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Ground Water Level Variability and their Cost Implications: A Case of Keiyo North Sub-County, Elgeyo Marakwet County, Kenya

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Abstract

Ground and surface water are the main sources of water in Kenya and world over. Due to climate change, environmental degradation as well as population pressure, water has become quite scarce and thus the need to exploit more ground water so as to satisfy the ever increasing demand. However, there has been a decline in the ground water level which has been linked to the disruption of the hydrologic cycle by human activities. As the water table drops, the depths of wells increase and so does the cost of drilling them. Similarly, a decline in water table often leads to a reduction in the amount of water in wells and thus unmet water demands in households. The households are then forced to extend their wells and thus incur some costs. This study therefore sought to determine the water table variability over time and their cost implications. The study was done in Keiyo North sub-County, Elgeyo Marakwet County, Kenya. Field surveys, structured questionnaires and interviews were the primary data sources while review of relevant published literature formed secondary sources. A total of 318 respondents were interviewed. The results revealed that 88% of households used wells as the main source of water while 12% rely on other sources of water such as rivers, streams, springs and piped water. Average water consumption per household was, 159.64 litres per day, while, 112 household were found to have extended their wells at an average cost of Ksh. 159.9 per foot. The total depth extended by the sampled households was 390.6 feet and the estimated total cost was Ksh. 62,284.142 with an average of Ksh. 556 per household. In conclusion, there has been a decline in ground water level which has led to reduced ground water supply in household wells. This has resulted in households extending their wells and hence incurring costs. The resultant cost of accessing ground water informs the water resource managers and policy makers on the need to address the ground water recession.

Key Words: Hydrological Cycle, Ground Water, Wells, Water Demand, Water Supply, Human Activities

Introduction

Water is life and is very vital for the survival of all living things. Humans and animals need water in order to survive as our bodies cannot function without it. Also, water is needed for crop production, powering equipment, and to keep us comfortable. Ordinarily, water cannot be created on the planet rather it is transformed through a well-coordinated hydrological cycle between the earth and the atmosphere (Caswell, 1989). Nature goes through a unique process to provide us with groundwater. The surface water that we can see is heated by the Sun and goes into the atmosphere through evaporation. Water vapour then through precipitation falls from the sky as rain and snow. Once water falls from sky and onto the ground, it is absorbed into the Earth and is then stored as groundwater in aquifers. Energy from the sun is the source of energy that necessitates the evaporation process for the formation of the rainfall in the atmosphere. When it rains, the surface runoff as well as the ground water is recharged (FAO, 2010).

According to World Bank, (2011), economic activities from human action tend to disrupt the hydrological cycle especially from advanced agriculture and industries which produce greenhouse gases that degrade the atmosphere. Accumulation of greenhouse gasses in the atmosphere result into global warming which subsequently cause climate variability (Caswell, 1989 & Epstein, 1999). Occurrence of climate change will cause effect to the elements of hydrological cycle resulting into disrupted rainfall distribution pattern (FAO, 2010). Since spatial variations of water availability on earth are influenced by rainfall and/or runoff distribution pattern, water scarcity both on runoff and underground ensue as a consequence of degraded atmosphere from anthropogenic activities. Therefore, the effect of human activities on the environment that causes climate change manifests into changing rainfall patterns which tend to create water scarcity both on the earth's surface and underground (Epstein, 1999 & FAO, 2010). Human activities are also known to be responsible for the degradation of the vegetation cover which plays a great role in determining the amount of water that infiltrates into the ground after a down pour. The infiltrated water eventually forms the ground water.

According to FAO (2013), the potential global water status availability for the earth's population excluding ground water decreased from 12,900 m^3 per capita per year in 1970 to 9,000 m^3 in 1990 and to less than 7,000 m^3 in 2000 with the trend showing gradual decrease. Also, with densely populated parts of Asia, Africa and central and southern Europe, current per capita water availability is between 1,200 m^3 and 5,000 m^3 per year. Generally, the global availability of freshwater is projected to drop to 5,100 m^3 per capita per year by the year 2025, due to continuous increase in population and retrogressive climate variability arising from global warming (World Bank, 2011). Since the availability of global freshwater is dependent on an effective hydrological cycle (Epstein, 1999), then management of watershed areas, vegetative cover and reduction of greenhouse gasses is required (Pounds & Puschendorf, 2004; FAO, 2010).

