eISSN 2345-0363
Journal of Water Security, 2017, Vol. 3
Article Number: jws2017007
DOI: https://doi.org/10.15544/jws.2017.007

DETERMINANTS OF GROUNDWATER RETENTION IN WELLS: A CASE OF KEIYO NORTH DISTRICT, ELGEYO MARAKWET COUNTY, KENYA

Andrew Rutto Kiptum, Catherine Chebet Sang

School of Environmental Studies (Environmental Economics), University of Eldoret, P.O BOX 1125-30100, Eldoret, Kenya. Email: kiptumandrew@gmail.com

Submitted 22 June 2017; accepted 02 October 2017

Abstract. Continuous degradation of biophysical factors and over utilisation of available water through unsustainable consumptive means, tend to threaten the existence of groundwater supply. The aim of this study was to examine the influence of human activities and biophysical factors on groundwater retention in wells in Keiyo North District, Elgeyo Marakwet County, Kenya. Structured questionnaires were used to obtain primary data. Systematic simple random sampling technique was applied in the study. Excel and Statistical Package for Social Sciences (SPSS) were used for data analysis. The results of the study showed that biophysical factors had significant influence on groundwater level and/or retention capacity during dry season and no association during rainy season. Altitude and land use were insignificant in influencing groundwater retention during both dry and wet seasons. The logit model showed that nearness to the forest, swamp, river had high probability to influence groundwater retention in the wells. However, the random factor in the regression model showed significant difference in influencing groundwater retention, which explains more on the impact of other parameters that were beyond the scope of this study such as soil characteristics and climate on water retention capability. The findings of this study will inform policy and decision makers as they develop sustainable conservation strategies that will ensure continuous groundwater supply.

Keywords: *biophysical factors, groundwater level, human activities, land use.*

Introduction

Globally, groundwater is highly dependent as water source and a resource that enormously contribute to social well-being of the human population (Kemper, 2004; Wada *et al*., 2010). However, the increasing growth in population and degradation of biophysical environment has resulted into modified weather pattern and subsequent surface water scarcity in terms of both quality and quantity (Hao *et al*., 2008; Chen *et al.*, 2010; Hsu *et al*., 2012). Global use of groundwater is estimated to be 750 – 800 km^3 which is a twofold increase if compared with the past two decade (Wada *et al.*, 2010). This indication of high dependency of groundwater has prompted water utility firms and households to seek prudent ways in managing water resource which has become demanding resources and to avoid water crisis.

There are two main global water supplies used for human utility which are surface water and groundwater. The water surface sources include springs, seepages into streams, rivers and large water bodies like lakes, seas and oceans. According to FAO (2013) groundwater remains the main source of water for household consumption in rural homes especially in the developing countries because of its purest form, reliability and its accessibility to agricultural activities. However, indiscriminate destruction of water catchment areas, global warming and exploitation of groundwater has led to a decline in groundwater level over time (Fei, *et al*., 2009). A study by Cao (2013) revealed that groundwater depth has been increasing at an average rate of 0.36 metres per annum over a 50 year period from 1961 to 2010.

Groundwater as described by Brassington (2007) is that part of precipitation that percolates through the earth to the water table which forms hydrological cycle. The volume of water that percolates into the soil after precipitation or flooding could define the accessibility of groundwater. Hydrological cycle starts when energy from the sun evaporates water from the oceans, vegetation and earth surface to form large cloud masses that are moved by the global wind system and, when conditions are right, precipitate as rain, snow or hail (Brassington, 2007). Thereafter, the occurrence and movement of ground water in an area is governed by several biophysical factors such as vegetation, topography, lithology, geological structures, weathered zone thickness, drainage pattern, landforms, climatic parameters and to some extend anthropogenic factors (Mogaji *et al*., 2011). According to Wada *et al*., (2010), the volume of surface water that percolates into the aquifers and household wells could have an association with the biophysical environment and human activities. Groundwater reservoirs such as aquifers can also be defined as the geologic material that stores, transports, and yields groundwater (Mogaji *et al*., 2011). Therefore the sought groundwater for household use flows through saturated soil and rock which is driven by a hydraulic gradient, in unconfined aquifers or water table.

