IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 15, Issue 7 Ser. I (July 2021), PP 22-30
www.iosrjournals.org

Pollution Risk Assessment of Groundwater at Kamkuywa Market Center, Bungoma Using Geospatial Technology

Dinah Ayoma Wechuli, Benjamin N. Mwasi, Victor A. O. Odenyo
1(Environmental Monitoring, Planning and Management, University of Eldoret, Kenya)
2(Environmental Monitoring, Planning and Management, University of Eldoret, Kenya)
3 (Environmental Monitoring, Planning and Management, University of Eldoret, Kenya)

Abstract:
Background*: Pathogenic contamination of groundwater, due to poor sanitation, has continuously posed a significant health risk to human health. Kamkuywa market center, a peri-urban settlement, relies heavily on shallow wells contamination. This study used GIS-based risk mapping to establish the extent of groundwater pollution by coliforms and determine the relationship between selected risk factors, namely: depth to the water table, distance from a shallow well to the nearest pit latrine, pit latrine depth, soil permeability and ground slope for purposes of establishing the optimal well-pit latrine separation distances under different hydro-geological conditions.*

Material and Methods*: All shallow wells and pit latrines in the study area were mapped and the separation distances compared to the recommended standards. Water samples in 32 shallow wells were collected and analyzed for fecal content. The regression model was used to determine the relationship between coliform concentration and the selected risk factors as well as establish the extent of contamination and optimal distancing.*

Results*: The results indicate that 67.6% of shallow wells did not meet the World Health Organization and the Kenya safe distance criteria. In terms of relationship, pit latrine depth and soil permeability positively correlated with contamination. A negative relationship was established between groundwater contamination and water table depth and no relationship with surface slope. Out of 32 shallow wells sampled for fecal coliform analysis, 31 tested positive for fecal coliforms. Over 75% of the study area was established to be high risk for groundwater contamination. Finally, the predicted optimal distance between wells and pit latrines in the study area ranged between 31m-33m.*

Conclusion*: The study concluded that Kamkuywa Market Center is water scarce as a result of extensive groundwater contamination. Lastly, safe distances can vary from area to area depending on the climatic and hydro-geological conditions of an area.*

Key Words: *Contamination; Fecal coliforms; Groundwater; Kamkuywa; Regression; Safe distance*

Date of Submission: 28-06-2021 Date of Acceptance: 12-07-2021

I. Introduction

Water is scarce when there is insufficient freshwater to meet the standard water demand of a population. Studies [1] indicate that four billion people face water shortages and that “Half a billion people in the world face severe water scarcity all year round.” However, besides scarcity, the global water is exacerbated by water pollution. Vital as it is for human existence; water is also an important carrier of organisms and contaminants that are a threat to life. For water to be used for domestic purposes particularly drinking, its pollution must be within specified thresholds. According to the [2] 13% of the world's population do not have access to safe drinking water. Additionally, 40% of the world’s total population does not have access to improved sanitation [3]. This translates to 2.6 billion people in the world who are unable to access a sewage system, septic tank, or even a simple pit latrine. Approximately 1.7 million people every year die of water-borne diseases resulting from unsafe drinking water, inadequate sanitation, and poor hygiene [3]. Developing countries account for 84% of these deaths with 90% of them being children under the age of 5 years. [3] Estimated that up to 6% of these deaths and 9% of all diarrheal diseases could be prevented by improving the water safety, sanitation and hygiene globally. Globally, 38% of improved water sources are contaminated by fecal bacteria according to [4]. Also it has been established that contaminated and untreated groundwater is a major source of health problems in the developing world and a burden to these countries [5]. According to the [6], the goal of the United Nations through the Millennium Development Goals was to halve the population living without access to sustainable sanitation by 2015. The target was to have I billion people in the urban world and 900 million people in the rural world have access to sustainable improved sanitation facilities. Unfortunately, these targets were not achieved [7].To save the situation, the United Nations identified Sustainable Development Goal No 6 whose focus is on clean water and sanitation. The goal acknowledges that while substantial progress has been made in the world over the decades to increase access to safe drinking water and better sanitation, 637 million people globally still lack access to these basic social amenities. Therefore, this goal has a target to improve the quality of water globally through reduced water pollution from agricultural waste, domestic waste, dumping sites and industrial waste by 2030. Most people residing in rural areas in developing countries derive their water supply from groundwater and their sanitation through pit latrines. This unfortunately, is also largely evident in urban areas where land has been greatly fragmented. Consequently, a potential groundwater contamination risk crops up, especially when pit latrines and shallow wells are sited in close proximity. This pattern is prevalent in Kenya. The most common method of human waste disposal in Kenya’s rural and peri-urban settlements is the pit latrine, probably because it is relatively cheap, affordable, reliable and efficient way to dispose human waste for the poor urban and rural populations.