Kenya as part of the globe is facing a number of serious challenges related to water resource management which is attributed to degradation of vegetative cover in watershed areas (USAID, 2007). Agricultural land increased considerably from 243.7 km^2 in 1995 to 2346.65 km^2 in 2004, indicating nearly 9 times of land expanded for agricultural activities and estimated deforestation rate was about 5,000 hectares or 12,355.27 acres per year in 2010 (Kenya Forest Service, 2010). Reduced vegetative cover has profound effect on surface water runoff and ground water retention capacity (Epstein, 1999; USAID, 2007). Another factor is increase in temperature, caused by high levels of the greenhouse gases. High temperatures lead to high evaporation rate and hence reduction in ground water retention, since more water will evaporate back to the atmosphere leaving very little to infiltrate and form the ground water (Pounds & Puschendorf, 2004; Adedeji, Reuben, & Olatoye, 2014).

The effects of deforestation and production of greenhouse gases include a decline in the levels of ground water and surface runoff (Adedeji *et al.*, 2014). These spill-over effects could have a far raging cost to the population even beyond adjacent areas where deforestation took place. In welfare economics, sustainability in resource use should exhibit Pareto improvement. However, it is often untrue in environmental services (Pearce, 2002), because environmental services are characterised by non-excludability and non rivalry. This occurs because environmental goods often exhibit 'tragedy of the commons syndrome' and this is exacerbated by lack of restriction especially on explicit market value that can be used to impose penalties to reduce resource damage (Sangkapitux, 2009).

Ground water decrease is a serious problem in water resources given that apart from surface water, ground water is the other major source of water for households. However, ground water is widely used given that surface water is not always safe for consumption and is more difficult to filter than ground water. In addition, societies require much more clean water than is available from precipitation and surface water which often get in contact with pollutants, making groundwater to be highly sought and demanded for consumption. Consequently, ground water has been very valuable and greatly preferred by most communities globally because of its reliability, accessibility and natural taste (FAO, 2010), and is usually accessed by drilling boreholes and wells. Simply, a water well is an excavation or structure created in the ground through digging or drilling to access groundwater in underground aquifers (Caswell, 1989).

Ground water depletion has been widely experienced and is commonly attributed to by frequent pumping of water from the ground continuously such that the aquifers cannot find time to replenish (Adedeji *et al*., 2014). This is due to high population growth rate and expansion in agriculture which requires more water for irrigation from all sources. Without enough water, it will be extremely difficult to provide drinking water and water for crops and animals that would help communities to sustain their livelihoods especially during climatic shocks (USAID, 2007; FAO, 2010). Scarcity of water will result into domino effects, that is; the lesser the water available, the lower the rate crop production will be resulting to deprived livelihood. Therefore, the problems that emanate from water scarcity causes spiral effects in every aspect of human livelihood (Sioufi, 2010). The activities that lead to groundwater depletion comes mostly from humans, and a portion of it also come from changes in climate which can speed up the process (Epstein, 1999; Sioufi, 2010; Adedeji *et al*., 2014). Apart from human activities and climate change, topography, soil characteristics and discharge and recharge dynamics also influence the level of ground water in a place (Adedeji *et al*., 2014), and it is important to note that all these factors can be influenced by human activities.

Reduction in ground water is thus attributed to human activities, the basic draw back here being the distortion of the ecosystem functions that result into inefficiency in the water cycle on earth due to unsustainable human actions. Hence, water demand can be expressed in a functional form as;

Water demand (Cost) = f (human actions)

Water use is often influenced by socio economic factors like age, sex, education level, income and the nature of degradation on biophysical factors such as soil, atmosphere, wetland, vegetation/forest and watercourse over a period of time (Pearce, 2006; Sangkapitux, 2009). All these variables can be put together to derive underground water demands' function as:

$$W_d = ß + f\,(P_E, S_{ec}) + \varepsilon$$

Where: $ß$ = is the constant term in which water demand is assumed to be linear function of; P_E = is biophysical environment which are often degraded by human actions and influence underground water variability like soil, atmosphere, wetland, vegetation/forest and watercourse; S_{ec} = is the socioeconomic characteristic such as age, education level, income, household numbers and sex; ε = is the random component.

According to the economic theory, total maximum utility which is equivalent to total demands of the variables should be equal to total costs incurred to obtain such commodity for the continued use by the consumer (Pearce, 2002). The relationship can be shown as:

W_{dij} (water demand) = U_{ij} (maximum utility) = Estimated cost or willingness to pay for the continuous consumption of water from the well.

Based on the above functional relationship, it can be deduced that, the total price households are willing to pay in extending wells so as to access receding ground water indicates maximum utility and households water demands. This therefore formed the basis of this study.

Materials and Methods

The Study Area

Elgeiyo Marakwet County is situated at an expansive Rift Valley region with an area of 3,050 km^2 in Kenya. It has a population that stands at 369,227 with about 17,055 households according to the post-census of the year 2009. It has also a substantive annual growth rate of 2.3% according to the Kenya National Bureau of Statistics, (2010).