Mogaji *et al*., (2011) defines water table as the depth at which water saturation exists below the ground.

The bottom of the zone of saturation is marked by an impermeable layer of rocks, clay or other material, which is part of the upper limit (top) saturation zone of the earth containing the groundwater (Brassington, 2007; Mogaji *et al*., 2011). Point of saturation is the zone where households dig their unlined open wells to access groundwater for domestic use. In this zone of the earth, water cannot soak through this layer, so it instead slowly flows downhill through hydraulic flow with the aid of gravity (Mogaji *et al*., 2011). Contrary to popular belief, groundwater is not a ground river or lake. Rather, it is all the water below the water table stored in subsurface void spaces. Therefore, aquifers are rocks that contain groundwater and allow water to flow through them in significant quantities (Brassington, 2007).

Many studies have pointed out several biophysical factors that influence recharge and discharge of groundwater which includes topography, soil type, precipitation, water levels and underlying bedrock. According to Mogaji *et al*. (2011), biological and physical environments influence ground water flow and hence ground water recharge and discharge. Mogaji *et al.* (2011) further points out that soil acts as a natural filter to screen out many substances that mix with the water affecting retention rate, thus, amount of groundwater recharge, storage, discharge, as well as the extent of ground water contamination, all depend on the biophysical factors and soil properties. Therefore, groundwater fluctuates considerably, in both water level and water quality. This sought information gives a glimpse to water users and researchers on the way groundwater behaves, however, socio economic and biophysical information that influence groundwater and occur on the surface of the earth are lacking. This study tends to bridge that knowledge gap.

Temporal and spatial variations of groundwater level fluctuations could also be influenced by hydro meteorological and geological factors respectively; that is, during rainy season earth material get saturated with water from precipitation resulting to water retention and the converse happens during dry season (Hao *et al*., 2008; Hsu *et al*., 2012). Therefore, significant climatic change in both prolonged rainy or dry season can have a considerable effect on groundwater availability and movement (Brassington, 2007). Study of Fei *et al*. (2009) found that, several years of low precipitation tend to cause a progressive decline in groundwater levels, and when there are several years of high precipitation then it causes a corresponding rise in ground water level. Similarly, Hao *et al*., (2008) pointed out that groundwater level changes are naturally influenced by climatic variation. However, biophysical factors that influence hydrological cycle are under threat from human exploitation and overconsumption from increasing population, mismanagement and pollution (Fei *et al*., 2009). The degrading factors to biophysical environment emanate from anthropogenic factors which are happening unnoticed and continuously (Konikow, Kendy, 2005). Most of the changes that occur in biophysical environment are either small or temporary, although some intensive anthropogenic activities tend to significantly affect groundwater dynamics in the short term through alteration of biophysical factors. Therefore, it is particularly important to study biophysical and socio economic factors in order to understand the magnitude of influence to groundwater dynamics and retention capability by household wells. This knowledge would enable water resource managers to seek ways to mitigate causative agents that deplete groundwater. Hence the purpose of this study was to determine the biophysical factors that influence ground water level.

Materials and Methods

The study area

This survey was carried out in the month of June to September in the year 2013 in the highlands of Keiyo North Sub-County in Elgeyo Marakwet County, Kenya. The study area lies between latitudes 0°30'N and 0°53'N and longitudes 35°20'E and 35°35'E (Fig. 1). The highland part in Figure 1 was selected as a study area due to its geology that allows digging of wells by household to access groundwater for consumption. Open unlined wells are the common type of wells found in the study area. The altitude is between 1400 m above sea level on the northern part and 2400 m above sea level on the southern part. The mean annual rainfall is 1800mm with a pattern showing bimodal type of rainfall with the long rains between March and June, and short rains from September to November (Kenya..., 2013).

The rainfall experienced during the study period was near normal with tendency towards above normal (Kenya..., 2013). The temperature varies between 14°C and 24°C with lower altitude experiencing a higher temperature.

The types of soils in the study area are Oxisols on the hill slopes and Luvisols on the valley bottoms (Sombroek, 1990). The climate combined with type of soil tends to favour wide range of agriculture and livestock activities which account for about 90% of the economic activities. The most preferred animals reared in the study area are chicken, cattle and sheep which are often reared in paddocks, while the popular crops grown are maize, beans and vegetables such as kales and cabbages.

