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Full Length Research Paper

Well water contamination by pit latrines: A case study of Langas

Clement Kiprotich Kiptum[1] and Julius Musyoka Ndambuki[2]*

[1]Department of Civil and Structural Engineering, Moi University, P. O. Box 3900, Eldoret, Kenya.
[2]Department of Civil Engineering, Tshwane University of Technology, Private Bag X680, Pretoria 0001, South Africa.

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In many peri-urban areas of Kenya, potable piped water does not exist and where it does, it is rarely reliable. Thus, in such areas, residents heavily rely on groundwater sources for their daily survival. Therefore, it is common to find individual wells in each plot within such a peri-urban dwelling. Furthermore, in most cases, such dwellings lack municipal sewers, hence forcing residents to construct pit latrines at close proximity to their wells. Indeed, it is not uncommon to find a well located just a few metres from an un-lined pit latrine. A study was carried out on the well water contamination by pit latrines in Langas which is peri-urban settlement of Eldoret town, Kenya. The study sought to establish the safety (quality) of water in wells located near pit latrines on individual plots of the settlement. The results show that most wells were contaminated and posed a health risk to the dwellers of the settlement. From the results it is recommended that a safe well-pit latrine separation distance of 48 m be maintained which will avoid contamination of well water from pit latrines.

Key words: Groundwater, wells, pit latrines, modelling, contamination.

INTRODUCTION

Despite intensive research and implementation of water projects over the past two decades in Kenya, the percentage of population with no satisfactory water and sanitation facilities is still high and on the rise especially in the urban areas. Indeed, it was with this in mind that the United Nations declared the theme of the World Habitat Day 2003 as “Water and Sanitation for Cities”. The theme highlighted the need to provide the urban poor with clean water and decent sanitation (Karanja, 2003).

When water and sanitation facilities are being planned, they are usually done in such a way that they cover the present local authority boundary leaving out the neighbouring plots or farms. As the population increases, the demand for plots near the local authority increases. This forces the owners of farms near the local authority to subdivide their farms and sell the plots. The new plot owners develop their plots with no regard to planning for essential services like roads, electricity, water and sanitation facilities. These developments are spontaneous in such a way that planning for water and sanitation facilities by the local authorities, in most cases municipal councils is difficult. Eldoret town is a typical example of such a situation.

Eldoret town has various residential estates such as Elgon View, Kapsoya, West Indies, Kamukunji, Huruma, Langas, Kipkaren, State Lodge and Pioneer Estates. For example, Langas is an estate that is about 5 km south of the from the central business district where the majority of the people are low income earners. This estate was once a farm with eucalyptus species trees owned by a person known as Malel who later sold the farm in form of plots that are 30 × 15 m in dimensions. The new plot owners erected semi-permanent structures, built latrines and sunk shallow water wells in their plots without consulting the relevant authorities when siting the latrines and wells. This resulted in situations where the well-pit latrine distances, in some cases, are as short as 5 m posing a risk of groundwater contamination by these pit

*Corresponding author. E-mail: ndambukijm@hotmail.com.

latrines.

The prevalence of shallow water wells is due to the high water table in the estate. Piped water from Eldoret Water and Sanitation (ELDOWAS) is another source of water serving 35% of the population. The water is obtained from water kiosks and some individual connections. The high prices that residents pay for the water and the distance to piped water in water kiosks coupled with low water pressures at some areas results in 65% of the population using water from shallow water wells. Most of the wells are uncovered or partly covered leading to contamination of well water from spillage while drawing water and surface runoff during rainy season. The estate has over 300 existing privately owned traditional hand-dug wells, six water kiosks of which one is operational and about 110 individual connections. Most of the people use the untreated water from the shallow water wells to meet their daily water demands.

