources of infections resulting in diarrhoea and other diseases' (EPA& MoEDC, 1997). The seriousness of this problem is also attributed to lack of awareness of water quality and its health related impact. This has been described as very low' (DHV, 2003).

Anthropogenic contaminants

In Addition to a potential threat of infectious disease due to unhygienic pit latrines, chemicals originating from anthropogenic activities particularly from human waste may pose a serious risk. This risk is pronounced in cases where there is a large scale use of groundwater, concurrently with a reliance on pit latrines as a form of low cost human waste disposal. Anthropogenic activities consist of the activities of agriculture, animal husbandry, industries and onsite sanitation.

In urban areas, where sewerage service is low or is not available, on-site sanitation may cause significant contamination of groundwater. Identifying trace elements found in groundwater which may be sourced from human waste, may therefore be used as indicators of contamination. In order to get meaningful assessment, the tracing elements have to be soluble in water (and hence easily transported to water bodies), and remain unchanged for a considerable period of time. These chemicals also ought not to be adversely affected by the soil.

Considering these factors, nitrates and chlorides are two of the chemicals found in human waste that could be good contamination indicators. Nitrate has been associated with groundwater pollution by septic tank systems (Scalf & Dunlap, 1977). Chloride has also been utilized as a tracer of anthropogenic pollution (Canter & Knox, 1991). Due to its anionic nature and mobility in water, and the ineffectiveness of septic tank systems to remove it, chloride can, in conjunction with nitrates, be a useful indicator of groundwater contamination.

Nitrate can be derived from various sources, and exist in seven oxidation states, which are environmentally of interest (Sawyer *et al*, 2006). These are, NH_3, N_2, N_2O, NO, N_2O_3, NO_2 and N_2O_5. Of these, three forms combine with water to form inorganic ionized species that can reach high concentrations.

$$NH_3 + H_2O \longrightarrow NH_4^+ + OH^-$$

$$N_2O_3 + H_2O \longrightarrow 2H^+ + 2NO_2^-$$

$$N_2O_5 + H_2O \longrightarrow 2H^+ + 2NO_3^-$$
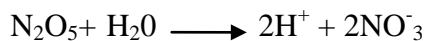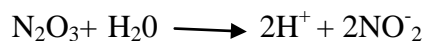
The water soluble elements formed, ammonium, nitrite, and nitrate are the main elements of concern in environmental engineering. Excess nitrate either from agricultural or human waste sources if unutilized is leached to the groundwater causing health concerns.

Ammonia and Nitrites are decomposed in the soil and change to nitrate which is soluble in water and can therefore be used as a tracing element (Sawyer et al, 2006). Nitrates may also occur naturally in groundwater but seldom exceeding a concentration of 2 mg/L as N. Excessive concentrations may then indicate sources of past or present pollution. Septic systems are considered to be one of the sources nitrate in groundwater contamination (McQuillan, 2004), (Todd, 1995), (Hounslow, 1995), (Power & Schepers, 1989). Additionally, chlorides may be sourced from sewage, connate water and intruded seawater (Todd, 1995; Hounslow, 1995). The correlation of nitrate with chloride in groundwater with that of Dissolved Organic Carbon (DOC) may therefore suggest contamination with wastewater (Foster, 1990). Because chloride is present in all sewage and is not subject to adsorption, ion exchange or

oxidation reduction 'redox' reactions and it increases linearly with an increase in nitrate, it can be used as a good indicator parameter of sewage impact on groundwater (McQuillan, 2004) (Canter & Knox, 1991). Tamiru et al., (2005) suggest chloride levels in unpolluted water is less than 10 mg/L and may often be less than 1 mg/L.

Nitrates and chlorides are therefore valuable trace elements in the identification of contamination by human waste. As both chemicals are soluble in water and do not easily break down, both may be used as an indicators of contamination. Nitrates have been known to have penetrated hundreds of feet into aquifers and most soils do not affect chlorides and nitrates.

The presence of nitrate in groundwater due to contamination by human waste has been reported in various literature. Tredoux et al. (2006), reports high levels of nitrate due to pollution by anthropogenic activities with excess sludge application and inappropriate on-site sanitation considered as the main culprits in South African groundwater. Foster (1990) cites Nitrogen compounds (nitrate or

ammonium) as impacting groundwater resources as a result of un-sewered sanitation in Latin America. In West Africa wells located in highly populated areas, with poor waste disposal facilities have shown high level of nitrate, an indicator of pollution due to anthropogenic causes (Langenegger, 1994). McQuillan (2004) reports of septic systems polluting groundwater in numerous areas of New Mexico with nitrate concentrations exceeding the allowable limits. Almasri *et al.,* (2003) reports nitrate as being the most common pollutant found in shallow aquifers due to both point and non point sources in the United States, with septic tank contribution being of significant local effect.

Wide spread use of individual waste disposal systems such as cesspools and septic tanks have been reported to be 'largely responsible for the increase of nitrates in groundwater on long island in the United States (Kimmel, 1984). Sadek and El Samie (2001) also report high nitrate content in the city of Cairo as possibly due to, among other sources that of septic tank effluents. Nitrate and phosphate are considered to be the main inorganic pollutants indicated in groundwater pollution due to effluents from septic tank (Harman *et al.,* 1996).

In this regard some studies have pointed out the possibility of such an occurrence in Addis Ababa. Studies by Molla, (2007), WWD&SE (2007), Yirga (2008) and Birhanu (2002) have suggested the possibility of anthropogenic pollution in the central areas of Addis Ababa. Tamiru *et al.* (2005) suggest abundant chloride levels in groundwater as indicators of sewage contamination of water resources.

Estimation of Pit Latrines Density

The majority of the population of the city use pit latrines for human waste disposal. About 25% of the population does not have access to sanitation at all. In spite of this large usage, the exact number pit latrines or their spatial distribution is not accurately known. Estimates of the number of pit latrines can be made based on either the size of the population or the number of housing units in an area. Considering the population of the city to be about 2.8 million and an area of about 530.14 sq. km, and with 75% of the population with an average family size of 4.1 having access to a pit latrine, the total number of pit latrines in the city may be estimated to be around 966.2 latrines per square kilometer.

Alternatively, considering the total number of housing in the city to be 374,742 and with 75% having access to a form of sanitation while assuming each house has

one pit latrine, the total number of pit latrines in the city may be considered to be in the range of 281,056.5 latrines. This amounts to about 530 latrines per square kilometer. Alternatively, taking the 61 major urban centers survey of sanitary facility availability (2003) as the norm and considering 40% as having private latrines, with approximately 18% as using shared facilities, this will yield:

40/100 * 374,742 =149897 individual latrines

18/100 * 374,742= 67454 shared facilities,

In total,

149,897 + 67,454 = 217,351 pit latrines. This would yield a spatial distribution of

217351/530.14 =409.99 or about 410 pit latrines per square kilometer.

If the 1994 National Census is considered, in which of the total 374,742 urban housing units in the city: 168,732 used shared pit latrines, 67,895 housing units had a private pit latrine and 30,113 and 14,815 units had private and shared flush toilets respectively.

This would add up to 281,555 pit latrines spread over the total 530.14 square kilometers of the city, yielding an average density of 531.1 latrines per square kilometer. This is based on the assumption that, 25% of the houses did not have any form of toilets, while 49 % and 26 % used shared and private facilities, respectively. In general, therefore, the total density of pit latrines may be considered to be in the range of 410 to 966.2 latrines per square kilometer. On the other hand if new housing developments in the city are taken into consideration, this figure may be higher.

Spatial Distribution of Pit Latrines

Addis Ababa has 10 sub cities (Fig.2); considering an average value of 410 latrines per square kilometer, the spatial density of pit latrines over the ten sub cities is as follows (Table 1). On the other hand, the spatial extent of the built up areas of the city, shows that habited areas are not uniformly distributed over the whole city (Fig. 2).

This would suggest that the spatial distribution of pit latrines, while useful as an indicator of pit latrine distribution, may not yield an accurate value. It would therefore be more appropriate to take the number of people living in an area, reflected in the built up area extent, as an indicator of pit latrine usage and density. These values are shown in column 7 of Table 2.

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Table 1 Addis Ababa sub cities pit latrine distribution over aquifers