Sampling procedure and data collection

Sampling in this study employed multi-stage approach in selecting sample units while systematic sampling was used in carrying out interviews at household level. To determine the sample size, post-census enumeration maps and list of household at purposively selected location down to the sub-location was used. Systematic sampling was then applied to select the sample households for interview from each cluster in the sub-location where every fifth household was selected. A starting house from a reference point such as junction of the road was randomly selected.

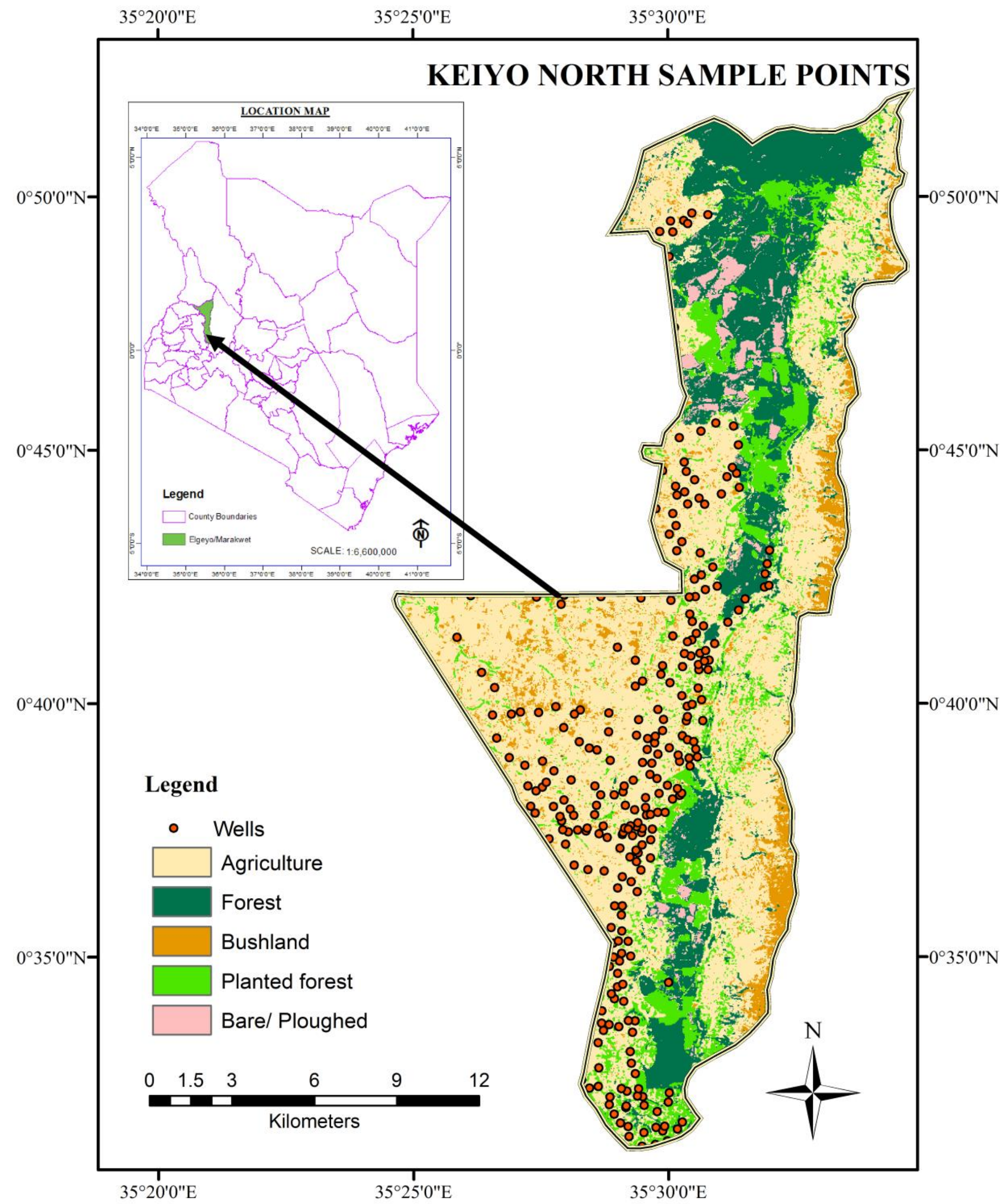

Fig. 1. The study area

Interviewers were then to follow the right hand rule method from the first household chosen at reference point for the subsequent selected households to be contacted. The sample size required for sampling was achieved by using the following formula (Kothari, 2004):

$$n = \frac{NC^2}{C^2 + (N-1)e^2}, \qquad (1)$$

where; n – size of sample;