For an estate like Langas that is densely populated with a population of over 25,000 people and a growth rate of 10%, pit latrines become appropriate for disposal of faecal matter as they are cheap. Therefore, latrine sanitation systems will remain a popular form of low-cost sanitation for many years to come if the municipal council of Eldoret does not expeditiously consider extending its sewerage facilities to Langas estate. At the time of the research, the estate had over 800 pit latrines. Research over the years has shown that bacteria can be transported some distance through the ground by liquid leach ate from pit latrine, and could thus contaminate groundwater (Mara, 1996). In this estate, most of the pit latrines that are full cannot be emptied because they are not accessible to exhausters (honey suckers) due to poor physical planning of the estate. If a latrine is full and is not emptied, the contents end up spilling on the floor especially in the rainy season and can be transported via foot to a nearby shallow well resulting in contamination.

Groundwater pollution is common occurrence in most areas as a survey of recent literature shows. For instance, a study to explore groundwater contamination in Langas found out that by injecting a bacteriophage (viruses' only attacking bacteria) in a pit latrine, its presence could be detected in a well located 40 m away within a week. Stenstrom (1996) did not consider the hydrogeology (for example, the soil conditions) during the research. Several other studies have been done in Kenya to investigate groundwater contamination in other areas. For instance Orwa (2001) in his study in Kisumu (Manyatta and Migosi estates) found out that the mean nitrate value in groundwater was 70.312 mg/L, mean phosphorus content of 0.23 mg/L and a mean E. coli of 654 counts/100 ml was detected in the well water. A similar study done in Cost Province by Kenya Marine and Fisheries Research Institute (KEMFRI) concluded that the residents of Shimoni, Kwale District and Malindi faced the highest risk of consuming contaminated water as boreholes and most wells were highly contaminated (Mayoyo and Kilalo, 2003). The contamination was attributed to the high population and large number of wells dug near pit latrines/septic tanks. Though the above studies showed a relation between the pit latrine-well contaminations, none of them attempted to study the hydrogeology, and in particular, use numerical methods to model the flow of groundwater. This study considered the hydrogeology of the area in its investigations.

The geology of the study area has igneous rocks (volcanics) of tertiary period of Cainozoic era. Tertiary volcanic of upper tertiary age is mainly alkaline type and includes phonolites. The base of the phonolite is located at an elevation of 1860 m at the North-Western extremity of the plateau, near Moi's Bridge, and rises southwards to nearly 1920 m West of Eldoret Town (GOK, 1997). The predominant soils in the study area are gleysols. Gleysols are poorly drained mineral soils which are periodically water-logged. Periodic or permanent saturation by groundwater is reflected by greyish colours or prominent mottling.

METHODOLOGY

Water quality parameters that indicate interaction of leachate from latrine and groundwater are nitrates, phosphates and faecal coliforms. The high levels of nitrates found in domestic well waters are mainly due to near proximity of the pit latrines to the wells (Lewis et al., 1980). Phosphorus occurs in natural waters and in wastewater almost solely as phosphates. Primarily, biological process form organic phosphates which are contributed to sewage by body wastes and food residues. Numerous hand dug shallow wells and pit latrines have been sunk in an unconfined aquifer in Langas.

Due to the large number of pit latrines and shallow water wells in the study area, a total of 30 representative wells were selected after zoning the study area into five zones. The criteria used to get the representative number of wells were the density of wells, density of latrines, the closeness of the well to a nearby latrine and the location in reference to the road network in the study area. The 30 wells were selected randomly from the five zones to analyse for the presence of faecal coliforms, nitrates, phosphate ions and pH. Random sampling was used since the chance of selecting a well in a given zone was the same. Figure 1 is a map of the research area. It was divided into five zones according to the mentioned criteria (Figure 2). The features of different zones are as elaborated briefly as:

1) Zone 1: The zone is located on the western side of the study area. The latrine-well distance was small owing to the size of individual plots and samples were taken from nine wells. The mean latrine distance was 13.3 m.
2) Zone 2: This zone lies at the centre of the study area. The mean well-latrine distance was 14 m and samples were taken from eleven wells.
3) Zone 3: This zone is located to the northern part of the study area. The mean well-latrine distance was 11.8 m and samples were taken from five wells.
4) Zone 4: This lies to the east of the study area and has mean well-latrine distance of 34.5 m. The samples were taken from two wells.

