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RISK AMONG CONSUMERS OF NITRATE CONTAMINATED GROUNDWATER IN LANGAS, ELDORET, KENYA

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Abstract

Nitrate is one of the most common contaminants of both surface and ground water. Nitrates are known to have health impacts if consumed in different concentrations. These include methemoglobinemia in infants, gastric lymphoma in adults, miscarriages among pregnant women, insulin-dependent diabetes mellitus, thyroid disease and increased risk for Non-Hodgkin Lymphoma. The study set out to investigate the risk among consumers of nitrate contaminated groundwater in Langas, the biggest informal low-income human settlement in Eldoret Town. Nitrate in groundwater obtained from wells in Langas was analyzed by a colorimetric method. The extent of nitrate contamination of the groundwater was determined and the level of exposure to residents obtained through questionnaires. Risk was then determined using the nitrate concentration against effects arising thereof. Results showed 11% percent of the wells had a mean concentration above 10 mgL^{-1} NO_3-N; the WHO and NEMA maximum limits for drinking water. Residents exposed to groundwater containing nitrate levels above 10 mgL^{-1} NO_3-N were 8 % of the total number of people living in the households sampled. Risk of childhood diabetes was shown among 92 % of groundwater users; risk of neural tube defect in newborn babies was shown among 82.8 % of groundwater users while that of methemoglobinemia in infants was shown in 53.5 % of groundwater users. The study concluded that there was risk of nitrate effects among groundwater users. The information generated is useful in making follow-up at health centres.

Keywords: Risk, Nitrate, Groundwater

INTRODUCTION AND LITERATURE REVIEW

Nitrates

Groundwater is the source for drinking water supplies in many rural areas most of which are agricultural. Agricultural activities are the major non-point sources of nitrate contamination of groundwater because of greater use of nitrogen fertilizer on crops and increased animal farming (Luk & Au-yeung, 2002; Almasri, 2007;). Nitrate can also get into groundwater through leaching from pit latrines (Hudak, 2000). Once in the water, nitrate typically behaves as a conservative contaminant. Maximum contaminant level (MCL) for nitrate in drinking water is 10 mgL-1 NO_3-N, given by various authorities (Focazio, Tipton, Shapiro, & Geiger, 2006) as well as the Government of Kenya (Republic of Kenya., 2006).

Studies reveal that many wells all over the world are contaminated with nitrate, with some containing concentrations above the MCL (Focazio, Tipton, Shapiro, & Geiger, 2006; Manassaram, Moll, & Backer, 2006; Sacco, Offi, De Maio, & Grignani, 2007). A study reported nitrate in groundwater of Eastern Botswana that resulted from deep leaching from pit latrines (Hudak, 2000). The presence of nitrates in groundwater in Langas has been shown in an earlier study (Kiptum, 2006, Unpublished Thesis). The study sampled wells between 5.5 m and 48 m from pit latrines. Wells that were less than 8m from pit latrines were found to have nitrate levels while those that were over 30m from pit latrines were found to have lower levels.

Risks associated with different concentrations of nitrate in drinking water have also been recorded (Croen, Todoroff, & Shaw, 2001; Manassaram, Moll, & Backer, 2006; Knobeloch, Salna, Hogan, Postle,

& Henry, 2000). Elevated nitrate concentrations in drinking water are linked to health problems such as methemoglobinemia in infants (Sadeq, Attarassi, Cherkaoui, ElAouad, & Idrissi, 2008). There is usually a methemoglobin reducing system in humans that maintains the methemoglobin level to less than 1% in adults. But where there is an unusual exogenous oxidation exposure the methemoglobin levels can increase to higher percentages (Maurtua, Emmerling, & Ebrahim, 2004). Infants under 6 months of age are particularly susceptible to methemoglobinemia because they have lower amounts of the key reducing enzyme (Avery, 1999).