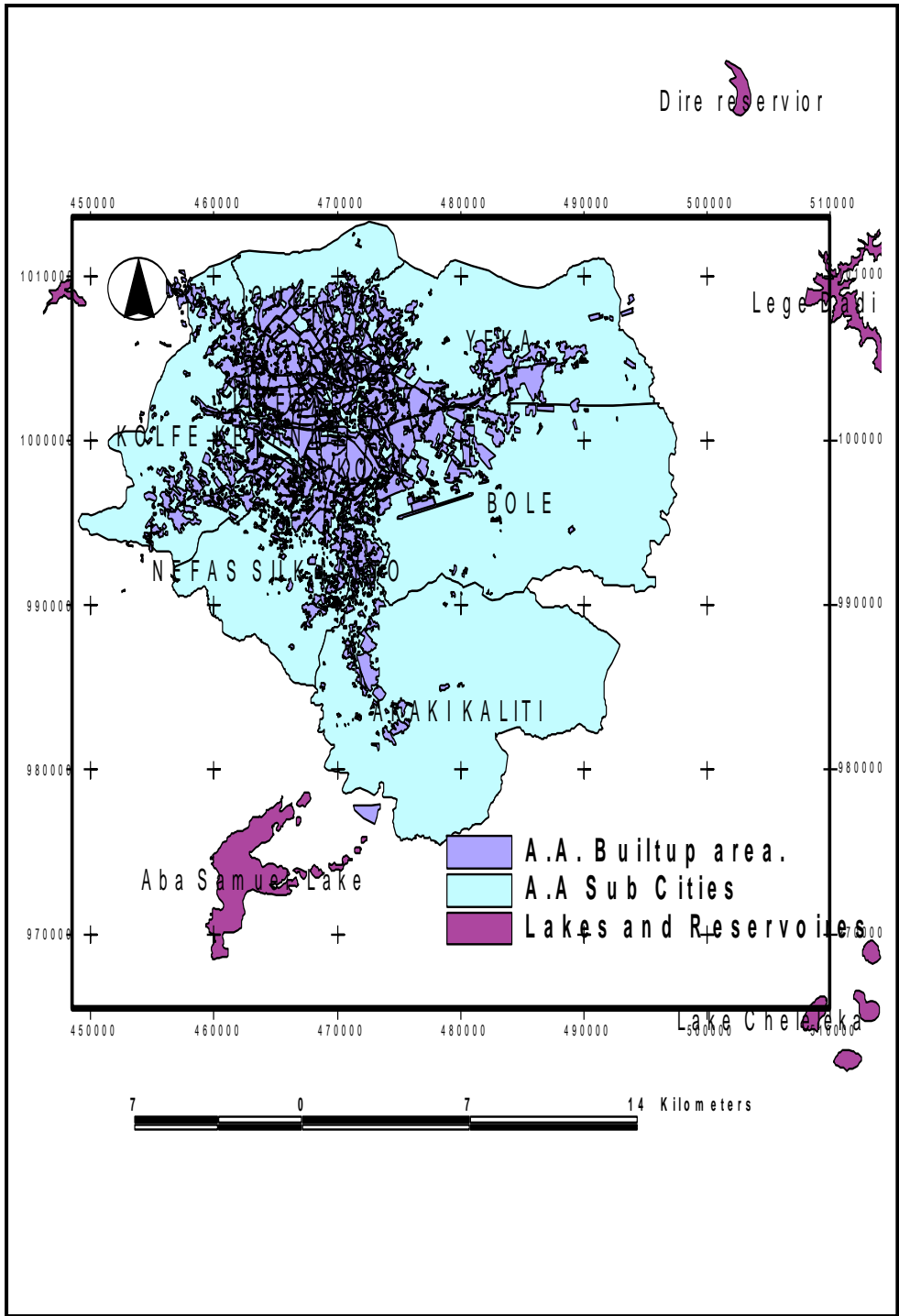| Name of Sub City	Population	Area Sq Km	No of pit latrines at 410/sq km	Location in aquifers
Akaki-Kaliti	181,202	124	50,840	Major Aquifer
Nefas Silk Lafto	316,108	59	24,190	Minor Aquifers
Kolfe Keranyo	428,654	63	25,830	Minor Aquifers
Gulele	267,381	31	12,710	Minor Aquifers
Lideta	201,613	11	4,510	Minor Aquifers
Kirkos	220,991	15	6,150	Minor Aquifers
Arada	212,009	10	4,100	Minor Aquifers
Addis Ketema	255,092	7	2,870	Minor Aquifers
Yeka	346,484	80	32,800	Minor aquifers
Bole	308,714	119	48,790	Minor Aquifers
Total	*2,738,248*	*519*	*212,790*	

Fig.2 Addis Ababa sub cities and built-up area spatial distribution (adapted from AWSSA)

Table 2 Addis Ababa Sub-cities and estimated nitrate loading on aquifers

Name of sub City	Population	No of people with no access to pit latrines at 25%	No of people with access to pit latrines (75%)	No of families using private latrines 26% (at 4.1 people per family)	No of families using shared latrines, 49% (considering one latrine for two families at a house hold size of 4.1 people)	Total no of pit latrines in sub-city	Nitrate loading Tons/year (at 4kg/person/year)	Location in aquifers
Akaki-Kaliti	181,202	45,301	135,902	8,618	8,121	16,739	724.8	Major Aquifer
Nefas-Silk Lafto	316,108	79,027	237,081	15,034	14,167	29,201	1264.4	Minor Aquifers
Kolfe Keranyo	428,654	107,164	321,491	20,387	19,211	39,598	1714.6	Minor Aquifers
Gulele	267,381	66,845	200,536	12,717	11,983	24,700	1069.5	Minor Aquifers
Lideta	201,613	50,403	151,210	9,589	9,036	18,625	806.5	Minor Aquifers
Kirkos	220,991	55,248	165,743	10,511	9,904	20,415	884.0	Minor Aquifers
Arada	212,009	53,002	159,007	10,083	9,502	19,585	848.0	Minor Aquifers
Addis Ketema	255,092	63,773	191,319	12,132	11,432	23,565	1020.4	Minor Aquifers
Yeka	346,484	86,621	259,863	16,479	15,528	32,008	1385.9	Minor aquifers
Bole	308,714	77,179	231,536	14,683	13,836	28,518	1234.9	Minor Aquifers
Total	*2,738,248*	*684,562*	*2,053,686*	*130,234*	*122,720*	*252,954*	*10953.0*	

The results shows that on average at least 252,954 pit latrines exist in the city. This spatial distribution appears to suggest a more realistic distribution. The less populated areas in the major aquifer zones show a lesser number of pit latrines. Of these estimated pit latrines at least 236,215 are estimated to be located in the central or highly populated areas, while the remaining 16,739 are located in the periphery of the city. These could be considered to be sources of significant nitrate loading on groundwater. Considering a nitrate loading of 4 kg/person /year the total nitrate loading on the aquifers would be in the range of 10,953 tons/year. The estimated nitrate loadings from pit latrines in each sub city are listed in column 8 of Table 2 above. In terms of the number of population in aquifer areas 181,202 or 6.62 % of the residents of the city are located around the major groundwater abstraction area. The remaining 93.38 % or 2,557,046 of the residents occupy the central areas of the city. This area is considered to be underlain by a minor aquifer with the high rate of use pit latrines in Addis Ababa could be considered to be a non point or diffused source of pollution.

Estimation of Pollution load on Groundwater Resource

As indicated Table 2 the total nitrate loading into the aquifers sourced from pit latrines over the geographic limits of the city adds up to 10953.0   tons per year. This averages about 21 tons/square kilometer per year. In addition to this, the 25% of the population which is believed to have no form of sanitary service is also contributing a nitrate loading to the ground. This portion of the population uses varying forms of sanitation, including defecating on edges of rivers and sewage streams. This input may be significant, as it may eventually find its way into the 'rivers' flowing towards the south-western parts of the city, to the major aquifer area. This is not, however, the only source of potential nitrate loading into the groundwater. Industrial and farming activities also contribute to the nitrate loading.

This may particularly be higher as the groundwater flows from the north towards the southwester areas of the city. It follows the natural slope of the ground, and along the way receives significant waste load from the surrounding industries and farming activities. The pit latrine waste taken to the treatment plants also finds its way into the groundwater as shown in Fig

3 below, and subsequently to the Aba
Samuel Lake

Fig. 3   The treatment plant in the vicinity of the Akaki Aquifer

The stream shown in the foreground also receives waste from the treatment plant. Nevertheless waste disposal in general, and pit latrines in particular, are perhaps the single most detrimental factor contributing to groundwater contamination. The exorbitant costs of providing sewerage services, the lack of awareness of the general public, the absence of enforcement capability of environmental policies have all combined to create a serious situation. Therefore the geographical spread and density of pit latrines would categorize them as diffuse sources of pollution. It can therefore be considered that the city of Addis Ababa is a massive non-point source of contamination on the groundwater.

An attempt was then made to collect data on physio-chemical water quality in boreholes and spring in Addis Ababa. .

Maps showing of nitrate, chloride and TDS levels in wells in and around the city are shown below (Fig. 4-6).
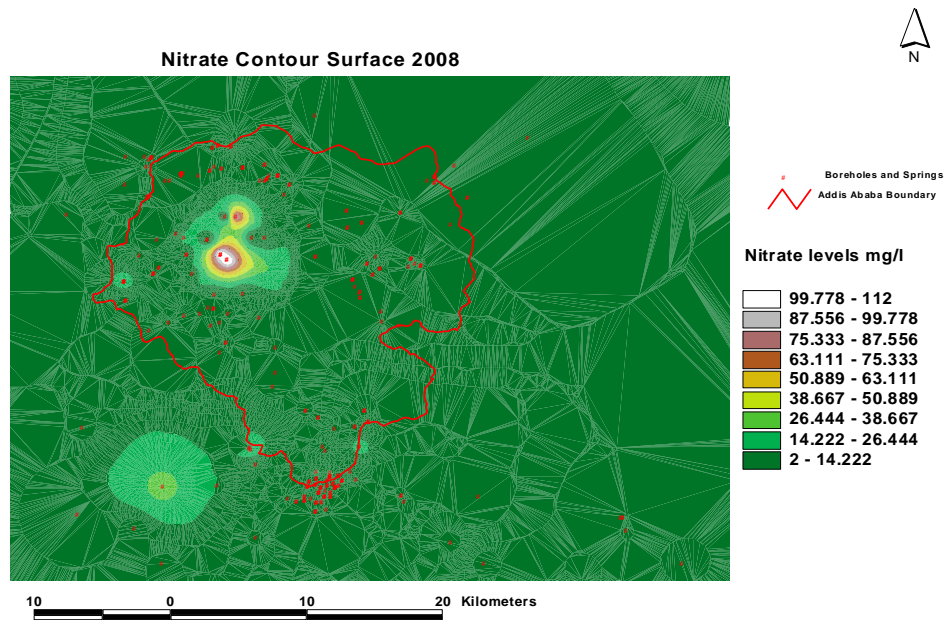
Nitrate Contour Surface 2008

Boreholes and Springs
Addis Ababa Boundary

Nitrate levels mg/l

	99.778 - 112
	87.556 - 99.778
	75.333 - 87.556
	63.111 - 75.333
	50.889 - 63.111
	38.667 - 50.889
	26.444 - 38.667
	14.222 - 26.444
	2 - 14.222

10   0   10   20 Kilometers

Fig. 4 Nitrate detection in wells in the minor and major aquifers 2008/09

Chloride Contour surface 2008

Boreholes and Springs
Addis Ababa City Boundary

Chloride Level mg/l

	88.889 - 100
	77.778 - 88.889
	66.667 - 77.778
	55.556 - 66.667
	44.444 - 55.556
	33.333 - 44.444
	22.222 - 33.333
	11.111 - 22.222
	0 - 11.111