N – size of population,

C – coefficient of variation at (95%) confidence limit, while e is the standard error at 5% level.

The target population included all the households with wells in the highland part of Keiyo North District, Elgeyo Marakwet County. The sample size was then 318 households. To cater for spoilt and incomplete questionnaires, additional of 10 households were interviewed to make 328 households. A sub-location was considered as the smallest sampling unit in administrative boundaries and household was viewed as the basic unit in a community. All the sampled wells were mapped with Global Positioning Systems (GPS). Through interviews with respective owners of the wells, information on the depths of the wells such as coordinates and altitude were sought and recorded against the GPS readings of each well. In a case where the respondent was not sure of the depth of the well the interviewer would then measure using a tape measure and a rope. The distance to the forest and river and/or the stream from the well was estimated by the enumerator.

The information that was collected to determine the factors that affect water level fluctuations in wells include biophysical factors such as (distances to the nearest forest, river and/or stream and altitude), characteristic of the household well such as year of drilling, well depth and socioeconomic factors such as farming type, and household population. All these were conceptualized to ease analysis of data and interpretation. Therefore, the influence of biophysical environment on groundwater retention in the wells which are the landscape features such as plants and geology in the study area was expressed in an equation form as:

$$Y = a + b_i X_i \quad (2)$$

where: Y – represent the volume of water in different depth level of the well;

X_i – represents specific biophysical factors such as distance from well to edge of forest, distance from well to the stream and/or river, altitude etc;

a – represent constant parameter estimate of the model;

b_i – represent coefficient of the selected parameter estimates which explain the magnitude and direction of influence of the selected variable.

To establish volumetric value of water in the well which was used as dependent variable in this study, a comparison was made by taking measurement in-situ on the highest water level during rainy season and subsequent lowest water level on dry period. Since survey was done during rainy season, it was easier to determine the highest level, while the lowest water level which is experienced during dry season was determined by asking respondents to show the lowest water point in the well. The highest water level point experienced during rainy season in most wells sampled was visible which made it easier to take depth measurements.

Since all wells were circular in shape, the diameter of the well was taken to be used in calculating amount of water in the well using the volumetric formula:

$$V = \pi r^2 h, \quad (3)$$

where: h – was the lowest and highest water level point in the well during dry and rainy period respectively;

r – as the radius of the well which is obtained by dividing the diameter by two.

The determined volumetric value of water in the well using volumetric Formula 3 was then used as dependent variable to regress biophysical factors. Hitherto, the ‘a’ and ‘b’ values in Equation 2 are parameter estimates which were obtained from ordinary least squares (OLS).

Therefore, the linear regression model used could be specified as:

Amount of water in the well = f (distance from well to edge of forest, distance from well to the stream and/or river, amount of water available at low, high level in the well and land use near the well).

While in equation form, it can be expressed as:

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 \cdots + b_n X_n + e_i \ , \quad (4)$$

where: Y – volume of the water in the well at any level;

X_i – biophysical factors;

a – constant;

b_i – coefficient of selected parameters in the OLS regression model;

e_i – random factor.

Since groundwater resources are seen to be important for human survival, determining influencing factors is crucial to water stakeholders so that causative agents could be identified and thereafter mitigation measures are sought. Therefore, in this study the use of parameter estimates of the OLS regression model was used to determine the level and magnitude of influence by socio economic and biophysical factors on groundwater retention capability using household open wells.

However, binary functions cannot be estimated through the ordinary least squares method, because the predicted values from the resultant linear probability model cannot be constrained to the required interval without imposing restrictions on the values of independent variables. Hence, to give meaningful statistics binary functions can be estimated through maximum likelihood methods. In this study logit model was selected for analysis of probability on the basis of ease of computation.