Because methemoglobin is unable to transport oxygen (the role played by hemoglobin), a concentration of about 15% of the total circulating hemoglobin produces symptoms of cyanosis. Affected infants develop an unusual blue-gray or lavender skin color and are often described as irritable or lethargic, depending on the severity of their illness. Methemoglobin levels of over 50% can quickly lead to coma and death if the condition is not recognized and treated. It is related to increased level of diarrhea in children (Salgado, Ribbe, Delgado, & Flügel , 2008). Nitrate in drinking water is also associated with increased risk for Non-Hodgkin Lymphoma (NHL) (Hudak, 2000; Knobeloch, Salna, Hogan, Postle, & Henry, 2000), gastric lymphoma in adults (Vermeer, Pachen, Dallinga, Kleinjans, & van Maanen, 1998) miscarriages among pregnant women, insulin-dependent diabetes mellitus and thyroid disease (Knobeloch, Salna, Hogan, Postle, & Henry, 2000; Manassaram, Moll, & Backer, 2006). Other studies suggested that low-level nitrate exposure might play a role in the etiology of insulin-dependent diabetes mellitus. In 1994, results from a nationwide case-control study of childhood diabetes in Finland found that case children and their mothers had higher intakes of nitrite-rich foods than did control children and their mothers (Knobeloch, Salna, Hogan, Postle, & Henry, 2000; van Maanen, et al., 2000). In a 1997 study conducted at the University of Leeds, it was reported that the risk of childhood diabetes increased from a baseline of 1.00 at nitrate concentrations < 3.22 mgL-1 NO_3- NO_3 to 1.27 at concentrations > 14.85 mgL-1 NO_3- NO3. These concentrations correspond to 0.7 and 3.34 mg/l NO_3- N respectively (Knobeloch, Salna, Hogan, Postle, & Henry, 2000; van Maanen, et al., 2000). Other studies showed that nitrate exposure might also play a role in the development of thyroid disease. In the Netherlands, thyroid volume and function in populations exposed to different nitrate concentrations in their drinking water was evaluated. The research revealed a dose-dependent difference in the volume of the thyroid between low and medium nitrate-exposure groups versus high nitrate-exposure groups. The authors observed thyroid hypertrophy at nitrate concentrations > 50 mgL-1 NO_3- NO_3 (11 mgL-1 NO_3- N). An inverse relationship was established between the volume of the thyroid and serum thyroid stimulating hormone levels (Knobeloch, Salna, Hogan, Postle, & Henry, 2000; van Maanen, et al., 2000).

Study area

Langas area, in Eldoret Municipality, has a high population of mostly low-income earners with no sewerage facilities but with a few plots having septic tanks. The area has a high number of pit latrines as well as water wells (Ministry of Lands and Housing, 2005) increasing the risk of groundwater contamination with nitrate.

MATERIALS AND METHODS

Experimental Design

The intent of the research was to estimate nitrate exposure and risk among groundwater users in Langas, Eldoret. The experimental design involved analyzing groundwater in the study area for nitrate and then determining exposure through questionnaires. The study assumed that residents using the same well were exposed to equal risk.

Methods

Nitrate Determination

Thirty-six wells were sampled randomly from the study area, with sample size obtained using the formula below (Kothari, 2004).

$$n \geq \frac{z^2 N \sigma^2}{(N-1) e^2 + z^2 \sigma^2}$$

The number of wells found in the study area was 327 (N) and this is the figure that was used in the calculation of sample size (n) at 95% confidence. A total of ten samples from each well were taken between November 2008 and April 2009 for nitrate analysis. The sampling procedure was carried out as described in (APHA, 1992). The nitrate was analyzed using the cadmium reduction method described in (APHA, 1992). Households using the wells were randomly sampled and number of residents in the households recorded.

Risk among consumers of nitrate contaminated groundwater

Risk is the likelihood of dying or developing a disease, or its precursors. The risk analysis was based on a model that included hazard identification, risk assessment and risk management.