10   0   10   20 Kilometers
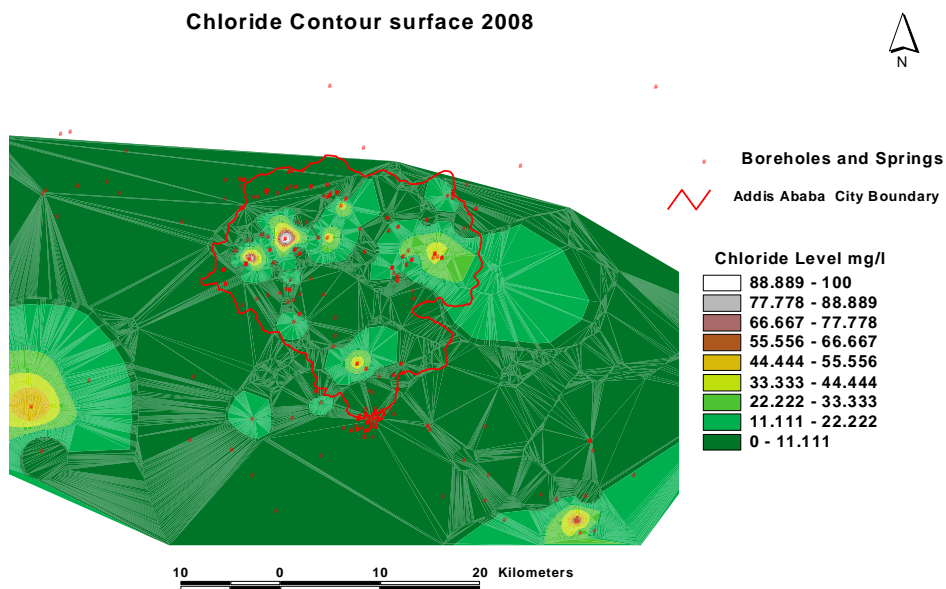
Fig. 5 Chloride detection in wells in the minor and major aquifers 2008/09
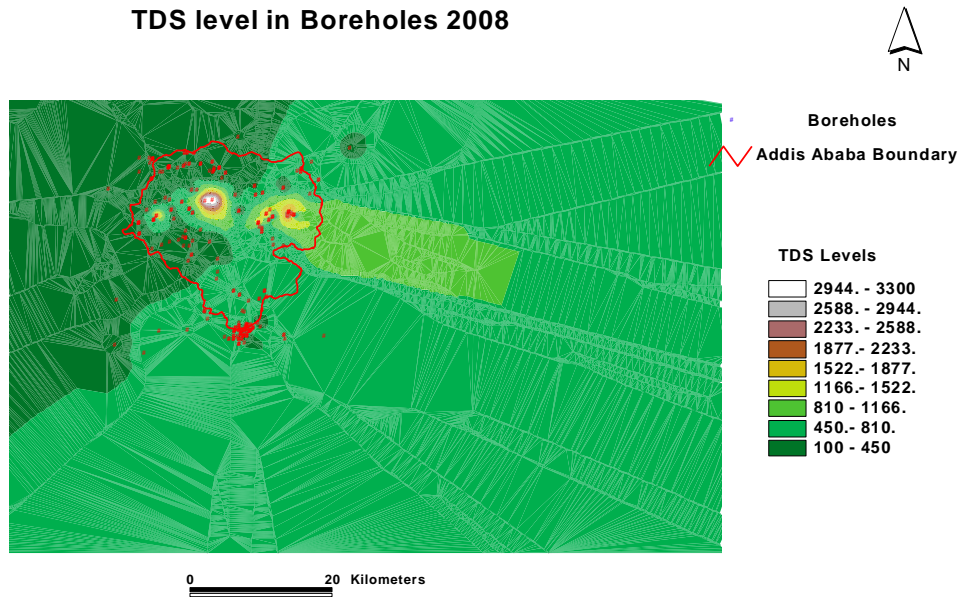
TDS level in Boreholes 2008

Fig. 6 Chloride detection in wells in the minor and major aquifers 2008/09

Conclusions

Observation suggest that aquifers in and around the city of Addis Ababa are showing signs of increasing contamination by chemicals including nitrate. This contamination appears to have increased over the last decades. The level of nitrate contamination in some areas, particularly the minor aquifers is observed to be above permissible limits as defined by local and international standards. At the central sections of the minor aquifer nitrate as NO_3 values as high as 112 mg/L have been observed. This is more than twice the WHO recommended maximum limit of 50 mg/L. At the major aquifers values as high as 24 mg/L have been observed. This is considered to be lower than the maximum permissible value, but a steady rise has been observed.

The spatial distribution of the contamination shows higher concentration of nitrate around the minor aquifer. The major aquifers located in the south of the city around Akaki-Kaliti areas have also shown elevated nitrate levels. The spatial extent also appears to increase outwards from the city center, with high values observed at highly populated areas. The most significant effect of this impact on groundwater resources would be on its quality, or suitability for human consumption and industrial purposes. A direct relationship between the highly populated areas of Addis Ababa and higher detection of nitrates and chloride also appears to be present.

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Temporal Variation of selected contaminants in groundwater in Addis Ababa, Ethiopia

Girmay Kahssay, Jana Olivier, Tenalem Ayenew, Mogobe Ramose

Abstract

One of the challenges faced by the city administration of Addis Ababa is the provision of clean water to the residents. Recent attempts to address this shortage have mainly focused on abstraction of groundwater. On the other hand the city's sanitation service coverage is considered to be low, with a majority of the population relying on pit latrines. Observations in the city where the primary sanitation coverage is through low cost pit latrines, has indicated that groundwater resource, may be seriously threatened by chemicals originating from human waste from the proliferation of pit latrines. Boreholes in the city were assessed for the presence of two chemicals, nitrate and chloride commonly found in human waste. These chemicals are considered to be indicators of fecal contamination. Temporal assessment of nitrate and chlorides were assessed in boreholes and springs. The contamination is observed to be high in the city center around the minor aquifer areas. The major aquifer area displays a relatively low contamination.

Key words

Addis Ababa, low cost Sanitation, pit latrines, contaminants, contamination, groundwater, nitrate, chloride, temporal

A large number of the pit latrines in Addis Ababa are concentrated in the built-up area transecting the city in a north south direction and covering a relatively narrow area. The minor aquifer is located in the central and northern areas (colored beige and dark blue in Fig. 1), while the major aquifer (pale blue) is located in the south-western periphery of the city. A majority of the boreholes and springs are located in the built-up area.

Analysis of over 4000 water quality test data on boreholes and springs in the city was carried out for different periods to obtain an indication of the temporal degree of nitrate contamination. The data collected spanned 43 years. Two main evaluation scenarios were considered. The primary evaluation was conducted on test data obtained in 2000. The second was for the period covering 2008. Statistical calculations were conducted to obtain an indication of temporal change in contaminant levels. In order to determine whether contamination could be ascribed to human waste the relationship between the chloride and nitrate concentrations was determined using Pearson's product-moment correlation coefficient (r). Spearman's Rank Correlation Coefficient (r_s) was used in cases where there were fewer than 10 data points. The distribution of the wells and springs over the two aquifers covered in the subsequent analyses is shown in Figure 1.
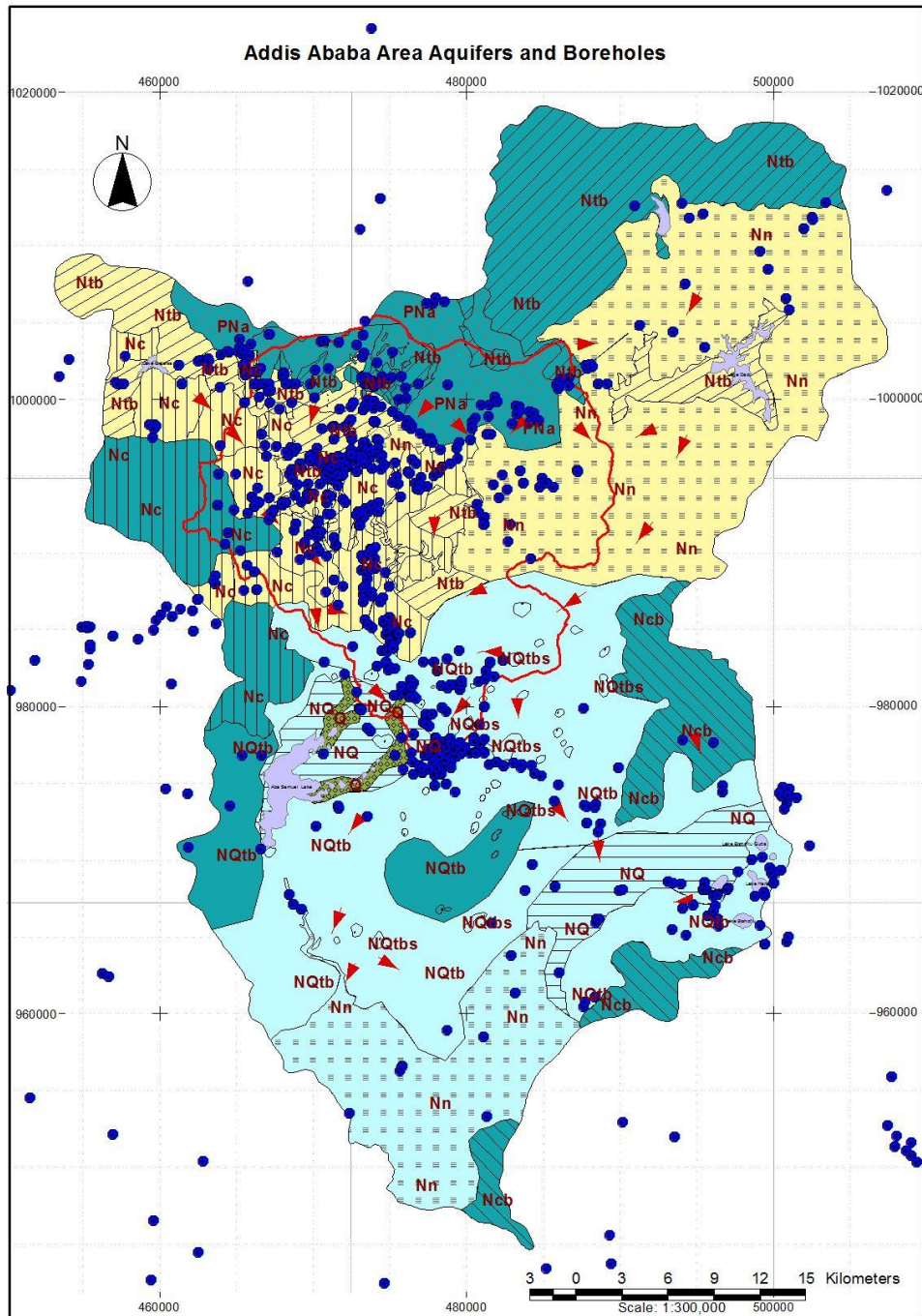
1