In context to this study, the logit model postulates that the probability of volumetric value of water in household’s well depth (P) at any season is a function of selected parameters (X_i..., X_n). These characteristics in case of this study are biophysical environments such as forest, swamp, streams, rivers and altitude. The model uses a logistic curve to transform binary responses into probabilities within 0 to 1 interval. The significance of computed Logit model value (P (i)) which is closer to 1 shows the variable to have higher influence while near zero or zero value reveal low influence or no significant influence. The parameter estimates in logit model can be specified as:

$$P(i) = 1/(1 + \exp(\beta_i X_i)) \ , \quad (5)$$

Where: $P(i)$ – The probability of well depth;

β_i – The coefficient value;

X_i – The selected biophysical parameters.

In the regression model, selected biophysical characteristics in this study that were postulated to have significant influence on amount of water retention capacity in the household wells were:

- Characteristic of the well: water demand by household, size of the household, cost of drilling the well and level of the water depth during dry and wet seasons which could influence the depth of the well.
- Distance from edge of the forest. Nearness of the well to the forest increases the probability of having a higher water table. This variable was measured by estimating the distance from the well to the edge of the forest and the volume of water in the well during rainy and dry period.
- Distance from the edge of the river, stream and swamp. The further the distance between the well and the

river and/or stream and swamp lowers the probability of reaching ground water table.

- Altitude. High altitude has reduced evaporation which influences water retention in the soil, it is hypothesized that altitude has a positive impact on the depth of the well and thus, amount of water in the well.
- Land use. Land use with increased vegetation cover has a positive impact to water retention in the soil and thus influence ground water in the wells.

Results and Discussion

Households characteristic and groundwater demands

To determine groundwater demands, an inferential test for the means of independent samples that include household characteristics and in-situ measurement of well dimensions was done (Table 1).

Table 1. Statistical test of households and well characteristics that influence groundwater demand.

Characteristic	Mean	SD	*t*-test
Household size, persons	8	2.79	3.21*
Household water use, L/day	159.64	72.54	1.70*
Depth of the well, m	38.96	9.55	2.10 NS
Well drilling cost, $/m	5.3	1.47	1.40 NS
Diameter of the well, m	0.64	0.06	1.80 NS

NS – not significant; * – significant at $p < 0.1$; Dollar exchange (1dollar = 100 Kenya shillings); SD – means standard deviation.

The average household population was 8 persons and the average water use per household was 159.64 litres per day. The findings showed water use per day and household population to significant influence water retention in wells during the dry season at ($t = 1.70$, $p < 0.1$) and ($t = 3.21$, $p < 0.1$) respectively. This influence could manifest from high demand for water use by household through various means such as watering kitchen gardens, household population or domestic use and for reared domestic animals. The high standard deviation value of 72.54 in arises because of the diversity in water uses (Table 1).

Further, the results revealed that water use during the dry season is significantly influences the water retention capacity of the well. However, the association of groundwater volume together with the characteristics of the well such as depth of the well, diameter of the well and the cost of drilling the well was insignificant in this study. These results concurs with the findings of Li *et al*. (2014) which showed that water use makes water level to drop subsequently leading to scarcity. When there is low saturation of water in the water, water molecules flow faster which is often experienced during dry season or when ground cover is exposed which increases evaporation rate (Jencso *et al.,* 2010). The causes of the dramatic changes in ground water level according to Li *et al.* (2014) are occasioned by climatic variability during seasons and human activities.

Influence level by parameter estimators

The relationship between parameter estimators with volume of groundwater in the wells was statistically tested using means of independent variables to reflect dry and rainy seasons (Table 2). The findings in Table 2 showed that estimated distances from the household well to the edge of the forest ($t = 1.40$, $p < 0.1$), to the river and/or stream ($t = 1.21$, $p < 0.1$) and to the swamp ($t = 1.57$, $p < 0.1$) were statistically significant during dry period and insignificant during rainy season. However, altitude where the well was located and diversity of farm activities in micro scale, which range from grazing in open field and/or paddocks among households, were insignificant in influencing water retention in household wells during dry and rainy period (Table 2). These findings are similar with that of Li *et al.* (2014) who found that human activities which often happen unnoticed tend to indirectly influence groundwater dynamics were atmospheric condition which is part of hydrological elements are distorted when greenhouse gas is produced.