Hazard identification was obtained by analyzing the nitrate concentration in the groundwater from 36 wells in the study area. Water with nitrate concentration above the maximum contaminant level was considered a hazard. The risk assessment was done by first carrying out an exposure assessment followed by effect/consequence assessment. Exposure was taken to be contact with groundwater that contains nitrate for a period of time while exposure assessment was taken to be the identification of the exposures that occur or were anticipated to occur in the human population in the study area. The exposure assessment was determined by carrying out an interview with a sample of groundwater users. In the assessment, 23 wells were randomly sampled out of the 36 initial wells. A random sample of 32 women respondents was chosen among users of the 23 wells. Women were preferred because they are assumed to know better about the water usage and consumption in the household. They are also affected more by nitrate in water through abortions and the fact that methemoglobinemia affects mainly infants to whom they are caregivers. The interview method was chosen over a written questionnaire so as obtain information in greater depth and to be able to bring the language used to the level of the respondents (Kothari, 2004). The questions asked were unstructured hence gave the respondents an opportunity to answer and express their views freely (Malhotra, 2007). A digital recorder (OLYMPUS Digital Voice Recorder (WS-300M) was used to ensure that the communication with the respondents was as natural as possible and also minimal time was spent with them. The flow of information was hence least interfered with. Effect/consequence assessment was determined by examining the adverse health effects depending on the concentration of nitrate. The effects of different concentrations of nitrates in drinking water was obtained from different literature and the consequences assessed according to the concentration of nitrate found in the groundwater and effects caused by the different nitrate concentrations. The exposure outcome was combined with possible effect to characterize the risk to the human.

Data Analyses

Statistical Analysis was both descriptive and inferential. Means and standard deviations, graphs and tables, have been applied. Analysis was done using STATISTICA version 9 and SPSS. The responses from the interview were coded and analysed manually because the number of respondents was not very large.

RESULTS

Nitrate in groundwater

Nitrate levels in the groundwater from the informal settlement varied in different wells. Some had high values compared to others with the values of each well changing with time. The overall mean nitrate concentration found was 5.19 ± 3.23 mgL^{-1} NO_3-N with monthly mean levels varying from 4.1±2.0 mgL^{-1} NO_3-N to 6.9±3.7 mgL^{-1} NO3-N (Fig.1). The large deviations were due to the fact that the different wells had large variations in nitrate concentrations. The mean nitrate levels for specific wells ranged from 1.3 to 13.9 mgL^{-1} NO_3-N with 11% of the wells having a mean above 10 mgL^{-1} NO_3-N. The actual concentrations ranged from 0.9 mgL^{-1} to 18.0 mgL^{-1} NO_3-N.

Risk among consumers of nitrate contaminated waters

Table 1 below shows the number of people in households, the duration they have stayed and the mean concentrations of the nitrate levels found in the groundwater they use.

From the table, it is seen that 7.89% of the total number of people in all households were exposed to water containing nitrate concentrations of over 10 mg/l NO_3-N which is the maximum concentration limit in the country for drinking water. Of these the ones who are exposed to the water for long duration (15-20 yrs) make 2.63% of the total number while 3.51% of the total number has been exposed for less than one year. Fifty percent of the total number of people have been exposed to the groundwater at the locations for less than five years with 24.6% of the total having been exposed for less than a year. Figure 2 shows the number of people from the sampled households exposed to water containing nitrate concentrations of over 10 mg/l NO3-N for different number of years.

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Only 15.6% of the respondents were able to quantify how much of the groundwater they use in their households per day. Of these, 9.4% use 100 litres, 3.1% use 90 litres and 3.1% use 80 litres of the groundwater per day for both cooking and washing.

Table 1

Number of people in the households, the duration they have stayed and the mean concentrations of the nitrate levels compared to 10 mg/l NO_3-N, the MCL in Kenya, found in the groundwater they use from Langas, a peri-urban informal settlement in Eldoret.

Duration of stay	Mean concentration range mg/l NO_3-N	Total number of people in household
Less than 1 yr	< 10.0	24
" "	> 10.0	4
1-5 yrs	< 10.0	29
" "	> 10.0	2
5-10 yrs	< 10.0	13
" "	> 10.0	0
10-15 yrs	< 10.0	4
" "	> 10.0	0
15-20 yrs	< 10.0	14
" "	> 10.0	3
> 20yrs	< 10.0	9
" "	> 10.0	0
Not specific	< 10.0	12