Fig. 1 Boreholes and springs distribution over aquifers

Variation of Nitrate and Chloride in Minor Aquifers 1999-2009

The 1999 test data for 22 wells in the same minor aquifer area, but covering a slightly wider spatial extent showed a low correlation between nitrate and chloride, of 0.42 (Fig.4). This value falls just outside the 5% significance level and hence there was no linear relationship between the two chemicals.
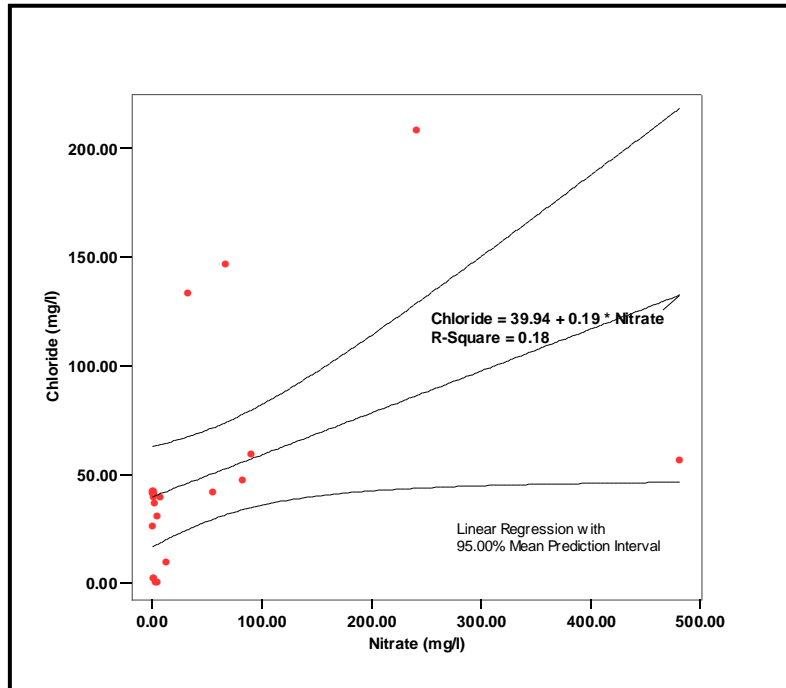
Fig. 4 Nitrate and chloride correlation in 22 wells in the minor aquifer area in 1999

Evaluation of water quality data for 261 wells in the minor aquifer area in 2000 showed a moderately strong correlation coefficient of 0.58 (Fig 2) (significant at the 0.01 level.)
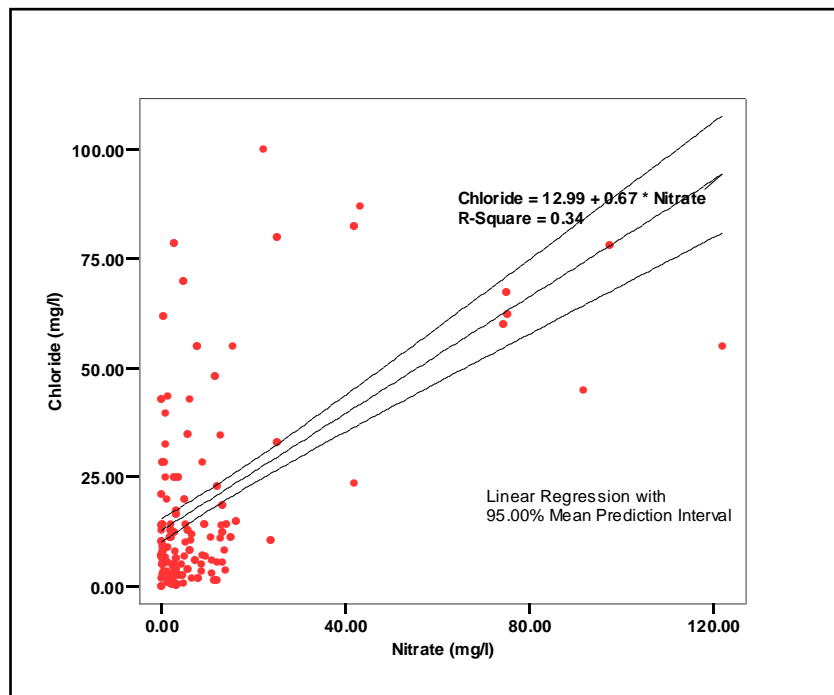
Fig. 2 Nitrate and chloride correlation in 261 wells in the minor aquifer area in 2000

Data from 2000 indicate that the two contaminants exhibit a moderate degree of correlation. This would suggest that contamination due to nitrate and chloride occurred and that this might have originated from human waste. In order to show the more recent situation, water quality tests were carried out in 2008/09 from 12 wells from the same location. This gave a correlation coefficient of r = 0.62 (Fig 3), between chloride and nitrate levels. The correlation was significant at the 0.05 level.
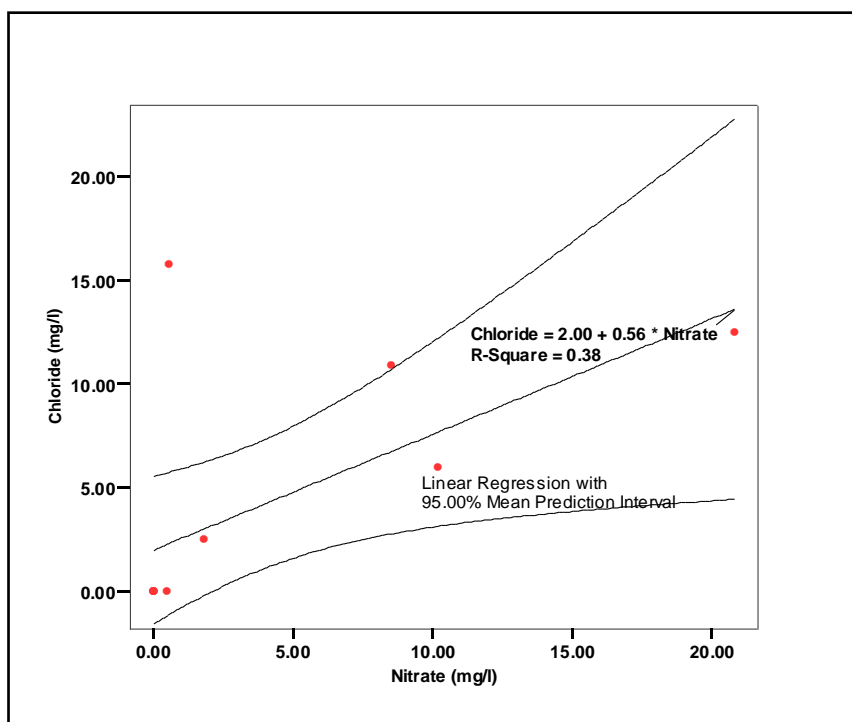

Fig. 3 Nitrate and chloride correlation in 12 wells in the minor aquifer area 2008

The correlation coefficient between chloride and nitrate levels collected from another 169 wells in 2008 were also calculated and found to be 0.27 (Fig 4). Despite the low r-value, the correlation was found to be significant at the 0.01 level.

The results obtained from wells in minor aquifers during the study period are summarized in Table 1 below.
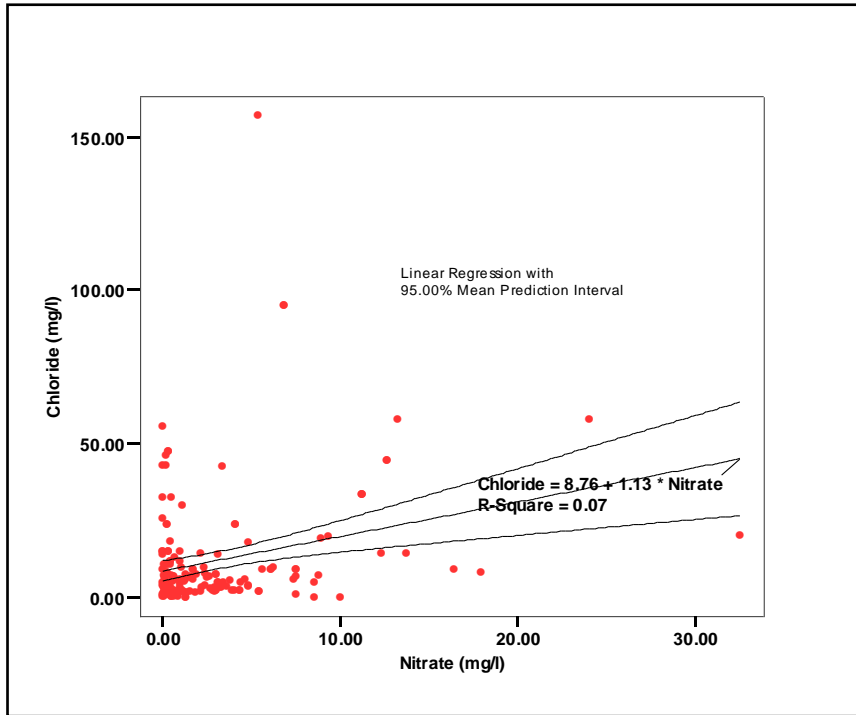
Fig. 4 Nitrate and chloride correlation in 169 wells in the minor aquifer area in 2008

Table 1 Summary of results obtained for the period 1977 to 2008/09

Year	No. of wells	Correlation coeff. (r)	Level of significance	Significant relationship
1977	8	0.96	1%	yes
1999	22	0.42	>5%	no
2000	261	0.58	1%	yes
2008/09	12	0.62	5%	yes
2008	169	0.29	1%	yes

From these results it appears that water from minor aquifers were already contaminated in 1977 and that this situation has not improved. The significant linear relationship between chloride and nitrate indicates that contamination is probably due to human waste.