Table 2. Statistical tests of variables that influence water retention capacity in wells during the dry and rainy period.

			t-test	
Characteristic	Mean	SD	Dry	Rainy
Distance from well to forest, km	2.9	2.5	1.40*	1.70 NS
Distance from well to swamp, km	2.97	1.6	1.57*	3.21 NS
Distance from well to river, km	0.96	0.55	1.21*	1.15 NS
Altitude of the well, A.S.L	2.34	347.72	5.57 NS	2.40 NS
Distance from well to garden, km	0.31	0.01	1.10 NS	1.02 NS
Distance from well to homestead, km	0.03	0.02	1.08 NS	1.01 NS
Distance from well to grazing land, km	0.06	0.01	1.02 NS	1.12 NS

These findings is supported by Wada *et al*. (2010) who found similar trend where water bodies such as lakes, rivers, and swamps tend to play an important role in recharging groundwater through infiltrates and seepage mechanism. While study by Pacific *et al.* (2011) showed that landscape ecology especially vegetation rather than altitude greatly influence groundwater saturation through minimal evaporation which renders infiltrates from precipitation to move slowly through the soil voids. Wada *et al.* (2010) explained that slow water percolation and oversaturation enables wells to retain high volume of water during rainy season and vice versa which is similar with the finding in this study.

Also, the finding revealed clear distinction on the amount of water retained by wells during dry and wet seasons. During dry period, distance of forest and water bodies tend to influence water retention in wells while during rainy season there is no association of water retention in wells and distance of biophysical factors. Brassington (2007) explained that forest cover which reduce evaporation rate and infiltration and groundwater percolation in soil tend to be very slow during dry season tend to improves water retention capacity in soil; that's wetness propensity index is improved. Irrespective of distance from biophysical and land use factors, water flow into empty spaces such as wells (Jencso *et al.,* 2010) increases the water level in wells. However, wetness propensity index is very rudimentary in this study.

It can be deduced from the findings that saturation of water in soil makes water to be retained in wells. Possible ways of maintain water saturation in soil is by maintaining vegetative cover in order to reduce surface evaporation. Conservation strategy can be done by planting trees in woodlot form by households in order to significantly influence groundwater retention capability of wells as depicted by biophysical distance of forest to the location of the well in Table 2.

Probability of influence by parameter estimators

The results from logit model regression (Table 3) were used to predict the probability of biophysical factors to influence water retention capacity in unlined open wells during dry season.

Table 3. Logit model statistical results on probability of influence by parameter estimators on water retention capacity (*Y*) in wells during the dry season

Parameter, x	Equation form	SE	P(i)	*t*-test
Distance from well to forest	$Y = -2.61x + 154.32$	2.41	0.93	2.32*
Distance from well to swamp	$Y = -1.28x + 154.32$	1.55	0.78	2.02*
Distance from well to river	$Y =-1.78x + 154.32$	1.98	0.86	1.94*
Altitude	$Y= 0.43x + 154.32$	5.53	0.39	2.67
Distance from well to garden	$Y= 0.62x + 154.32$	1.97	0.35	1.67
Distance from well to homestead	$Y= 0.28x + 154.32$	2.12	0.43	0.98
Distance from well to grazing land	$Y= 0.22$x $+ 154.32$	1.41	0.55	1.54
Error term	$Y= 1.08x + 154.32$	0.97	0.74	1.21*

Equation in this table takes the form $Y = \beta x_i + c$; where β is parameter estimators and c (constant value of 154.32) is the Y intercept when x_i is zero: P(i) is the probability of wells to retain water (it can be converted into percentages): SE – standard error.

Parameter estimators from the logit model in Table 3 revealed that distance from the edge of forest, swamp areas, river and/or the stream had great probability to influence water retention in wells with 0.93, 0.78 and 0.86 values respectively. The same parameter estimators for forest, swamp areas, river and/or the stream in logit model revealed to be significant in influencing water retention in the well during the dry seasons; that is distance from the forest edge (t = 2.32, $p < 0.1$), swamp areas (t = 2.02, $p < 0.1$), river and/or the stream (t = 1.93, $p < 0.1$) tend to influence water retention capacity in wells during the dry season. Biophysical factors such as distance from the garden, homestead, grazing field and altitude had substantial probability to influence water retention in wells with 0.35, 0.43, 0.55 and 0.394 values respectively; however, it had no significant difference in influencing water retention capability in the wells.