Expansion in improved water supply and access to improved sanitation such as sewer and water systems, water kiosks, community septic tanks and community boreholes in Kenya has been unable to match the rapidly growing population with improvements in water supply growing by only 0.9% and improved sanitation by 0.2 annually, according to the [7].In the recent times, concerns have been raised by environmentalists and public health experts on the increased use and dependency on both pit latrines and groundwater sources in low income areas in Kenya. Literature has shown that pit latrines can cause human and ecological health impacts largely associated with microbiological and chemical contamination of groundwater in their area of existence [3].The World Health Organizations minimum standards in water supply, sanitation, and hygiene promotion dictate that, Pit latrines and soak ways (for most soils) should be at a safe distance of at least 30m from any groundwater source and the bottom of any pit latrine at least 1.5m above the water table. Countries have different policies on the safe distance between latrines and groundwater sources specific to their hydro-geological factors. The Kenya Environmental Sanitation and Hygiene policy 2016-2030, guides that a latrine should be at a distance of at least 40m from a water source and its depth should be a minimum of 2m above the highest groundwater table. The 2m minimum requirement is anchored on the fact that Pit latrines generally lack a physical barrier, such as concrete between the sludge and soil/groundwater [8]. Studies [9]have established that contaminants from pit latrines over a period of time leach into underground water leading to contamination, and potentially threaten human health.

Kamkuywa Market Center is a rapidly growing peri-urban Center in Bungoma County (10). Over the years, the center has grown spatially and population wise. The Bungoma County Integrated Development Plan (2018) projected Kamkuywa Market Center to have a population of 30,178 people by the year 2020. According to the Kimilili Constituency Strategic Plan (2017), 90% of the households in Kamkuywa Market Center use pit latrines while 10% of the households are without pit latrines or any other method of extra disposal. In addition, Kamkuywa Market Center does not have access to piped water supplied by Nzoia Water and Services Company. The market Center is therefore entirely dependent on groundwater and rainwater for domestic and commercial use. Furthermore, Kamkuywa Market Center has not been planned to determine the minimum specified plot size (11). Essentially, the dimension of a plot affects the distance between the latrine and shallow well. Small plot sizes mean that the distances between the latrines and wells are shortened (12).This can lead to groundwater contamination which is likely to occur potentially, due to the reduced travel times of the pathogens from latrines to the shallow wells as well as downstream water springs when the safe distance is shorter than 40 meters recommended (12).

Typically, groundwater is characterized by long pollution residence time due to its slow flow. This makes groundwater pollution particularly problematic. The rate of flow and residence period is determined by several factors including soils (texture and structure), slope, and rainfall. To determine safe separation distances between a pit latrine and a well is thus not a constant factor but a function of these attributes. The specific safe distances in Kamkuywa are thus not known but rather dependent on the 40m standards by Kenya Environmental Sanitation and Hygiene policy 2016-2030. Given this reality in the study area, the purpose of this study was to establish the extent to which the groundwater in the study area is contaminated, to establish whether the level of contamination in the study area varies from one area to another and show the influence of hydro-geological factors such as soils, topography, and water table on spatial variation of contamination for purposes of determining appropriate well-pit latrine spacing. To achieve these objectives, the study was conducted in Kamkywa Market Area in Bungoma County, Kenya in 2020.

II. MATERIAL AND METHODS

Study location: Kamkuywa Market Center is one of the Largest open-air fresh-produce markets in Kimilili constituency, Bungoma County with a Projected Population of 30,178 people by 2020 [13]. It is located between latitude 0.77°N and longitude 34.79°E on a hilly topography with a gently sloping terrain. The geology of the area consists mostly of metamorphic rocks occupied by a somewhat gneissose pegmatite-rich leucogranite. The study area receives a bimodal type of rainfall, with warm and wet climatic conditions experienced all year round. The mean annual rainfall ranges from 1250mm to1800mm. The mean annual temperature ranges between 21° and 23° degrees Celsius.

Data and Data Sources

According to literature, the movement of contaminants through the soil medium into the groundwater is affected by several factors: First is the presence of the contaminant and its concentration. There is a higher likelihood to groundwater contamination when there is high concentration of contaminants such as fecal coliform bacteria in close proximity to a water source. Second is the depth of the water table whereby, pollutants are likely to spread faster where the water table is shallow as compared to a deeper water table. Further, contaminants will spread faster on gentle slopes than steep slopes if the pollutants origin is the surface because the former allow for more infiltration and percolation rate than steep slopes which produce more surface runoff. Finally, contamination will spread faster in sandy soils, which have higher soil permeability than in clay soils. To address the study objectives these factors were obtained from the sources described below. It should be noted that rainfall and temperature were assumed to be uniform since the study area is fairly small. Also, rain as a factor would be factored in the study if source of pollution was the surface and not point.