Temporal Variation of Nitrate and Chloride in Major Aquifers 1978-2008

A decade later an assessment of 10 wells in the same area showed a correlation of 0.43 between nitrate and chloride (Fig 5),

5

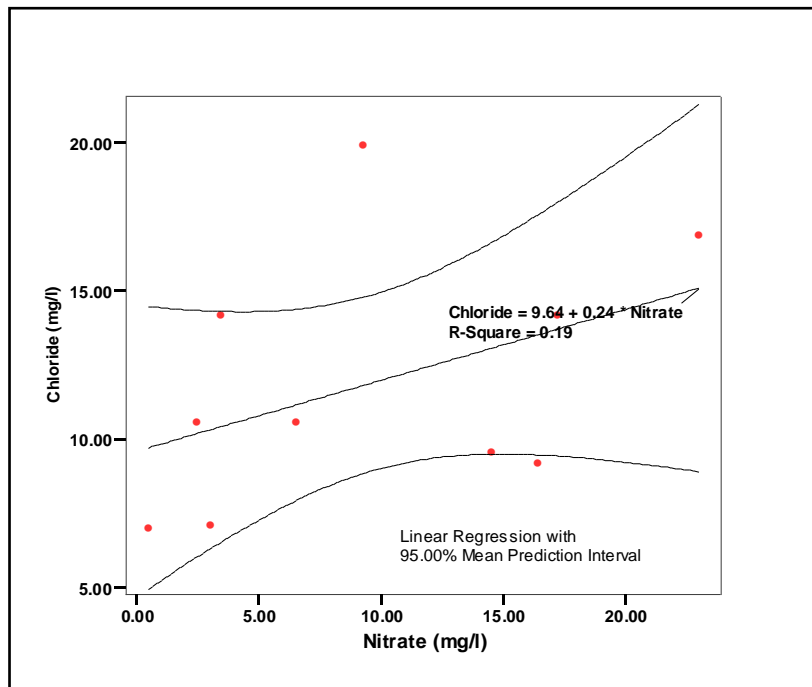but still does not indicate a statistically significant linear relationship.

Fig. 5 Nitrate and chloride correlation in 10 wells in the major aquifer area 1989

An evaluation of 1999 data for 31 wells in the major aquifer area indicates a correlation coefficient of 0.12 between nitrate and chloride concentrations (Fig. 6). Again, there is no evidence of a linear relationship. However, when spring water is tested, another picture emerges. For 1999 data, the level of contaminants in 21 springs in the major aquifer area indicates a moderately high correlation coefficient of r = 0.45 between chloride and nitrate content (Fig. 7). This correlation is significant at the 0.05 level and indicates that the contamination in spring waters could have originated from human waste.
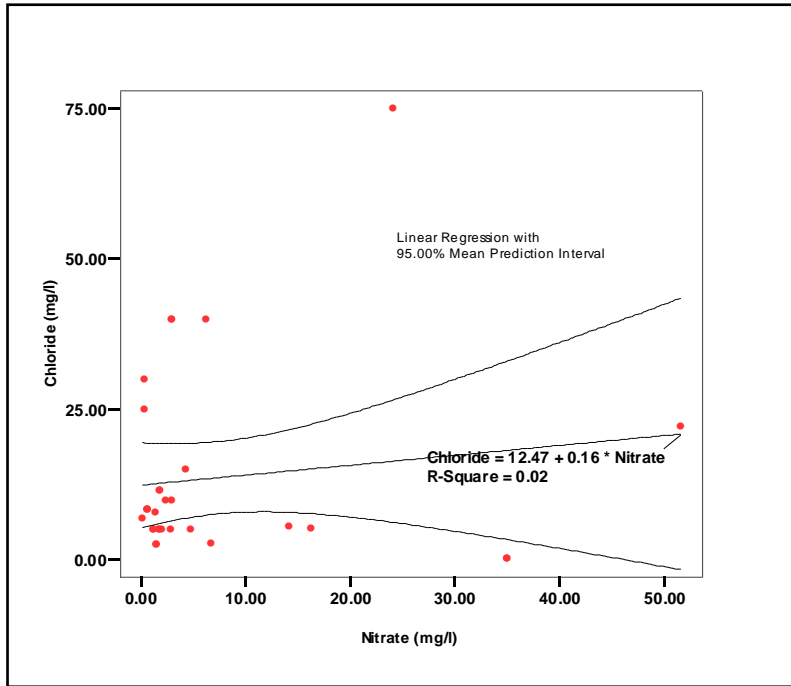
Fig. 6 Nitrate and chloride correlation in 31 wells in the major aquifer area 1999
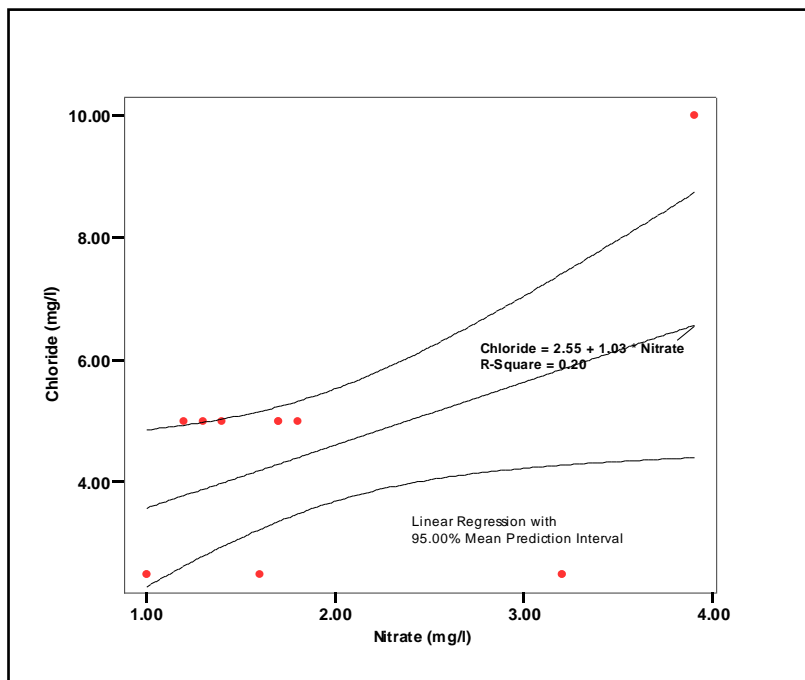

Fig. 7 Nitrate and chloride correlation in 1999 in 21 springs in the major aquifer area
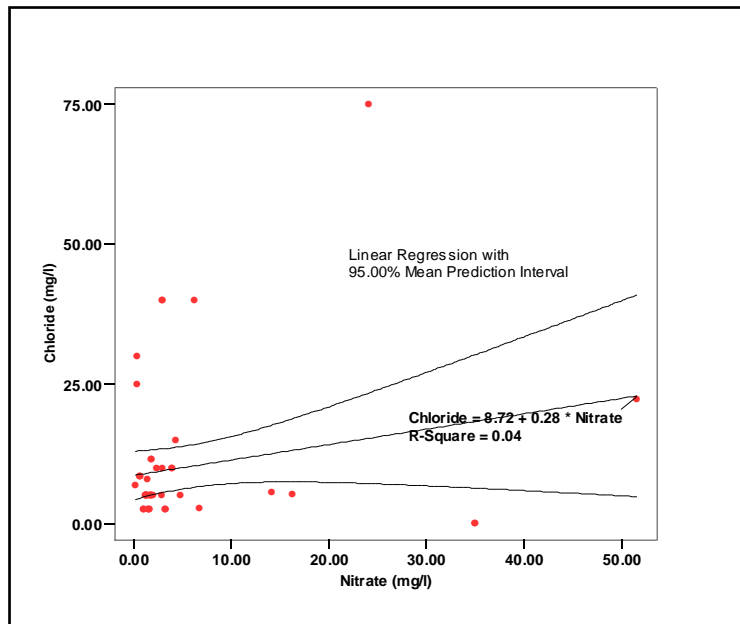
7

Fig. 8 Nitrate and chloride correlation in the major aquifer area 1999

When data for 52 springs and wells in the major aquifer area are combined, a correlation of r = 0.21 was obtained (Fig. 8). Since this value is not statistically significant it clearly indicates that there is no linear relationship between chloride and nitrate in major aquifers in Addis Ababa and hence, the major aquifers had not been contaminated by human excreta before 2000. It is not clear why spring water was contaminated, but this might have been due to surface runoff.

The 2000 data on level of nitrates and chlorides in 230 wells suggest a limited tandem occurrence of the two chemicals. This is shown in Fig. 9. Pearson's coefficient of correlation between the two chemicals is only 0.01, again showing no linear relationship.