The findings of studies by (Wada *et al.*, 2010; Cao *et al.,* 2013; Adedeji *et al.,* 2014) showed climatic variability as a major determining factor in influencing hydrological cycle and groundwater flow dynamics more than human activities. However, Adedeji *et al*. (2014), Li *et al.* (2014) and Pacific *et al.* (2011) pointed out that anthropogenic activities such as deforestation and burning of fossil fuel produce greenhouse gases which are which cause climate variability. Therefore, probability of influence especially from farm activities is of essence and should not be neglected despite the low level of its probability to influence.

The findings from OLS model parameter estimates such as the distance from the edge of the forest, swamp areas, river and/or the stream showed negative values (Table 3). This reveals how distance of biophysical parameters influence water retention in wells during dry periods. That is, the closer the well to the water body (swamp areas, river and/or the stream) and forest the higher the water retentive capacity of the well and vice versa.

However, there was a random factor value of P (i) = 0.74 from logit model which revealed a significant influence on water retention in wells. The stochastic variables in the logit model reveal that there were some omitted parameter estimators which were beyond the scope of this study. The random factors form the basis for a further study on other socio economic and biophysical factors such as soil characteristic, tree species, lithology and gradient of the land which remain unexplained in this study despite their significance in influencing groundwater dynamics.

Conclusions

The findings of this study show that nearness of a household well to forests, swamps and rivers tend to be critical in influencing groundwater dynamics during dry periods. However, altitude and socio economic factors such as open land used for grazing domestic animals, gardening and nearness of well to homestead were insignificant in influencing groundwater retention by wells in all seasons. Elevation of land was found to be insignificant in influencing groundwater retention capability of wells, while environmental elements tend to dictate groundwater dynamics during dry season. Since forest and water bodies are seen to be critical in influencing household wells to retain water during dry period, it is therefore recommended in view of its significance that forest, water streams and rivers that are near the household wells should be conserved and protected so as to enhance groundwater supply and retention capacity which is often in high demand by household to consume water from the wells. However, the selected variables in this study seem to be limited and cannot solely be relied upon as depicted by random factor in the regression model. It is therefore recommended that other socio economic and biophysical factors which were beyond the scope of this study be investigated more in order to determine their level of influence on the groundwater retention capability in wells.

Acknowledgements

The authors thank respondents who participated in the survey which made this study successful.

References

Adedeji, O.; Reuben, O.; Olatoye, O. 2014. Global climate change. *Journal of Geoscience and Environmnent Protection,* 2, 114–122. https://doi.org/10.4236/gep.2014.22016

Brassington, R. 2007. *Field Hydrology* (3rd ed.). John Wiley & Sons LTD, West Sussex. https://doi.org/10.1002/9780470057032

Cao, G.; Zheng, C.; Scanlon, B. R.; Liu, J.; Li, W. 2013. Use of flow modelling to assess sustainability of groundwater resources in the North China Plain. *Water Resource Research,* 49, 159–175. https://doi.org/10.1029/2012WR011899

Chen, H.; Wang, S.; Gao, Z.; Hu, Y., 2010. Artificial neural network approach for quantifying Climate Change and Human Activities Impacts on shallow groundwater level: A case study of Wuqiao in North China Plain. In: *18th International Conference on Geoinformatics Proceedings*, 18th -20th June 2010, IEEE: New York, NY, USA. https://doi.org/10.1109/GEOINFORMATICS.2010.5567678

FAO, 2013. *Advancing Agroforestry on the Policy Agenda: A Guide for Decision-Makers*. Buttoud, G.; Ajayi, O.; Detlefsen, G.; Place F.; Torquebiau. E. (Eds.) Agroforestry Working Paper, 1. Food and Agriculture Organization of the United Nations. FAO: Rome [online], [cited 15 May 2017]. Available at: www.fao.org/publications

Fei, Y.; Miao, J.; Zhang, Z.; Chen, Z.; Song, H.; Yang, M., 2009. Analysis on evolution of groundwater depression cones and its leading factors in North China Plain. *Resource Science,* 31, 394–399.