The County lies between latitude 0^0 48’ and 1^0 30’ North, and longitude 34^0 22’ and 35^0 10’ East. It is characterized by three distinct undulating landscapes of highland, mid or hanging valley and low valley area. The county lies at an altitude between 2400 m above sea level to the south and 1400 m above sea level to the north. The mean annual rainfall is 1800 mm with a pattern showing bimodal type of rainfall, with the long rains between March and June, and the short rains from September to November. The temperature varies between 14^0C and 24^0C with the lower altitude experiencing a higher temperature. The climate is diverse from semi-arid lands at low level and arable areas in the highlands. At the highland part, the climate is favourable for a wide range of agricultural and livestock activities which account for about 90% of the economic activities, while low lying areas are favourable for pastoralist.

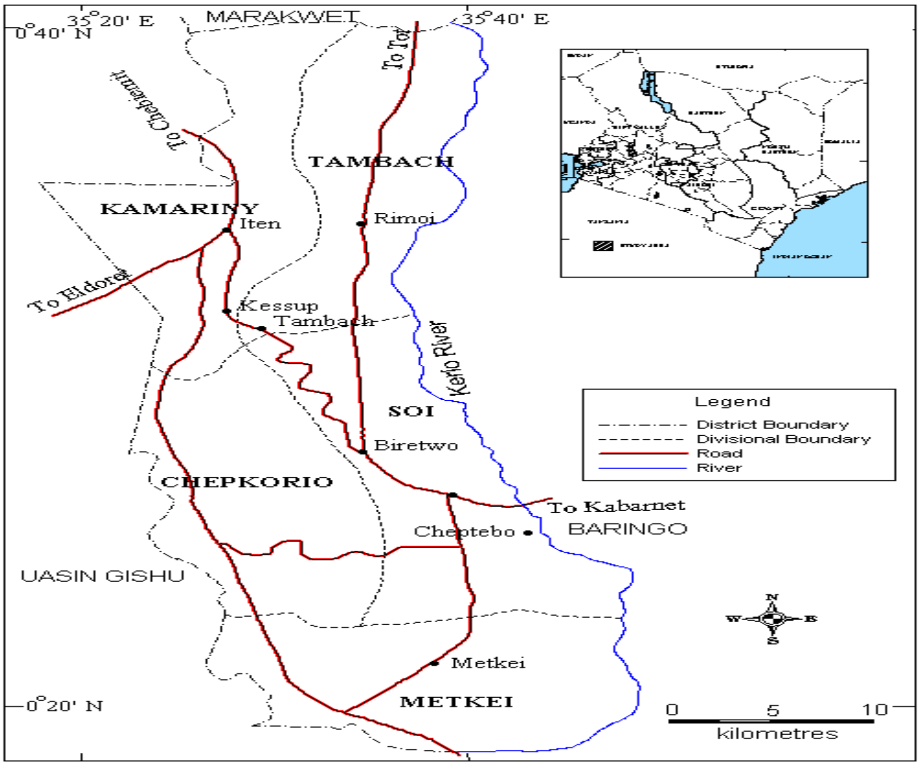

Figure 1. The Study Area

Data Collection

Primary data was collected from individual respondents through household survey. Two sets of questionnaires were used in this study; one for household heads from randomly selected households and the other was for the focus group discussions. Focus groups were the gathering of purposively selected individuals who acted as representatives of the sampled units. Household questionnaires were administered by trained enumerators interviewing household heads and filling the questionnaires in-situ. Observation method was used to cross-check information and gather supplementary information that was not captured in the questionnaire.

Sampling Procedures and Data Collection

The target population included all the households owning wells in Kamariny Division. The Sample size required for sampling was achieved by using the following formula (Kothari, 2004):

$$n = \frac{z2 .p .q.N}{e2 (N-1) + z2 .p. q}$$

This yielded a sample size of 318 households.

Multi-stage approach was used for sample selection. Cluster sampling was first applied where the five locations of the study area were treated as clusters. The sampling with probability proportional to size was then applied to get the sample size of each cluster. Systematic sampling was then applied to select the sample households from each cluster. A starting house on a random road was randomly selected. Interviewers were then to follow the right-hand rule method to select the remaining households to be contacted.

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 was sought and recorded against the GPS readings of each well (i.e. the position, elevation and the well depth). 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. Further information sought was the date of drilling, instances of well drying (particular months), year of extension if water level had dropped and needed extension, the cost of extending the well per foot, highest and lowest water level of the well during rainy and dry season respectively, approximate yield per day, other water sources and socio-economic data of respondents such as age, sex, household size and water uses among others.

Results and Discussion

Socio-Economic Characteristics of the Respondents

Table 1 shows the socio-economic parameters used to determine water utility demands which include gender, age, occupation, level of education and water sources.