A similar situation is evident in the more recent 2008 data for 34 wells in the major aquifer area. There is no linear relationship between the two chemicals as shown Fig. 10, with r = 0.1.
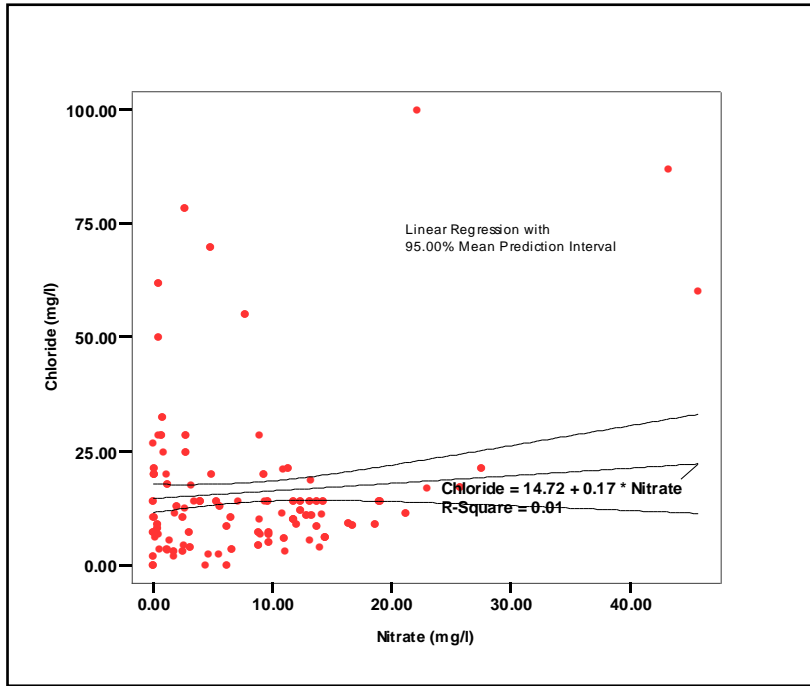
8

Fig. 9 Nitrate and chloride correlation in 230 wells in the major aquifer area in 2000
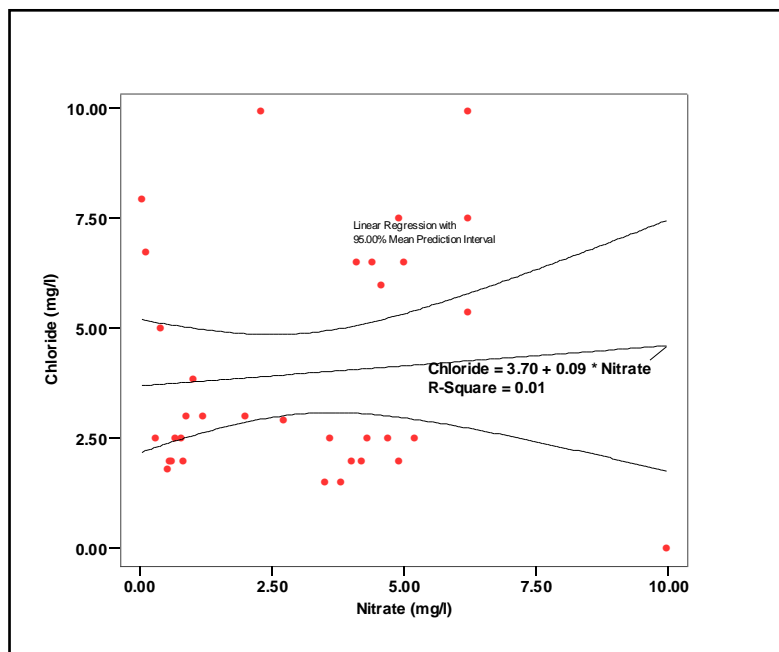

Fig. 10 Nitrate and chloride correlation in 34 wells in the major aquifer area in 2008/09

This is confirmed by an analysis of 2008 data for 189 well and springs located in the major aquifer area (Fig. 11). This also showed low correlation between levels of nitrate and chloride with r = 0.1. The low correlation between the two chemicals suggests that the nitrates and chlorides may have been sourced from

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anthropogenic sources other than human waste. Table 2 provides a summary of the results obtained for the correlation between chloride and nitrate levels for major aquifers for the period 1978 to 2008.

Linear Regression with
95.00% Mean Prediction Interval

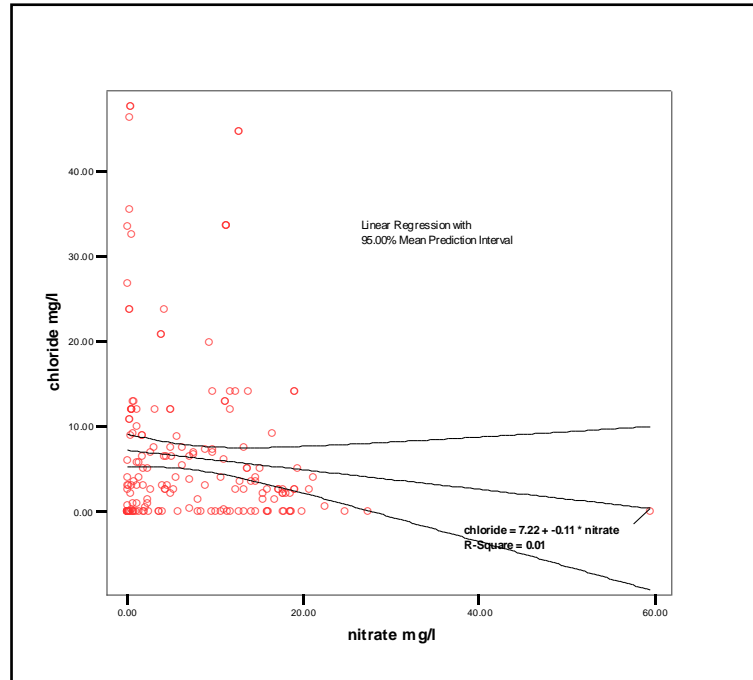chloride = 7.22 + -0.11 * nitrate
R-Square = 0.01

Fig. 11 Nitrate and chloride correlation in 189 wells and springs in the major aquifer area in
2008

Table.2 Summary of results obtained for the period 1978 to 2008 in the major aquifer area

Year	No. of wells/ springs	Correlation coeff. (r)	Level of significance	Significant relationship
1978	9	0.24	>5%	no
1989	10	0.43	>5%	no
1999 (wells only)	31	0.12	>5%	no
1999 (springs only)	21	0.45	5%	yes
1999 (springs and wells)	52	0.21	>5%	no
2000	230	0.03	>5%	no
2008	31	0.10	>5%	no
2008	190	0.10	>5%	no

Comparison of Tables 1 and 2 indicates that there is a higher correlation of the two chemicals in the minor aquifers in the center of the city. There is no evidence of such contamination in wells obtaining water from the major aquifers. However, the quality of water from springs in the latter area appear to be affected by poor sanitation. The results of the analyses also indicates that the shallow minor aquifers close to the city center were most contamination-prone. This corresponds well with the built-up area of the city, where the wells may be exposed to anthropogenic sourced contaminants.

Temporal patterns of Nitrate and Chloride in aquifers

In general, nitrate and chloride levels within the minor and major aquifers has increased over the last decade. As chapter 5 demonstrated a high concentration of pit latrines was associated with the central areas of the minor aquifer. Outlying areas, on the other hand displayed a lower value. Although, nitrate and chloride levels in some cases were lower than the WHO guideline values, a steady temporal increase was observed.

The analysis of grouped well data, whilst useful in rendering a wider perspective, may not give a clear insight into the degree of temporal variation of contaminants in individual wells. The following assessment attempts to analyze temporal contamination levels in individual wells in both major and minor aquifers.

Individual Minor Aquifers wells

One of the wells which has consistently shown a high level of nitrate is the *Tsebay Maremia* well. This well is located in the minor aquifer area. Aside from the small seasonal variation, the well shows an increase in nitrate concentrations over time, well above the WHO recommended maximum limit of 50 mg/L. The high value of 159.48 mg/L observed in September 2004, at the end of the rainy season, suggests a possible contaminant input from the surface (Fig. 12). The well also exhibited a corresponding temporal increase in chloride levels. Unfortunately the 2008 Chloride content was not recorded. However, compared with other boreholes the level of chloride in the *Tsebay Maremia* well is relatively high.
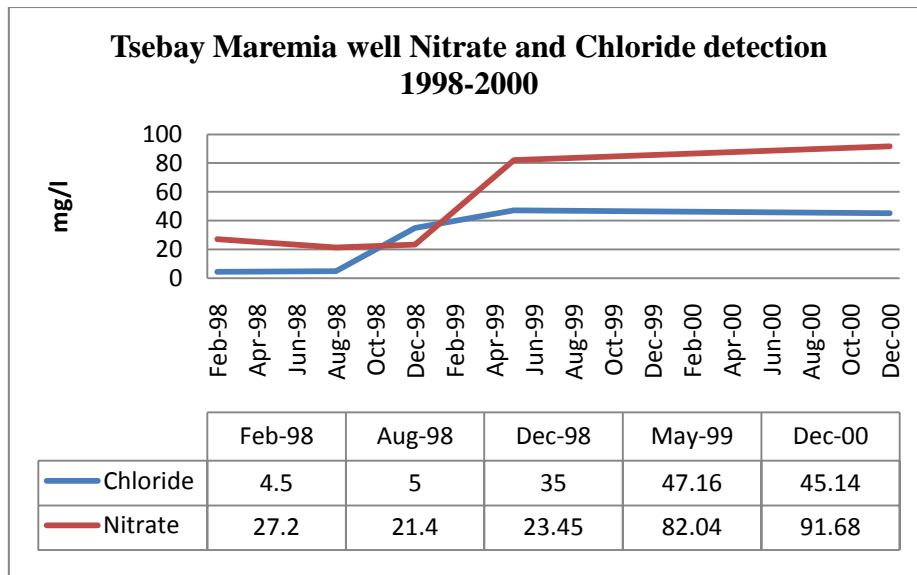
Tsebay Maremia well Nitrate and Chloride detection 1998-2000

(mg/l)

	Feb-98	Aug-98	Dec-98	May-99	Dec-00
Chloride	4.5	5	35	47.16	45.14
Nitrate	27.2	21.4	23.45	82.04	91.68

Fig. 12 Temporal Variation of nitrate and chloride in the Tsebay Maremia well 1998-2000

Tsebay Maremia well Nitrate and Chloride detection 2003-2005

(mg/l)