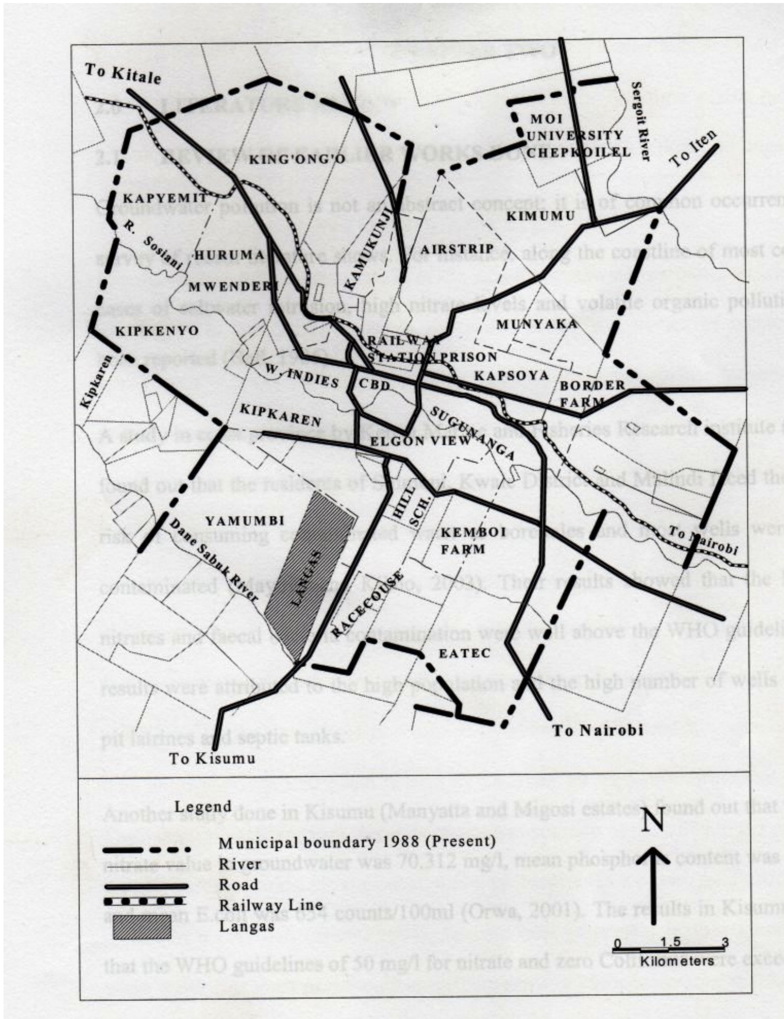

Figure 1. Location of Langas in Eldoret Town.

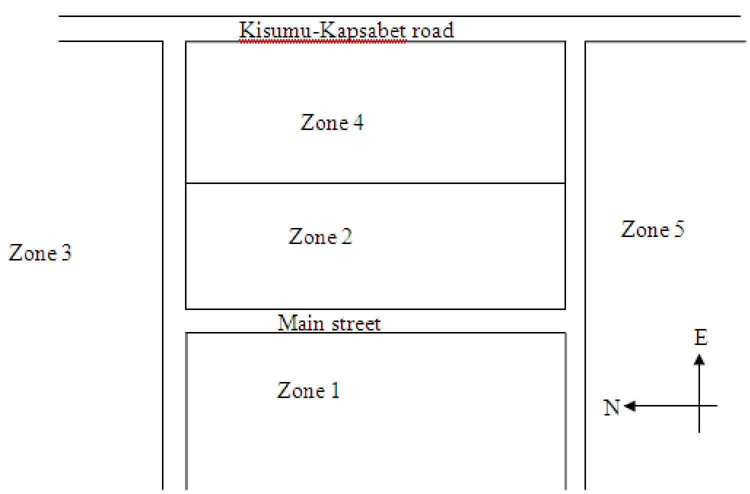

Figure 2. Study area showing the five zones.