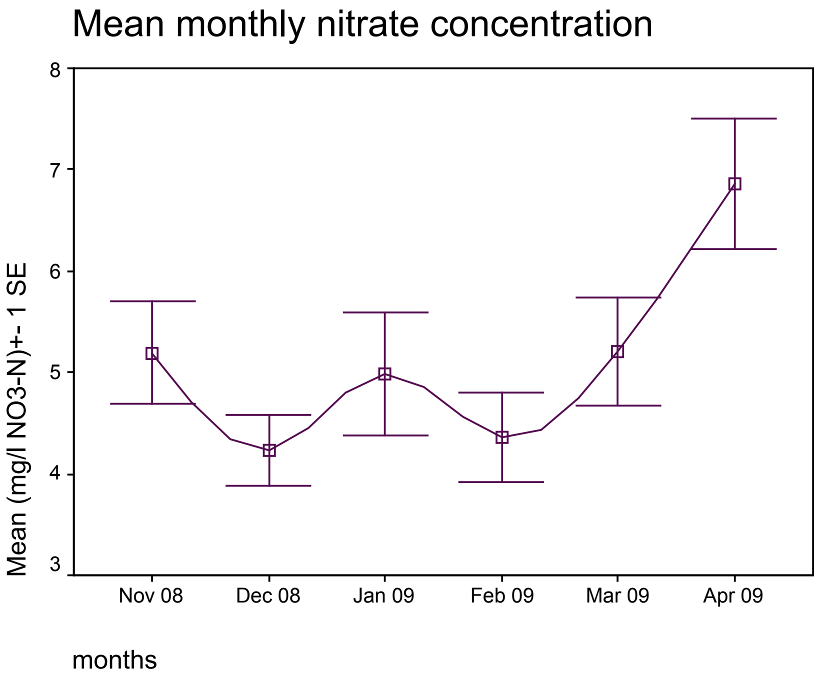

Figure 1

Graph showing monthly mean concentrations of nitrate in groundwater from Langas, a peri-urban informal Settlement in Eldoret, during the study period

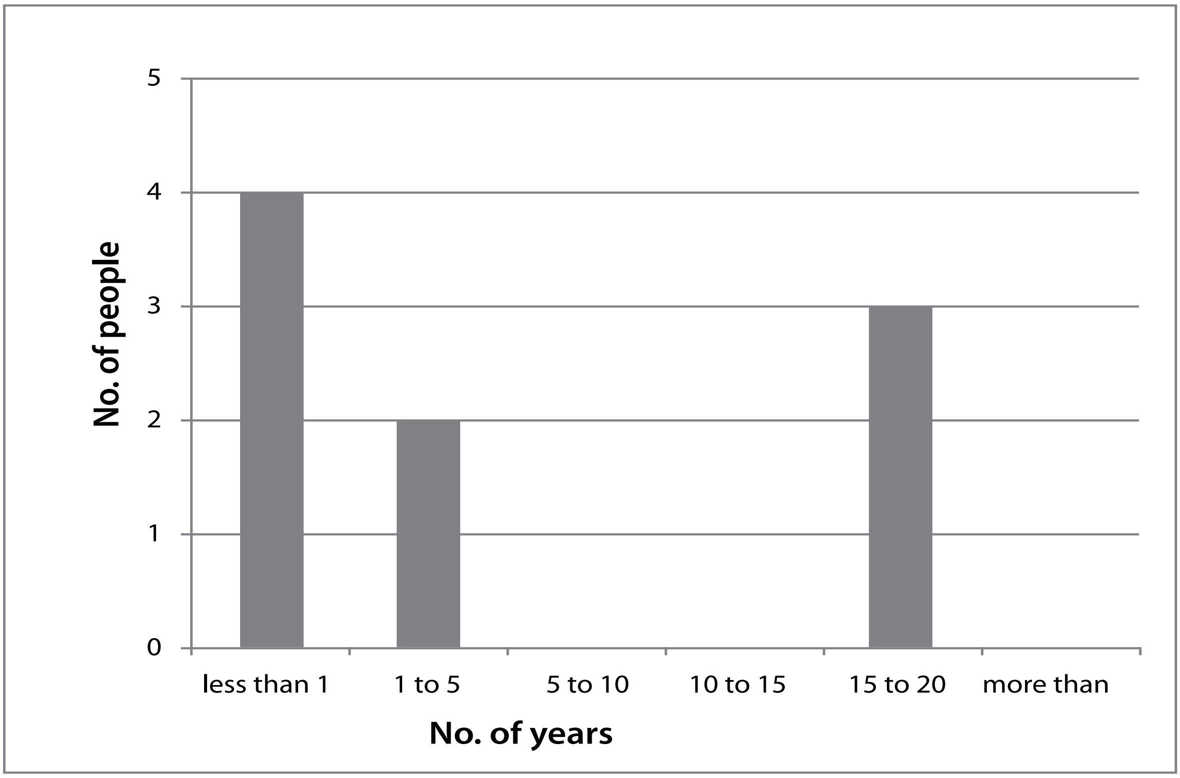

Figure 2

Number of people in the households sampled exposed to groundwater containing nitrate concentrations of over 10 mg/l NO_3-N for different number of years in Langas, a peri-urban informal settlement in Eldoret during the study period.