Data Collection and Processing

Soil permeability rates were determined in three steps as follows; First, directed benchmark sampling was used to select representative areas of the study areas by carrying out a visual survey of the study area and demarcating into 10 plots representative of its topographical, geological, and land use characteristics. This sampling method was selected because; the study area had distinct and well-defined features related to topography, drainage, and land use. The second step involved digging soil profile pits in the ten sample areas. Each pit was dug to a depth of 1.22m. For each pit the soil profile was examined according to the [14] guidelines for soil profile description. Geographic coordinates for all the pits were collected using mobile GPS. Third, a simple hydraulic field test was carried out to determine the soil texture. Finally, all the dug soil pits had their recorded characteristics analyzed and permeability rates determined according to Kenya Soil Survey standard procedures (1971). To associate each soil pit with an area, the Thiessen polygons technique was used to generate a soil permeability map using geographic coordinates and permeability rates. The output was a raster layer of permeability rates. The final stage for this process was the extraction of permeability values for each pit latrine using the 'extract multi values to points' tool in spatial analyst.

Slope data collection was obtained in four stages. Firstly, location data (Longitude, Latitude, and Altitude) for all pit latrines and shallow wells in the study area was collected. Secondly, the altitude data was used to generate a Digital Elevation Model (DEM) using Topo to Raster Interpolation Technique Spatial Analyst Tools. Thirdly, the generated DEM was used to generate a slope map indicating the steepness of the land surface using surface tools in 3D Analys of the ArcGIS softeware. Finally, slope values were extracted using the ‘extract multi values to points’ tool in spatial analyst.

The water table data was obtained in five steps. The first step was the collection of GPS coordinates for all shallow wells. The second step was the measurement of the depth of each shallow well using a 50 meters steel tape. The third step was using the respective shallow wells depths and altitudes to generate the water table elevation (z) values using the formulae (Water table = Altitude - depth). The fourth step was the interpolation of water table values to a water table surface map. Lastly, Interpolated water table values were extracted.

The Procedure for data collection for waste level was similar to that of water table data. First, there was the collection of pit latrine GPS coordinates. The second part was to record the depth of pit latrine depth. Unlike shallow wells, pit latrine's depths were not measured, as it was impractical and unhygienic to measure the depths of 1061 pit latrines used in the study. Therefore, the depths recorded were their initial depths when they were dug, which were obtained from the owners. For the third step, respective depths of all the pit latrines and their altitudes were used to generate waste level elevation (z) values using a formula (Pit latrine altitude – Pit Latrine Depth= Waste level).The fourth step involved the interpolation of waste level values. The resultant output was a waste level surface map. The last step was the extraction of the interpolated waste level values from the waste level surface map.

Fecal coliform concentration in water from shallow wells was used to establish how groundwater quality varied in different spatial locations in the study area. Purposive sampling was used to select representative shallow wells from the 531 shallow wells in the study area based on the following parameters; Density, depth, slope, soil permeability, and shallow well –pit latrine distance and whether the shallow well was protected or unprotected. Based on these parameters, a representative sample of thirty-two (32) protected shallow wells was selected. Water samples were collected from each of these selected shallow wells as follows: All samples were collected between 6:00 am to 7:00 am using specially prepared, sterile white pack bags. The bags contained a 0.1ml of a 3% solution of sodium thiosulphate a dechlorinating agent that neutralizes any residual halogen and prevents the continuation of bacterial action during sample transit [15]. As a standard requirement [16] for the sample volume for drinking water, 100ml of each sample was collected and carefully labeled. Sample Bags were numbered appropriately i.e. SW1, SW2, and SW3. The exercise also involved the collection of geographic coordinates, nearest pit latrine, depth, and the distances (m) to the nearest pit latrine of respective shallow wells whose water samples had been collected. To validate the results of the fecal coliform count test, duplicate water samples from the selected shallow wells were required. Four shallow wells i.e. SW9, SW5, SW24, and SW30 were randomly selected from the initially 32 sampled shallow wells and their water samples were collected the next day. The waster sample collection procedure was similar to the one detailed above. The whole process of water sample collection was carefully done as the samples were directly put in the bags from the wells to avoid contamination. All the Samples were kept cool in a 20liters cooler box and delivered to the lab for analysis within 3 hours in line with the [17] guidelines.