5) Zone 5 lies to the south of the study area with mean well-latrine distance of 14.6 m and three wells were sampled.

Measurement of distances, water sampling and analysis

A 30 m steel tape was inserted in the sampled wells until it just touched the water level; its reading was read and recorded. The readings enabled the computation of the heads in different wells in reference to a datum of 2096 m above the sea level that is, the depth at which the phonolite murram extends downwards. The distances between pit latrines and wells were measured using the same steel tape thus enabling the comparison between the separation distance and the level of contamination to be done.

Water samples were collected for analysis in sterilized bottles with stoppers prepared by heating for two hours at the temperature of 120℃. Slightly over 250 ml of each sample was collected in order to perform all the tests required for faecal coliforms, nitrates and phosphates. The samples were collected in the morning when the water had not been adversely disturbed and labelled. Since changes of water quality occur during transit and when stored, the samples were put in a cooled box while collection continued. The required time between sampling and analysis, which is four hours for nitrates and two hours for faecal coliforms were adhered to.

Membrane filter procedure with a dehydrated media (MF-C broth) was used to give uniform results. The presence of nitrates was tested using the cadmium reduction method with the help of Hach DR/2000 spectrophotometer at a wavelength of 500 nm. Ascorbic acid method was used to analyse the phosphate levels in the groundwater.

Modelling of the groundwater flow

Groundwater model is any system that can duplicate the response of a groundwater reservoir (Bell and Hamil, 1986; Ndambuki, 2001). Thus the groundwater flow system in the study area was modelled to get approximate safe distances between the wells and pit latrines. There are two types of models: physical and mathematical models. Mathematical models simulate groundwater flow indirectly by means of governing equations that describe heads or flows along the boundaries of the model. The general non-linear Boussinesq equation for flow in unconfined aquifer is (Ndambuki, 2001):

$$\frac{\partial}{\partial x}\left(K_x h\frac{\partial h^2}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y h\frac{\partial h^2}{\partial y}\right)=2\times S_y\frac{\partial h}{\partial t}-2\times R^* \quad (1)$$

Where K_X, K_y and K_z are hydraulic conductivities in their respective axes; R^* is the general source/sink term; S_y is the specific yield and (h) is the hydraulic head.

Equation 1 together with the specifications of flow and/or head conditions at the boundaries of an aquifer system and initial head conditions constitute a mathematical model of groundwater flow.

There are many situations (irregular shapes, different materials, anisotropy etc.), however, where analytical solution is difficult to obtain such as solution to Equation 1. Therefore, various numerical methods are employed to obtain approximate solutions. Numerical modelling was done using MODFLOW (McDonald and Harbaugh, 1988). It is a well documented and tested, easy to use and convenient computer code for developing multilayered simulation models of complex geological systems.

Before modelling there was need to first develop a conceptual model which is a pictorial representation of the groundwater flow system, frequently in the form of cross-section. The nature of conceptual model determined the dimensions of the numerical model and the design of the grid. In order to perform numerical modelling using MODFLOW, some input data is required. These are summarised in Table 2. The quantity of water extracted from different wells and the injection rates for the latrines are as shown in Table 3.

ANALYSIS AND DISCUSSION OF RESULTS

Water analysis

Bacteriological, nitrates and phosphates results for thirty wells sampled and tested in the dry and in the wet seasons are summarised in Table 1. Table 1 also shows the zones, type of covering, latrine well distance and the number of users.

All the zones had similar results as far as faecal coliforms are concerned. The level of faecal contamination exceeds the WHO guidelines of no counts per 100 ml of sample which means that the water is not fit for consumption because of high bacterial contamination.