The rest of the respondents said they use a lot of water as it is readily available and they cannot keep track of the volume. This information is depicted in Figure 3.

Together with that respondents said the amount used depended on how much washing they had. All the 32 respondents interviewed said they drink tap water and not the groundwater. Of these, 12.5 % obtain the tap water from taps available in the plots while the rest buy tap water either from water kiosks that are located at various points or from neighbouring compounds that have tap water supplied. Only one of the respondents said she sometimes gets drinking water from the well. .

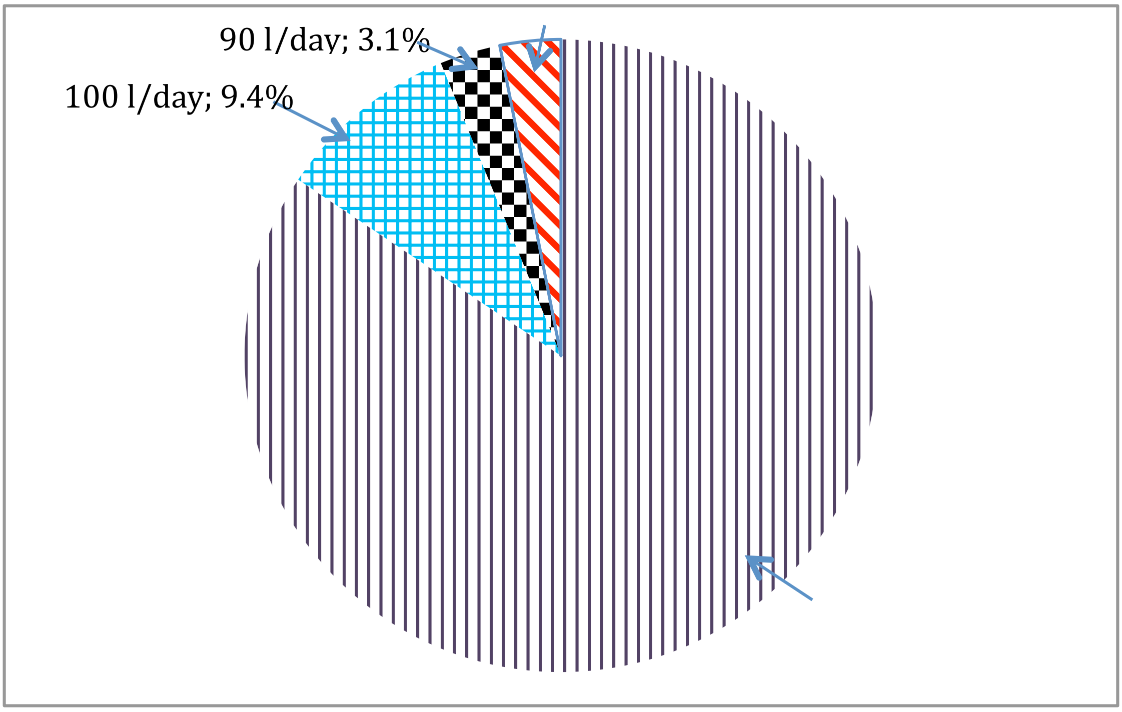

Figure 3

Quantities of groundwater in litres per day used in households as given by respondents in Langas, a peri-urban informal settlement in Eldoret, during the study period.

Eighty four point four percent of the respondents quantified how much tap water they use per day. All the respondents said they do not boil tap water for drinking since they believed the tap water is already treated.

Awareness of diseases caused by contaminated water was low, although 61% of the respondents were aware of typhoid. Figure 4 shows the respondents' answers when asked about their knowledge of diseases that are caused by contaminated water.

Table 2 shows the risk of effects that can be caused by consumption of water containing different concentrations of nitrate.