Data Analysis

Determination of the extent of contamination was carried out in three steps. First was the determination of the extent to which the World Health Organization and Kenya sanitation and Hygiene policy on well to pit latrine spacing had been flouted in the study area. The distance of each shallow well to the nearest pit latrine was calculated using nearest neighbor-proximity analysis tools in ArcGIS. The second analysis for this objective involved determining the extent of coliform contamination in the water samples. Sampled water from thirty-two (32) shallow wells underwent membrane filter test within three hours of sample collection as required under the World Health Organization water testing guideline. Specifically, a sample volume of 50ml from each sample was filtered through a membrane filter of 0.45 microns using a vacuum pump. Placed in a culture dish on a pad with growth enrichment media, the filter was incubated for 24 hours at a temperature of 44.5 degrees Celsius. Collected bacteria cells on the filter grew into dome-shaped colonies with a gold-green sheen colour. From the dish, these dome-shaped colonies were counted and recorded. Indicator shallow wells SW5, SW13, SW24, and SW20 required a 25ml dilution to achieve a clear countable membrane. The fecal concentration of each 50ml water sample and 25ml water sample for SW5, SW13, SW24, and SW20 were recorded as coliform densities calculated as units of the numbers of colonies per 100ml of sample water. A confirmation test was undertaken in an incubation period of 24hrs for the duplicate water samples SW5 (D), SW9 (D), SW24 (D), and SW30 (D). The result of these duplicates was used to validate laboratory analysis precision. Finally, coliform densities point values were transformed into a raster map to show continuous distribution of groundwater fecal coliform contamination in the study area. The interpolated contamination values from the raster map were extracted to the points representing shallow wells to have 531 contamination values each for the respective shallow well. Using the extracted values, a four-class contamination level surface map was created in 3D Analyst Using the Kriging interpolation technique.

To determine the relationship between contamination and hydro-geological factors, regression analysis using Regression analysis using spatial statistics tools (modeling spatial regression) was carried out to model, predict, examine, and explore spatial relationships to find out how these environmental factors affect groundwater contamination. To enable this, dependent and independent variables were determined with contamination as the dependent variable being modeled and slope, soil permeability, distances, and depths as independent variables (explanatory variables). Regression analysis was preceded by running the Ordinary Least squares regression tool to find out whether the model is accurate. The result of the OLS model was an equation constructed for every location in the data set for the independent and dependent variables existing within the bandwidth of each location. There was need to ensure that the OLS residuals were spatially random and therefore, spatial autocorrelation (Global Moran I) was performed on these residuals. Once the independent variables to be used in the GWR model had been validated by the OLS model, the next step was the running of the Geographically Weighted Regression Model. GWR was preceded by resetting the environment in the arc tool box. This involved aligning the processing extent, projection and the workspace.

To show high contamination risk zones, data analysis was done by applying the results of the GWR model by reclassifying independent variables maps using the 'Raster Reclass' tool of 3D analyst based on their established relationship (positive relationship, no relationship, and negative relationship). Each layer was reclassified into 4 classes with equal intervals. Weighted Overlay tool in spatial analyst was then used by applying a common measurement scale of values using the formula (slope +soil permeability+ water table depth + waste level depth + shallow well distances to the nearest pit latrine = Groundwater Contamination Vulnerability) to diverse and dissimilar the reclassified layers to create an integrated analysis showing areas of possible high to low groundwater contamination risk.

To establish the minimum safe distance of shallow well to the nearest pit latrine, geographically weighted prediction analysis was carried out in spatial statistics tools. The model calibrated the regression equation using known dependent variable values to create a new output prediction feature class run by modeling coliform densities against their respective pit latrine-shallow well distances. The output feature was interpreted and used to show precisely how an increase or decrease in coliform density varies outward from any one location with respect to distance, direction, and the study area's slope, soil permeability, and water table depth to give the optimal safe distance for the study area.

III. RESULTS

i. Extent of Groundwater Contamination in Kamkuywa Market Center

Out of the sampled 32 shallow wells, 31 shallow wells tested positive for fecal coliforms with a coliform density range of 4-68 colonies/100ml of water. Shallow well SW18 (Protected) tested negative for fecal coliform. Protected shallow wells had on average a higher coliform density than un-protected wells. Table 1and Table 2 presents these findings.

Table 1: Fecal coliform count report

Indicator shallow well	Status of the well	No. of colonies/50ml	Coliform Density ([(No. of colonies)/(volume filtered)] × 100)
SW1	Protected	26	52
SW2	Protected	25	50
SW3	Protected	27	54
SW4	Protected	33	66
SW5	Protected	34	68
SW6	Protected	19	38
SW7	Protected	29	58
SW8	Protected	20	40
SW9	Protected	2	4
SW10	Protected	24	48
SW11	Protected	17	34
SW12	Protected	8	16
SW13	Protected	34	68
SW14	Protected	13	26
SW15	Protected	30	60
SW16	Protected	31	62
SW17	Protected	24	48
SW18	Protected	0	0
SW19	Protected	13	26
SW20	Protected	32	64
SW21	Protected	27	54
SW22	Protected	3	6
SW23	Protected	19	38
SW24	Not Protected	30	60
SW25	Protected	19	38
SW26	Protected	20	40
SW27	Protected	21	42
SW28	Protected	16	32
SW29	Not Protected	26	52
SW30	Protected	11	22
SW31	Protected	9	18
SW32	Not Protected	19	38

Duplicate samples for both Shallow wells (protected and unprotected) replicated the same result after analysis to confirm contamination.