The values in Table 1 further show that 17 wells and 11 wells in the dry and in the wet seasons respectively had nitrate concentration in excess of WHO guideline limit of 50 mg/L. This means that more than a third of the sampled wells have high nitrate pollution. Phosphate levels from all the zones were much lower than the WHO recommended level of 5.0 mg/L meaning that the water is safe from phosphate pollution. The differences in the levels of contamination were because of different features of the wells in the study area. These features include type of cover, number of inhabitants, distance to the nearest latrine and lastly rainfall amount.

Covering to the wells is by use of either timber or concrete. Concrete covers are more expensive than timber and that is why 63% of the sampled wells had timber covers. From Table 1, there exists no correlation between the type of cover and the levels of nitrates and phosphates. However, there exists a strong correlation between the type of cover and faecal contamination. It was found that all the wells with concrete covers recorded low counts, while those with timber covers had higher counts in the dry season. Concrete covers guard the well against surface runoff, windblown substances and also help to exclude spilled water, which may be carrying faecal matter from flowing into the well. Timber covers cannot provide this type of preventive measure as required.

As mentioned earlier on, there exists a latrine and a well in each plot. The dimensions of a plot affect the distance between the latrine and well. Small plot sizes mean that the distances between the latrines and wells

Table 1. Water quality analysis results.

Well no.	F. coliform (counts)	Nitrates (mg/L)	Phosphate (mg/L)	Distance to Latrine (m)	Number of Users	Cover type
			Zone 1			
1D	TNTC	42.1	0.52	10	32	Timber
1W	TNTC	33.2	0.50			
2D	TNTC	63.2	0.58	9	23	Timber
2W	TNTC	49.3	0.56			
3D	108	38.1	0.54	20	57	Timber
3W	TNTC	30.9	0.52			
4D	TNTC	54.5	0.50	10	52	Timber
4W	TNTC	40.9	0.49			
5D	TNTC	68.5	0.52	5.5	21	Timber
5W	TNTC	54.8	0.46			
6D	64	51.1	0.42	11	23	Timber
6W	TNTC	38.8	0.41			
7D	TNTC	62	0.66	7	67	Timber
7W	TNTC	46.2	0.63			
8D	32	128.5	0.51	17	48	Concrete
8W	TNTC	98.2	0.48			
9D	TNTC	24.6	0.49	30	11	Timber
9W	TNTC	20.2	0.48			
			Zone 2			
10D	TNTC	54.1	0.48	18	24	Timber
10W	TNTC	43.3	0.46			
11D	30	20.2	0.32	16	17	Concrete
11W	TNTC	18.9	0.31			
12D	TNTC	157.5	0.61	6	66	Timber
12W	TNTC	61.6	0.58			
13D	TNTC	50.6	0.41	12	24	Concrete
13W	TNTC	41.0	0.40			
14D	TNTC	48.9	0.92	10	26	Timber
14W	TNTC	37.2	0.88			
15D	70	73.5	0.74	14	52	Concrete
15W	TNTC	59.4	0.73			
16D	TNTC	42.4	0.64	18	26	Timber
16W	TNTC	36.2	0.63			
17D	TNTC	63.6	0.62	12	33	Timber
17W	TNTC	50.4	0.61			
18D	64	64.5	0.46	14	45	Concrete
18W	TNTC	51.2	0.43			
19D	40	20.2	0.44	22	17	Concrete
19W	TNTC	16.3	0.42			
20D	TNTC	79.2	0.50	11	42	Timber
20W	TNTC	62.6	0.48			
			Zone 3			
21D	25	64.8	0.40	12		Concrete
21W	TNTC	56.8	0.38			
22D	TNTC	44.6	0.44	11		Timber
22W	TNTC	37.8	0.40			

Table 1. Contd.