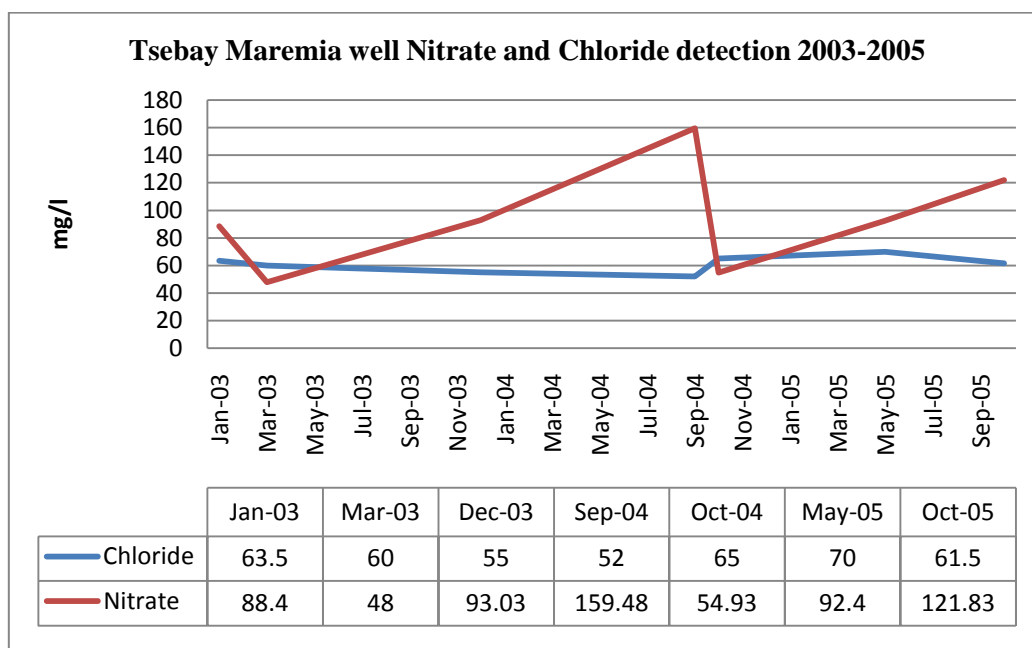|	Jan-03	Mar-03	Dec-03	Sep-04	Oct-04	May-05	Oct-05
Chloride	63.5	60	55	52	65	70	61.5
Nitrate	88.4	48	93.03	159.48	54.93	92.4	121.83

Fig. 13 Temporal Variation of nitrate and chloride in the Tsebay Maremia well 2003-2005

The temporal variation of nitrate and chloride in the wells for the 1998-2000 and 2003–2005 periods are shown in Fig. 6.16 and 13, respectively. Comparison of these two figures and the corresponding chloride and nitrate levels, clearly indicates a considerable rise in both chemicals over the 7 year period. Moreover, both chemicals seem to have the same temporal pattern of rising and falling values. This is confirmed by the correlation coefficient of 0.6 (statistically significant at the 5%

level) and suggests human waste to be the origin of the contaminants (Fig. 6.18).

There is some evidence of a seasonal pattern in the contamination levels. The peaks during April and May 1998 (Fig. 12) and again in August 2004 (Fig. 13) may be due to human waste contaminated runoff during the rainy months of March and August. However, the limited amount of temporal data precludes further investigation of seasonality.
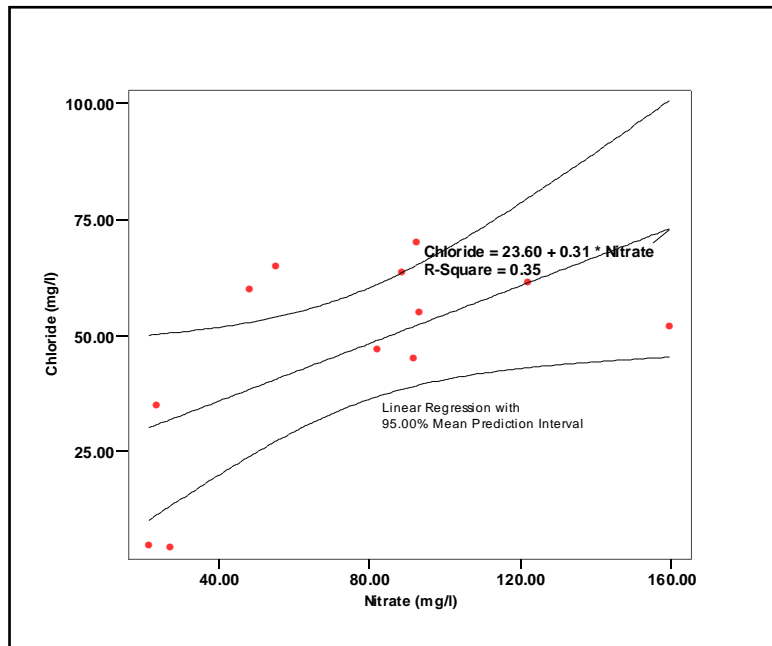

Fig. 14 Nitrate and chloride correlation in the Tsebay Maremia well 1997-2009

Other wells located in the city centre have also exhibited elevated nitrate content. Wells utilized by beverage factories and hotels appear to display elevated nitrate content as compared to other wells. .

Individual Major Aquifer wells

Individual wells in the major aquifer area located to the south of the minor aquifer, have also shown varying levels of nitrate and chloride. Well EP 8 located in the Akaki well field, showed a nitrate level of 18.16 mg/L in July 2003 which increased to 24.37 mg/L in October 2003 (after the major rainy season) and then decreased to 4.92 mg/L in December 2003 (Fig. 15). The fluctuations within that period suggest that the well may have been exposed to an external nitrate input. A sharp fluctuation is observed in the nitrate content for one year's duration during 2003-04 (Fig. 15). After January 2004 the observed values appear to remain low at about 4.5 mg/L.

In 2008 however, observed values have   been noted to increase to 16.4 mg/L.

Nitrate and chloride detection in well EP 8 major aquifer area

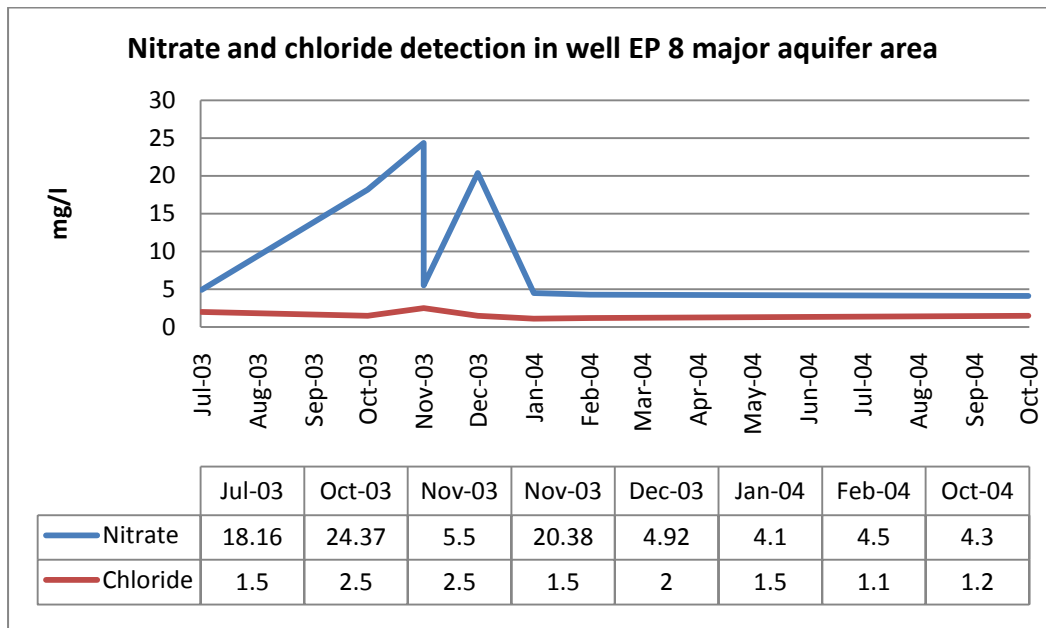|	Jul-03	Oct-03	Nov-03	Nov-03	Dec-03	Jan-04	Feb-04	Oct-04
Nitrate	18.16	24.37	5.5	20.38	4.92	4.1	4.5	4.3
Chloride	1.5	2.5	2.5	1.5	2	1.5	1.1	1.2

Fig. 15 Temporal variation of nitrate in well EP 8 Major aquifer area (2003-04)

As shown in Fig. 16 the nitrate and chloride correlation in well EP 8 is very low at 0.17. No linear relationship is evident between the two chemicals, suggesting the chemicals could have originated from anthropogenic sources other than human waste.
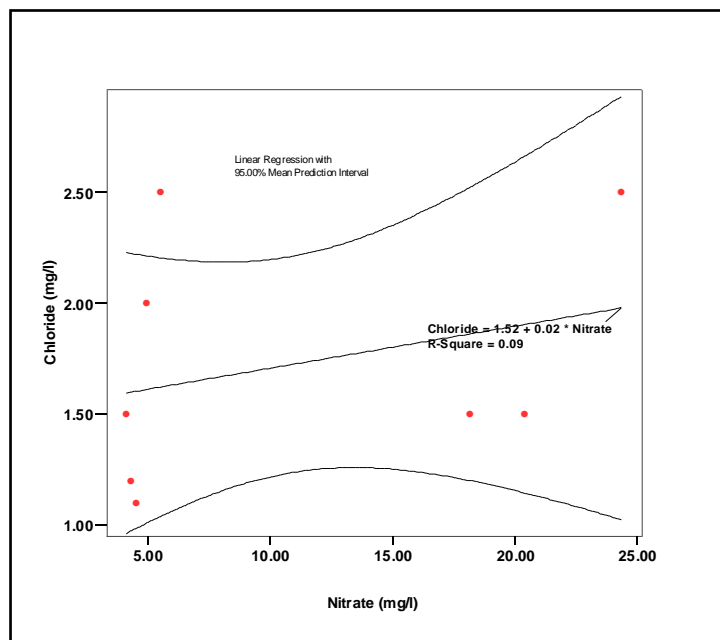
Linear Regression with
95.00% Mean Prediction Interval

Chloride = 1.52 + 0.02 * Nitrate
R-Square = 0.09

Fig. 16 Nitrate and chloride correlation in well EP 8 major aquifer area

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Borehole EP 4 in the same area also exhibits a similar fluctuation in nitrate content (Fig. 17). The change in nitrate content exhibits no predictable trend. The sharp fluctuations could possibly be due to external sources
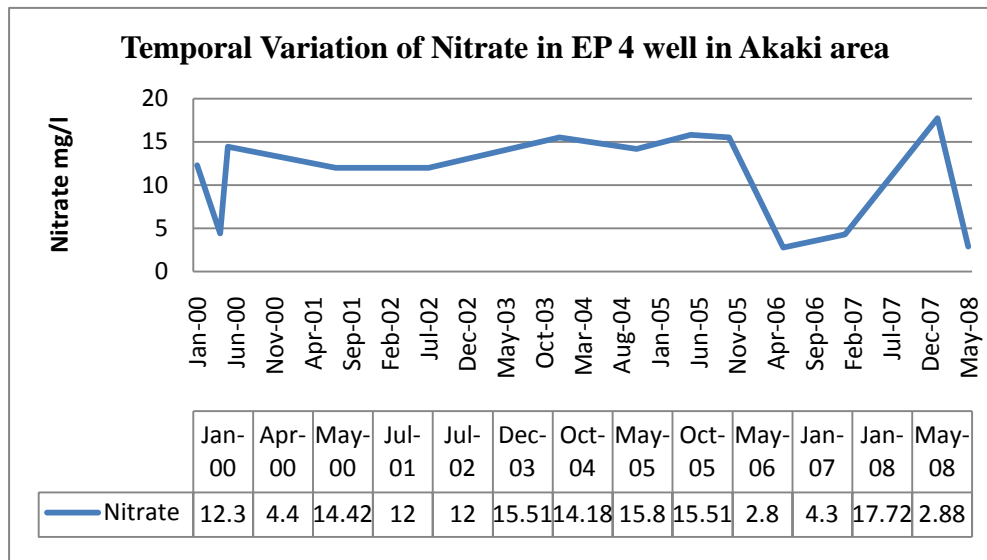