Table1: Field Duplicate Samples for Shallow wells

Indicator shallow well	No. of colonies/50ml	Coliform Density ([(No. of colonies)/(volume filtered)] × 100)
SW5(D)	34	68
SW9(D)	2	4
SW24(D)	29	58
SW30(D)	12	24

The analysis of contamination using coliform densities resulted in a continuous contamination surface map indicating the potential extent of groundwater contamination. Four zones of contamination interpreted as low, moderate, high, and very high within the study area were defined based on the coliform densities values ranging from 0-67 as shown in Figure 2.This indicated a large portion of groundwater is contaminated.

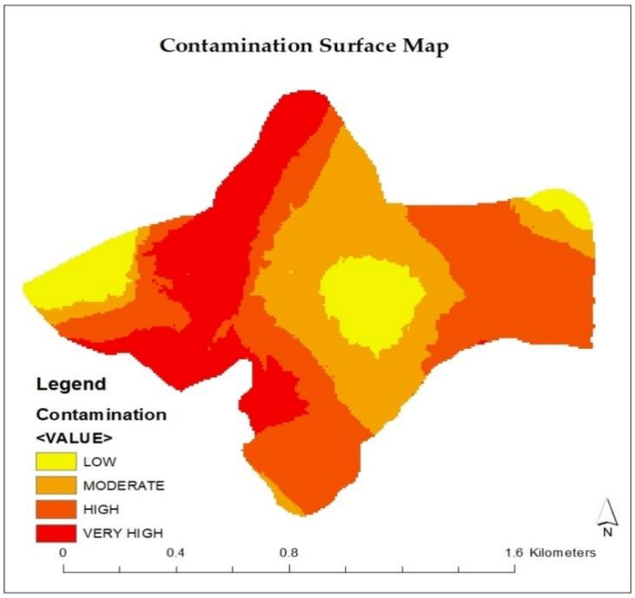

Fig.2: Contamination Surface Map

ii. Relationship between Contamination and hydro-geological factors

The main result of the regression analysis was a summary report containing the coefficient estimates, their standard errors, and a range of diagnostic statistics as shown in table 3. Examining the coefficient distribution in the summary table of the analysis showed the variation present and the relationship between groundwater contamination and the hyro-geological factors.

Table2: Summary of GWR w Results - Model Variables

Variable	Coefficient [a]	StdError	t-Statistics	Probability[b]	Robust_t	Robust_Pr	VIF [c]
Intercept	5.345983	0.256791	2.372239	0.000000*	0.536921	0.136205	1.458000
Slope	0.000025	0.008746	3.465872	0.000000*	-0.143256	0.523369	-2.000022
Soil Permeability	0.312915	0.002017	7.162642	0.050085*	0.003256	0.1901849	2.000022
Water table	-0.000093	0.000325	4.305321	0.000000*	-2.100001	0.123658	-2.000022
Waste Level	0.75326	0.085053	1.568321	0.000000*	0.217369	0.424169	2.000022
Distance	-0.812364	0.135689	5.782546	0.000000*	0.432845	0.142382	2.000022

iii. Groundwater Contamination Risk Zones in Kamkuywa Market Center

The resultant output from the weighted overlay analysis was a pollution map in Figure 4.4. The map showed groundwater contamination risk in Kamkuywa Market Center based on the key factors i.e. slope, soil permeability, and water table and waste level, and pit latrine- shallow well distance. The results showed 7.1 % and 14.3% of the study area was at low and moderate risk of groundwater contamination respectively while 73.6% of Kamkuywa market center was at a high risk of groundwater contamination. 5% of the study area was showed to be at a very high risk of contamination.