23D	TNTC	72.6	0.64	12		Timber
23W	TNTC	65.8	0.61			
24D	TNTC	78.6	0.54	8		Timber
24W	TNTC	61.7	0.49			
25D	56	84.5	0.58	14		Concrete
25W	TNTC	63.8	0.56			
			Zone 4			
26D	TNTC	45.7	0.32	21		Timber
26W	TNTC	36.6	0.31			
27D	80	2.2	0.26	48		Timber
27W	TNTC	3.5	0.24			
			Zone 5			
28D	68	40.5	0.30	25	21	Timber
28W	TNTC	34.5	0.27			
29D	TNTC	58.4	0.28	8	17	Concrete
29W	TNTC	44.2	0.25			
30D	TNTC	33.9	0.36	11	48	Concrete
30W	TNTC	25.4	0.33			

D, Water sample in the dry season; W, water sample in the wet season.

Table 2. MODFLOW input data from the study area.

S/N	Parameter	Value
1	Square grids of 15 × 15 m	80 columns and 108 rows
2	Layer type	Unconfined
3	Boundary conditions	Eastern and western boundaries were designated constant head boundaries. Southern and northern boundaries were designated non-flux boundary.
4	Aquifer thickness	15 m
5	Effective porosity	14.34%
6	Hydraulic conductivity	21.9 m/day
7	Recharge in Langas	0.00026 m/day

are shorter. The smallest plot measures 15 × 15 m while the largest measures 15 by 30 m. The distance from the water wells to nearby pit latrines ranged from 5.5 to 48 m. Contamination is likely to occur owing to reduced travel times of the leachate from latrine to a downstream well when separating distance is short. This is vividly illustrated in well number 5 during the dry season, which had very high faecal coliform counts due to short distance of 5.5 m between the well and the latrine (Table 1). Well numbers 7, 8, 12 and 24 that were less than 8 m from the nearest latrine also recorded high nitrate concentrations.

Well numbers 9 and 27, which were more than 30 m

Table 3. Pumping and injection rates for wells.

Well number	Number of people	Pumping rates (m^3/day)	Injection rates of latrines (m^3/day)
1	23	0.46	0.11
2	32	0.64	0.15
3	57	1.14	0.27
4	52	1.04	0.24
5	41	0.82	0.19
6	23	0.46	0.11
7	67	1.34	0.31
8	48	0.96	0.22
9	11	0.22	0.05
10	24	0.48	0.11
11	17	0.34	0.08
12	66	1.32	0.31
13	24	0.48	0.11
14	23	0.46	0.11
15	52	1.04	0.24
16	26	0.52	0.12
17	33	0.66	0.16
18	45	0.90	0.21
19	17	0.34	0.08
20	42	0.84	0.20
21	47	0.94	0.22
22	53	1.06	0.25
23	34	0.68	0.16
24	41	0.82	0.20
25	17	0.34	0.08
26	39	0.78	0.18
27	7	0.14	0.03
28	21	0.42	0.16
29	17	0.34	0.08
30	48	0.96	0.20

recorded less nitrate concentrations.

The number of users of wells ranged from 7 people in well numbers 27 to 67 people in well number 7. The larger the number of users, the higher the amount of water drawn from a well and the amount of water discharged into latrines. The more the water is drawn from a well, the higher the hydraulic gradient between the well and the latrine, consequently inducing higher rate of flow to the well and hence contamination. As expected, wells with fewer residents recorded lower counts. For example, well number 12 which had 66 users recorded the highest nitrate concentration levels while well number27 with 7 users recorded the lowest nitrate concentration. It is noted that the number of people using the well, type of cover and distance to the nearest latrine and the level of contamination is inter-related to each other. Where there is a timber covering, short separation distance between pit latrines and wells and high number of users, e.g. in Well No. 12, heavy contamination levels occurred.

The tests were done in both the dry season and in the wet season to find whether there was a relationship between contamination and rainfall. During the dry seasons, counts less than 100 counts were observed while during the rainy seasons all the wells registered numerous counts. Many counts were observed in the wet seasons as a result of the rise in water table due to recharge from rainfall. This meant that more of the contents of the pit latrines flow to the nearby downstream wells in the wet season resulting in greater contamination. During the rainy season, the concentrations of nitrates and phosphates were diluted by about 25% due to the higher recharge rate from rainfall.