Hao, X.; Chen, Y.; Xu, C.; Li, W., 2008. Impacts of climate change and human activities on the surface runoff in the Tarim river basin over the last fifty years. *Water Resource Management,* 22 (9), 1159–1171. https://doi.org/10.1007/s11269-007-9218-4

Hsu, K.-C.; Yeh, H.-F.; Chen, Y.-C.; Lee, C.-H.; Wang, C.-H.; Chiu, F.-S. 2012. Basin-scale groundwater response to precipitation variation and anthropogenic pumping in Chih-ben watershed, Taiwan. *Hydrogeology,* 20 (3), 499–517. https://doi.org/10.1007/s10040-012-0835-5

Jencso, K. J.; McGlynn, B. L.; Gooseff, M. N.; Bencala, K. E.; Wondzell, S. M. 2010. Hillslope hydrologic connectivity controls riparian groundwater turnover: Implications of catchment structure for riparian buffering and stream water sources. *Water Resources Research*, 46(6), W10524. https://doi.org/10.1029/2009WR008818

Kemper, K. E., 2004. Groundwater: From development to management. *Hydrogeology*, 12(1), 3–5. https://doi.org/10.1007/s10040-003-0305-1

Kenya Meteorological Department, 2013. *The outlook for the March-April-May (MAM) 2013 "long-Rains" season in Kenya and Review of the performance of the October-December 2012 "Short Rains" Seasons as well as the weather during January-February 2013*. Report from Government of Kenya [online], [cited 7 July 2017]. Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/The%20outlook%20for%20the%20March-April-May%20%28MAM%29%202013%20%E2%80%9CLong-Rains%E2%80%9D%20season%20in%20Kenya.pdf

Konikow, L.; Kendy, E., 2005. Groundwater depletion: A global problem. *Hydrogeology,* 13(1), 317–320. https://doi.org/10.1007/s10040-004-0411-8

Kothari, C. R. 2004. *Research Methodology, methods and techniques* (2nd ed.). New Age International (p) Ltd. Publishers, New Delhi [online], [cited 16 March 2017], Available at: https://www.modares.ac.ir/uploads/Agr.Oth.Lib.17.pdf

Li, X.; Li, G.; Zhang, Y. 2014. Identifying major factors affecting groundwater change in the North China Plain with Grey Relational Analysis. *Water,* 6, 1581-1600. https://doi.org/10.3390/w6061581

Mogaji, K. A.; Aboyeji, O. S.; Omosuyi, G. O. 2011. Mapping of lineaments for groundwater targeting in the basement complex region of Ondo State, Nigeria, using remote sensing and geographic information system (GIS) techniques. *International Journal of Water Resources and Environmental Engineering,* 3(7), 150-160 [online], [cited 21 May 2017]. Available at: http://www.academicjournals.org/journal/IJWREE/article-full-text-pdf/57F993F54739

Pacific J. V.; McGlynn, B, L.; Riveros – Iregui, D. A.; Welsch, D., L.; Epstein, H. E. 2011. Landscape structure, groundwater dynamics, and soil water content influence soil respiration across riparian–hill slope transitions in the Tenderfoot Creek Experimental Forest, Montana. *Hydrological Process*, 25, 811-827. https://doi.org/10.1002/hyp.7870

Sombroek, W. G.; Braun, H. M. H., van der Pouw, B. J. A. 1980. *Exploratory soil map and agro climatic zone map of Kenya. Scale 1:1, 00,000.* Kenya Soil Survey Report No. E1, Nairobi. [online], [cited 28 August 2017]. Available at: https://library.wur.nl/isric/fulltext/isricu_i00006336_001.03.pdf

Wada, Y.; van Beek, L. P. H.; van Kempen, C. M.; Reckman, J. W. T. M.; Vasak, S.; Bierkens, M. F. P. 2010. Global Depletion of Groundwater Resources. *Geophysical Research Letters, 37.*

https://doi.org/10.1029/2010GL044571