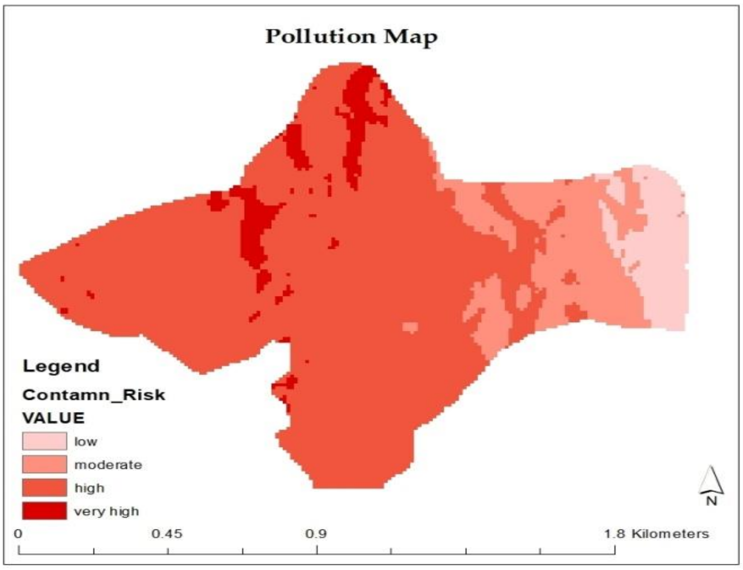

Fig.1: Pollution Map

iv. Optimal Siting of Shallow wells from Pit Latrines

Running of the prediction model established at what point was there no contamination considering the variability of the existing hydro-geological factors in the study area. From the prediction model, the optimal siting (safe) distance of wells in Kamkuywa at which there was zero contamination prediction was between 31meters-33meters accounting for variability in soil permeability, topography, and water table as shown in Figure 4.However, this distance (31-33m) was predicted on the assumption that the waste level depth was 2m above the water table.

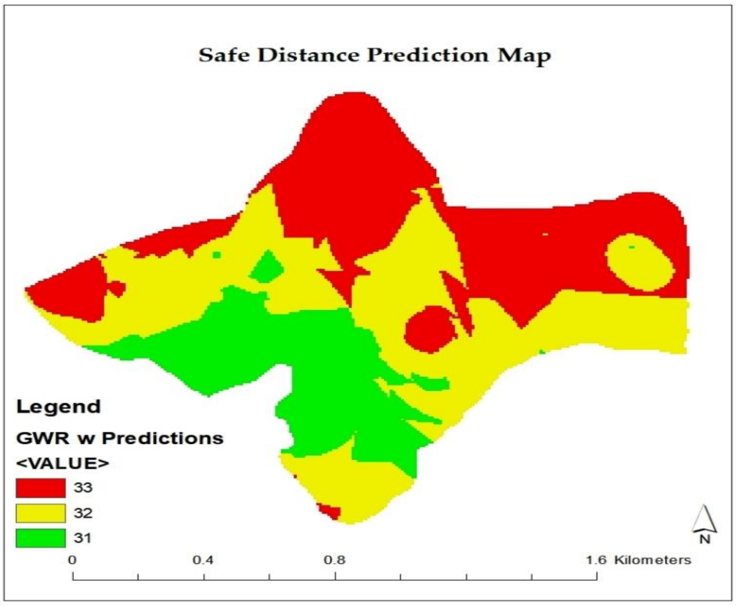

Fig.4: GWR w Prediction Output.

IV. Discussion

Extent of Groundwater Contamination in Kamkuywa Market Center

The results indicate possibility of high contamination (31 of 32 wells sample are contaminated) and only 11% of wells are beyond 40m distance from a pit latrine. It is thus possible almost 90% of the wells are contaminated. The presence of fecal contamination is an indication of potential health risks for individuals using water from these wells. Fecal coliforms by themselves are usually non-pathogenic. They are indicator organisms, meaning they indicate the presence of other pathogenic bacteria. While these bacteria do not directly cause disease, high quantities of fecal coliform bacteria suggest the presence of disease-causing agents. If large numbers of coliform are found in water, there is a high probability that other pathogenic bacteria or organisms such as giardia and cryptosporidium may be present.

Beside, two thirds (67.6%) of shallow wells in Kamkuywa were located at a distance of less than 30m and therefore were likely to be unsafe and contaminated while 44.8% of shallow wells located less than 15m from pit latrines. These findings were supported by the laboratory results for the fecal coliform count test. Shallow well SW18, the only shallow well that tested negative for fecal coliforms with zero (0) coliform density, was at a distance of 32m from the nearest pit latrine. In several other such studies on the safe distance between pit latrines and groundwater sources, varying transport distances for pathogens were established. Cadwell and Parr (1937) found the safe distance among total coliforms, anaerobe and B.Coli to be between 3meters to 25 meters depending on the degree of soil saturation and the velocity of groundwater flow. A study on well-water contamination by pit latrine showed a high level of contamination in well water in Langas, Eldoret-Kenya (Kiprotich and Ndambuki, 2012). The study found nearby pit latrines to be the main source of groundwater contamination. Further, noting that the state of the shallow well (protected or unprotected) was a major contributor to groundwater contamination in its recommendations, the study recommended for protection on wells achieved by lining the well and covering the top using concrete so as prevent contamination through surface runoff and spillage.