Model results

The purpose of modelling was to know the distance to which a contaminant would move from a pit latrine to a well. This was achieved by using the semi-analytical particle tracking method in PMPATH modelling environment of PMWIN (Chiang and Kinzelbach, 1996). To demonstrate the flowpaths and travel distances, hypothetical particles were placed in one cell. The results showed that the particles travelled at an average velocity of 1.2 m/day. According to this rate, the shortest time for groundwater to flow from the latrines to a nearby downstream well ranged from 5 days to 40 days. The travel times were calculated using the shortest separation distance of 5.5 m and longest distance of 48 m respectively. In this study the separation distance of 48 m was taken as the safe well-latrine distance because it had the longest travel time. A long travel time means that a pollutant will likely be filtered out as it moves through a porous media. The filtration process results in the removal of pathogens and hence reducing contamination of wells.

In order to check the accuracy of the initially assessed aquifer parameters, it was necessary to make thorough and critical comparisons between the simulated and observed head distributions (Abderrahman and Rusheeduddin, 2001). The root mean square error (RMSE) was estimated in order to compare the observed and simulated heads. The root mean square error is defined as follows:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(h^{s} - h^{o}\right)}{n}} \tag{2}$$

Where h^s = simulated head (L); h^o = observed head (L) and n = number of observations.

Comment: The letter L is used to designate both the units of simulated head and observed head. Is it L_1 and L_2 or just L?

The RMSE was computed using the measured heads at selected wells and found to be 0.26. The maximum difference was 0.40 and the model was taken to have satisfactorily simulated head patterns in terms of water level trends.

Another statistical parameter used to assess how MODFLOW procedure predicted observed heads in Langas is goodness of fit, R^2. The R^2 is a measure of the amount of variance between observed and simulated heads and is given by Equation 3 (Johnson and Gouri,1986):

$$R^2 = \left[\frac{\sum_{i=1}^{N}\left(h^{o} - \bar{h}^{s}\right)\left(h^{s} - \bar{h}^{o}\right)}{\sqrt{\sum_{i=1}^{N}\left(h^{o} - \bar{h}^{s}\right)^2} \times \sqrt{\sum_{i=1}^{N}\left(h^{s} - \bar{h}^{o}\right)^2}}\right]^2$$

In this study a value of goodness of fit (R^2) of 0.931 was obtained which meant that the model could predict head patterns as the value is close to unity.

Conclusions

In this paper, the results on the level of contamination in the shallow wells sampled by performing water quality analysis to test for faecal coliforms, nitrates and phosphates which are the main indicators of contamination have been presented. The results show that the level of contamination in shallow water wells is high because they exceeded the WHO guidelines limit of zero counts for bacteria and 50 mg/L for nitrates. The main source of the contamination was found to be the nearby pit latrines that were situated close to the shallow water wells.

Further, numerical modelling technique was used to simulate groundwater flow in the area. The results indicate that groundwater flows at an average rate of 1.2 m/day. Short separation distance between a pit latrine and water well means that the contaminants can travel from the pit latrine to the well in a few days resulting in higher levels of water contamination in the well. The safe separation distance between the pit latrines and wells was calculated to be 48 m. The distance can aid in reduction of contamination because it subjects the contaminants to a longer travel time from a latrine to downstream shallow water well which will allow for the filtration of any pollutants in it.

To prevent contamination of the water in the wells, it is recommended that lining to the wells and concrete covering be done to prevent surface runoff and spillage from entering the well. The results of the study show that the water in most of the wells are highly contaminated and is not safe for domestic use especially cooking. Thus some form of treatment such as chlorination or boiling should be done before it can be used for domestic purposes. It is also recommended that the authorities should consider providing piped water at a reasonable cost to the residents of Langas.

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