DISCUSSION

Nitrates in Groundwater

The overall nitrate concentration mean was 5.19 ± 3.23 mgL^{-1} NO_3-N. There was a big standard deviation because of the differences in the nitrate concentrations from the different wells which ranged from 0.9 mgL^{-1} NO_3-N to 18 mgL^{-1} NO_3-N. The nitrate mean values found are not as high as those found

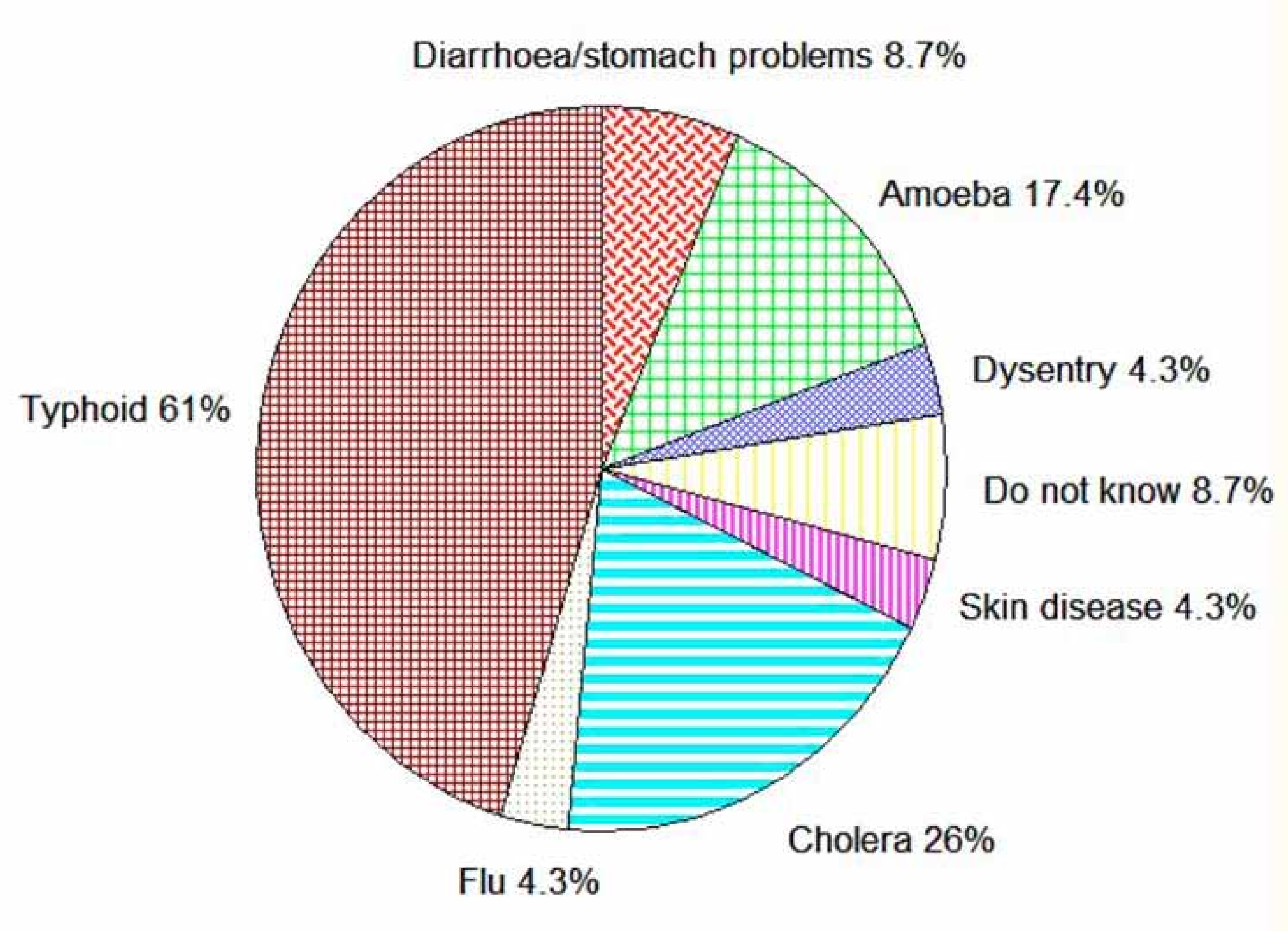

Figure 4

Respondents' knowledge of diseases that are caused by contaminated water in the study carried out in Langas, a peri-urban informal settlement in Eldoret during the study period

Table 2

Risk of various effects of different concentrations of nitrate on groundwater users in Langas, a peri-urban informal settlement in Eldoret.