Relationship between Contamination and hydro-geological factors

The long established environmental monitoring has involved the measure of the main parameters mainly paying attention to physical-chemical parameters i.e. soil permeability, slope, distance, water table, and pit latrine depth. Geographically weighted regression analysis results confirmed the relationship between these factors and groundwater contamination. The Coefficient represented the strength and type of relationship between each explanatory variable and the dependent variable.

Soil Permeability: The regression model showed a positive correlation between contamination and soil permeability rates in the study area with a coefficient value of 0.312915 indicating the higher the permeability rate, the higher the contamination level. Soil permeability influences the potential contamination of groundwater. Previous studies of this relationship have established that, a greater seepage is likely in areas with more permeable soils. *[18]*, points out that the more permeable the soil, the faster is the movement of fecal coliform bacteria through the soil medium. His findings conform to the events in Kamkuywa Market Center. This explains why areas with a high level of contamination coincide with the soil permeability rate of 2.5 which is the highest in the study area.

Water Table: Regression analysis in Table 3 showed that there is a negative relationship between the depth of the water table in the study area and the contamination levels. This means that an increase in the water table depth results in a decrease in groundwater contamination level. In many groundwater pollution and quality assessment studies, water table depth is one of the most important parameters that has been found to help in understanding the groundwater availability status as well as determining the distance between the land surface and the water table, through which bacteria travel to the groundwater (19). Fluctuations in water table depth can either increase or decrease the risk of groundwater contamination.

Waste level Depth: From the regression analysis, it is evident that pit latrine depth affected the quality of groundwater as there was a positive coefficient of 0.075326 for waste level and therefore a positive correlation. Areas with waste levels closer to the water table are highly vulnerable to groundwater contamination. Although pit latrines recommended depth varies from one study to the other, most studies have recommended that it should not be dug deeper than to a vertical distance of at least 2m above the groundwater with regards to the water table's seasonal highest level [20]. Based on the recommendations by [21], and [22], the 2m safe distance requirement above water table was violated and the waste levels were too close to the water table. This explains why high groundwater contamination was confirmed particularly in areas with a deep water table because though the water table was deep, most pit latrines in these areas were less than 2m above the water table.

Slope: The slope affects the amount of infiltration and the rate at which pathogens move downward through the soil to the water table. Low slopes are more conducive to high infiltration rates than steep slopes and therefore vulnerable to groundwater contamination. The interpretation of the slope shows a majority of the study area has a slope of 0-50 degrees which is vulnerable to groundwater contamination. However, the results of the regression analysis that shows no relationship between slope and contamination. This can be interpreted to mean; variation in ground slope does not influence groundwater contamination when the source of pollutant is a pit latrine.

Groundwater Contamination Risk Zones in Kamkuywa Market Center

There is a long-recognized relationship between land use and groundwater pollution, although this phenomenon may take a longtime to be noticed. Land use and economic activities in rapidly growing peri-urban centers such as Kamkuywa with no piped water and sewage system need to be subjected to government regulatory control and requirement of approvals before proceeding with the construction of pit latrines and shallow wells. Once groundwater has been polluted it becomes very expensive and extremely difficult to clean it up and undo the damage.

Optimal Siting of Shallow wells from Pit Latrines

Geographically weighted regression prediction model (GWR w) predicted spatial variability of contamination against distance, indicating a safe distance of 31m -33m for the study area. This implies that at a distance of 31m-33m based on the variability of the specific environmental conditions of the study area; - there will be zero risk of contamination of a well from a pit latrine. This prediction was further supported by the results in table 1 where the only shallow well that tested negative for fecal coliforms was at a safe distance of 32m, a distance that was within the model's prediction safe distance. This information is useful for the physical planning of Kamkuywa Market Center in determining the minimum specified plot size to ensure adherence to the required safe distance in protecting groundwater from contamination and also the health risks associated with it while also accommodating population growth, land-use change, and urbanization. It also contributes to the implementation of the Kenya Environmental Sanitation and Hygeine Policy 2016-2030

V. Conclusion

Based on the results and discussion of the study, the following conclusions were drawn highlighting the key discussion points. First, groundwater in Kamkuywa Market center is polluted. The presence of fecal coliforms in shallow wells’ water indicates contamination confirming that there is a greater risk that other pathogens are present. Secondly, pit latrines often promoted as safe and improved methods of sanitation are a major risk source of groundwater safety In Kamkuywa Market Center. Therefore, the dependency on pit latrines as the main method of sanitation in Kamkuywa Market Center could result in long-term health problems unless necessary precautionary measures are taken to prevent seepage into groundwater which is the major source of domestic water. Thirdly, reduced safe distances between pit latrines and shallow wells, and pit latrine depths and water table increase the risk of groundwater contamination. Groundwater in the study area is polluted largely due to the violation of safe distance standard guidelines. Lastly, based on an area’s environmental characteristics, pit latrine –shallow well safe distances can change or vary. Thus, 31m -33m is the minimal safe distance applicable for the Center.