Temporal Variation of Nitrate in EP 4 well in Akaki area

	Jan-00	Apr-00	May-00	Jul-01	Jul-02	Dec-03	Oct-04	May-05	Oct-05	May-06	Jan-07	Jan-08	May-08
Nitrate	12.3	4.4	14.42	12	12	15.51	14.18	15.8	15.51	2.8	4.3	17.72	2.88

Fig. 17 Temporal variation of nitrate in borehole EP 4 Major aquifer area

Major Aquifer Springs

Springs in the city have also shown high nitrate levels. Some of the springs, including the Lideta and Gebriel Abo springs, are found in the vicinity of churches and are considered as medicinal, *'Tsebels'* 'holy waters'. The linear correlation of nitrate and chloride values in 20 springs in the minor aquifer area show a correlation coefficient of 0.42 (Fig. 18) which falls just outside the 5% level of significance. It is thus possible that the springs were contaminated from a variety of anthropogenic sources, some of which may have been human excreta.

When analyzing chloride and nitrate levels in individual springs, an interesting picture emerges (Fig. 19). Although low, the correlation coefficient between nitrate and chloride in the Fanta springs appears to suggest no linear relationship between the two chemicals, both values peak during October 1999 and reach a minimum in November 2003. In view of the small number of data points available for Fanta springs, it was decided to use Spearman's Rank Correlation Coefficient (r_s) to indicate possible linear relationships. The r_s was found to be 0.94, indicating a highly significant relationship between chloride and nitrate levels. This finding

indicates that, at least some of the contamination could be due to human waste. The difference in r and r_s, values might be due to a combination of various sources of waste
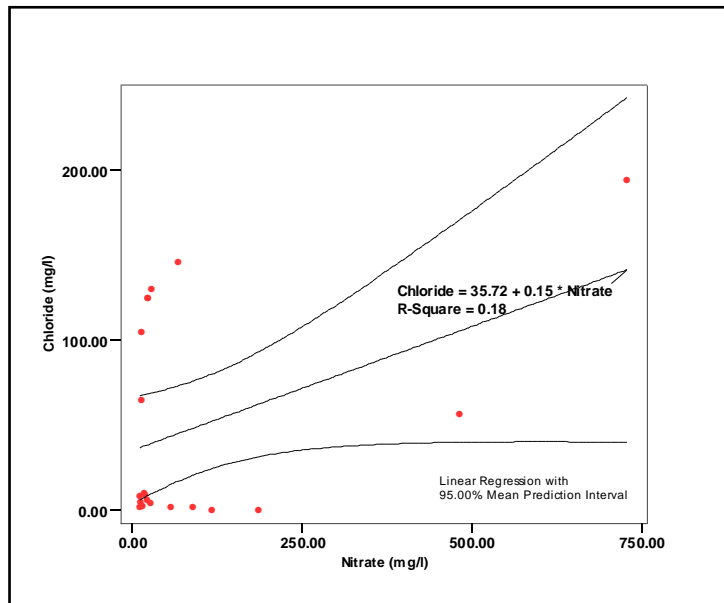
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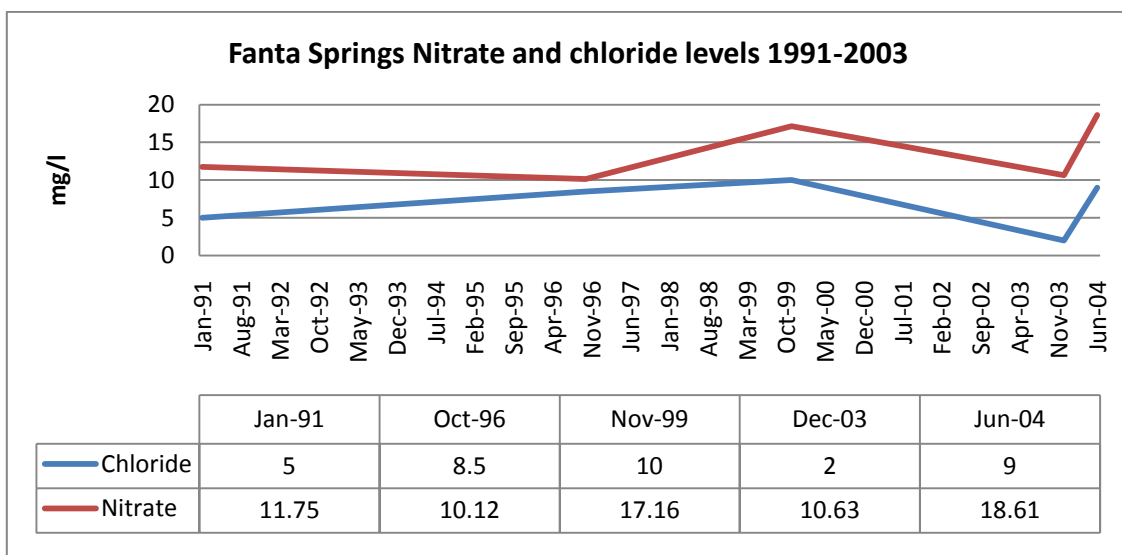Fig. 18 Nitrate and chloride correlation in 20 springs in the minor aquifer area

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Fig. 19 Temporal variation of nitrate and chloride in the Fanta springs area (Major aquifer area)

16

Analysis of the Lideta spring data showed a high nitrate level at 728.21 mg/L and chloride at 194 mg/L in June 1999. Both contaminants decrease over time. It is noticeable that the high value corresponds with the beginning of the rainy season.

Excluding this high value, which may possibly have originated from direct human waste contact, or direct sewage flow, and evaluating 2003 levels shows the following trend (Fig. 20).

Lideta Spring Chloride and Nitrate levels in 2003

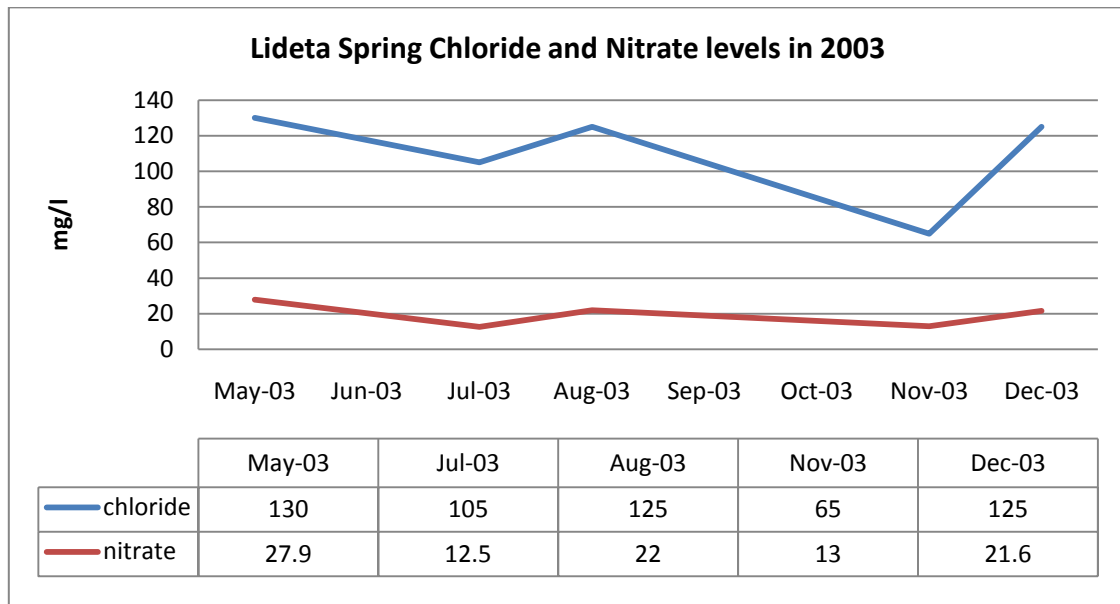|	May-03	Jul-03	Aug-03	Nov-03	Dec-03
chloride	130	105	125	65	125
nitrate	27.9	12.5	22	13	21.6

Fig. 20 Temporal variation of nitrate and chloride in the Lideta spring (minor aquifer area)

Again, although levels are comparatively low, the simultaneous variation suggests a possible seasonal variation. This may have been due to springs located in shallower aquifers being exposed to a higher contamination risk from anthropogenic activities. This is confirmed by an r_s value of 0.95.

The Lideta spring is also located in highly populated areas, as compared to the Fanta springs which are located at the peripheries of the city. This may have been one reason why comparatively elevated nitrate content is observed in the Lideta spring.

Conclusions

The study has shown that the concentration of nitrates and chlorides are linearly correlated in the minor aquifer areas. This indicates that the contamination probably originates from sewage. By contrast, the major aquifer areas showed no significant linear relationship between these two chemicals and hence, these pollutants appear to be largely from other anthropogenic sources such as agriculture and industrial activities.

The study has thus indicated that the level of nitrates and chloride has increased spatially as well as temporally. Although current levels of these chemicals are lower than permissible values in many of the areas, particularly in the southern major aquifer areas, the increase will eventually impact groundwater resources in the city. Therefore the minor and major aquifers in the vicinity of Addis Ababa are at risk.

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