Risk of	Nitrate concentration in mgL^{-1} NO_3-N	% well	% users
Childhood diabetes baseline of 1.27	>3.34	85.6	92
Thyroid hypertrophy	>11	11	5.2
Neural tube defect in newborn babies	>3.5	82.8	82.5
Methemoglobinemia	>5	44	53.5
Unsafe water for adults	>10	11	7.89

in an earlier study. The highest value in the previous study was 157.5 mgL^{-1} NO_3-NO_3 equivalent to 35 mgL-[1] NO_3-N (Kiptum, 2006, Unpublished Thesis). The difference may be due to the fact that the wells for this study were picked at random while the wells in the earlier study were picked depending on the distance between the well and the pit latrines (Kiptum, 2006, Unpublished Thesis). The other reason for the difference may be the fact that there was a lot of rain than is usual at the time of the year when the study was carried out. Where nitrate in groundwater is as a result of leaching from pit latrines, the concentrations are lower during the rainy season due to dilution from increased recharge (Boumans, Fraters, & Van Drecht, 2001). Where nitrate in groundwater is as a result of leaching of fertilizer from an agricultural area the concentration increases with increase in rainfall. Rainy periods lead to leaching of the fertilizers and, as a consequence, of the nitrates in the soil, polluting the groundwater (Perez, Antiguedad, Arrate, Garcýa-Linares, & Morelld, 2003). Nitrate contamination of the wells in the study area is considered mainly as a result of leachate from pit latrines and not from agricultural activities. The trend in the monthly nitrate concentrations was similar to that of an earlier study where the nitrate concentration in the dry season was higher than that of the wet season.

Risk among consumers of nitrate contaminated waters

The US EPA determined that nitrate concentration in excess of 10 mgL-[1] NO_3-N for adults and 5 mgL-1 NO_3-N for infants in drinking water is unsafe

(Withgott & Brennan., 2008). NEMA in Kenya has put the maximum limit of nitrate in drinking water at 10 mgL-[1] NO_3-N. The high nitrate levels in some wells put to risk users of the water. Forty four percent of the wells in the study had mean values above 5 mgL^{-1} NO_3-N making the water unsafe for infants by increasing the risk of infantile methemoglobinemia. For the adults 7.89 % of them are at risk of unsafe concentration. From the interview, most of the people said they use tap water for drinking and well water for other domestic purposes. But the fact that they purchase the tap water from water kiosks or plots with taps makes it likely that not all of them buy the water.

Table 2 gives a summary of risks associated with groundwater in the study area. There is an increase in baseline for the risk of childhood diabetes to 1.27, at concentrations greater than 3.34 mgL-[1] NO3-N (Knobeloch, Salna, Hogan, Postle, & Henry, 2000; van Maanen, et al., 2000). In the study area 85% of the wells have nitrate levels in this category with 92.1 % of total household members. Eleven percent of the wells contain nitrate levels that may result in thyroid hypertrophy (nitrate concentrations > 11 mgL^{-1} NO_3-N) (van Maanen, et al., 2000) for over 5.2 % of total household members. Eighty two point eight percent of wells contain water with nitrate concentrations above 3.5 mgL^{-1} NO_3-N being used by 82.5 % of the total household members risking pregnant mothers to bear newborn babies with neural tube defect (NTD) (Manassaram, Moll, & Backer, 2006).

CONCLUSION

The study has shown existence of risk of several diseases in the Langas area from the nitrate concentration obtained in groundwater. The study has also provided information that can be used as a basis for follow-up to medical facilities in the study area to find out whether cases related to nitrate contamination have been reported or whether there is an increase of such cases.

The results will also help managers of water resources as well as public health officers to come up with informed management decisions that can also be applied to other areas with similar problems. An awareness campaign should also be carried out in order to enlighten residents on many of the diseases caused by contaminated water including those that result from nitrates such as methemoglobinemia and certain cancers as well as the importance of knowing the nitrate concentration of groundwater. The residents can be asked to check the nitrate levels in their groundwater once a year during the dry season, or public health officers be mandated to do that. The wells with nitrate levels above the maximum concentration limit should be avoided for cooking and drinking because the available treatment methods are expensive and cannot be afforded by the residents.

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