Acknowledgement

This research was (partially) funded by an African Doctoral Dissertation Research Fellowship (ADDRF) award offered by the African Population and Health Research Center (APHRC) and funded by the Bill and Melinda Gates Foundation through a Project Grant to APHRC. Grant Number: ADDRF FELLOWSHIP AWARD 2020-2022 ADF 002

References

[1]. Hoekstra A. Y., and Mekonnen M. M. (2012). The water footprint of humanity. Proceedings of the National Academy of Sciences 109 (9): 3232–3237. doi:10.1073/pnas.1109936109

[2]. World Health Organization and United Nations Children’s Fund (2008). Progress on Drinking Water and Sanitation: 2008 Update. New York: United Nations Children’s Fund; Geneva, Switzerland: World Health Organization

[3]. World Health Organization (2010). Progress on Sanitation and Drinking Water.

[4]. Bain S., Gundry S.W, Wright J. A., Yang H., Pedley S., Bartram J.K. (2014). Global assessment of exposure to fecal contamination through drinking water based on a systematic Review: Water Institute, University of North Carolina

[5]. Murphy G. A., Gathara D., Aluvaala J., *et al.*(2017).Effective coverage of essential inpatient care for small and sick newborns in a high mortality study in Kenya

[6]. World Health Organization (2012b).Guidelines for Drinking-water Quality. 4th ed. Geneva: WHO.

[7]. Joint Monitoring Program (2013): Progress on Household Drinking Water, Sanitation and Hygiene 2000–2013: World Health Report 2013. Geneva: WHO, 2013.World Health Organization (WHO) (2008). Cause-specific mortality: regional estimates for 2008.

[8]. Fourie A.B. and Van R., (1997). Low-cost urban Sanitation: Loughborough University.

[9]. Graham J. P. and Polizzotto M.L (2003). Pit Latrines and Their Impacts on Groundwater Quality: A Systematic Review. Environ Health Perspect 121, 2013, 521-530: (Accessed 16th June 2019)

[10]. Kimilili Constituency (2017). Kimilili Constituency Startegic Plan 2017-2022

[11]. County Government of Bungoma (2018). County Integrated Development Plan 2018-2021

[12]. Gudda F. O., Montur W. N., Omondi S. O., Muchiri E. W. (2019). Pit latrine fill uprates: Variation Determinants and public health implication in informal settlements, Nakuru, Kenya. BMC Public Health 19,68.

[13]. Food and Agriculture Organization (2007). Transport of pathogens through soils and aquifers: New York, WileyLiss:.p103-24

[14]. American Public Health Association (1992). Standard Methods for the Examination of Water and Wastewater. 18th Edition, American

[15]. American Public Health Association (APHA), American Water Works Association (AWWA) and Water Pollution Control Federation (WPCF), Washington DC.

[16]. World Health Organization and International Programme on Chemical Safety (1996). Guidelines for drinking-water quality: Vol. 2- Health criteria and other supporting information, 2nd ed.

[17]. Goovaerts P., Soares A., Pereira M. J. & Dimitrakopolous R. (2008) Geostatitical Analysis of Health Data: State-of-the-Art and Perspectives. Proceedings of the Sixth European Conferences on Geostatistics for Environmental Applications (pp. 3-22). Heidelberg: Springer.

[18]. Brown A. E. (2012). Factors Affecting Groundwater Contamination

[19]. Federico O., Zanini A., Petrella E., Angelo L. (2015). Groundwater characterization from an ecological and human perspective: An interdisciplinary approach in the Functional Urban Area of Parma, Italy.

[20]. Reed B. (2010). Adapting existing experience with aquifer vulnerability and groundwater protection. J Afr Earth Sci. 2007;47(1):30–38

[21]. Banks D., Karnachuk O.V., Parnachev V.P., Holden W., Frengstad B. (2002). Groundwater contamination From rural pit latrines: examples from Siberia and Kosova. J Chartered Inst Water Environ Manage; 16(2):147–152

[22]. Ministry of Health (2016). The Kenya Environmental Sanitation and Hygiene Policy 2016-2030

Dinah Ayoma Wechuli, et. al. “Pollution Risk Assessment of Groundwater at Kamkuywa Market Center, Bungoma Using Geospatial Technology.” *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 14(7), (2021): pp 22-30.