The findings in Table 1 show that 72% of the respondents were between the age of 31 to 50 years old, revealing that the study area is characterized by a productive age with a combination of youthful and middle aged population. On gender, the percentage of respondents interviewed was, females (63%), and males (37%). This was good for the study since women are more in charge of fetching water for their homes and are therefore quite conversant with water resource issues as compared to their male counterparts. The main economic activity in the study area was farming (87%) and this explains the high demand for water and the degradation of the watersheds as more land is cleared for agricultural expansion.

Table 1. Socio-Economic Characteristics of Respondents

Variables	**% of respondents**
Size of the household	8 (mean)
Gender	
Males	37
Females	63
Age group respondents in years	
18-30	14.6
31-40	39.8
41-50	32.5
Above 51	13.0
Occupation	
Farmer	87.9
Civil servant	5.0
Teacher	3.7
Student	0.3
Business Person	1.9
Athlete	1.2
Education level	
No formal Education	7.7
Primary level	39.4
Secondary level	46.0
Tertiary	6.5
University	0.3
Sources of water	
River	0.6
Well	86.3
Rainwater	0.9
Piped/tap water	0.6
River and well	0.3
Piped/tap water and well	11.2
Total number of wells	318

The average number of persons per household was eight indicating that household consumption could be high. The most preferred source of water in the study area was ground water which was obtained from wells (86.3%) and this can probably be due to its accessibility, reliability and affordability. Respondents whose main source of water was tap water were 11%, however, majority in the focus group discussion indicated that tap water was not reliable . It was also necessary to find out the education level of the respondents because literate people tend to be more knowledgeable in water resource issues and thus the answers they provide would be more reliable. It was thereafter established that a majority of the people had at least obtained basic education (Table 1).

Characteristic of the Wells

Figure 2 shows in percentages the number of wells drilled in the study area from 1960 to 2012. The increase in the number of wells drilled over time reveals the significant use of well water compared to other sources in the study area.

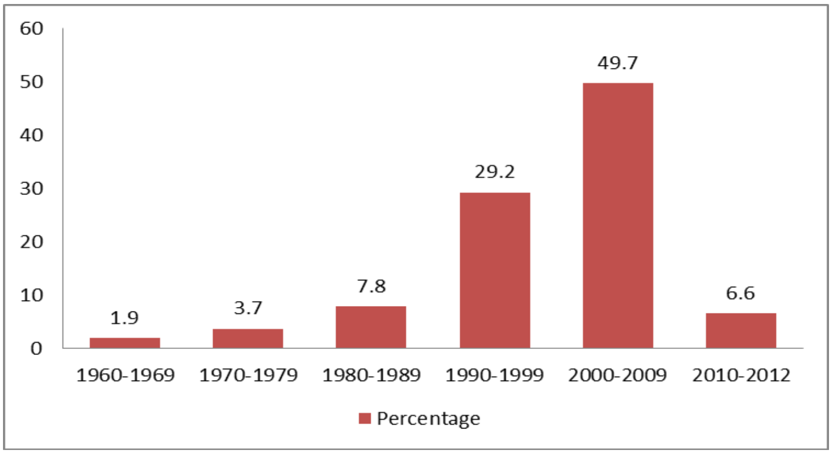

Figure 2. The Percentage of Wells Drilled over Time in the Study Area

The results showed that the highest number of wells were drilled in the period 2000-2009(160, 49.7%); followed by 1990 – 1999 (94, 29.2%), while the least number was (6, 1.9%) drilled in the 1960-1969 period. Continuous drilling of wells as shown in Figure 2 reveals that ground water could remain to be the most relied on and preferred source of water compared to other sources. The results indicate an increase in the number of wells drilled over time and this could be attributed to increase with population increase that would lead to a higher demand for water.

The average depth of the maximum water level measured from the bottom of the well, was at 40.62 feet or 7.58 feet from the ground level often occurring during the rainy season, while the depth of water at its lowest occurring during the dry season, was at 39.61 feet from the ground level or 8.61 feet from the bottom of the well.

Table 2. Characteristics of Wells in the Study Area

Characteristic	Mean	SD	Average volume of water using formula (Лr^{2}depth)
Average volume of water used per day	159.64 litres	2.79	
Average depth of the wells	48.2 feet	6.26	
Average depth of the highest water level	7.58 feet	5.55	3614.04 litres
Average depth of the lowest water level	39.61	13.40	766.06 litres
Average cost of drilling wells (per foot)	159.47/=		
Average diameter of the wells	2 feet		

The maximum volume of water that a well could hold was 3614.04 litres and this occurred during the rainy season, and the minimum was at 766.060 litres during the dry season. The lowest water levels were experienced in the period between January and April while the highest were in May, August, September and October (Table 2). Since it is evident from the results that water levels vary over the seasons, water harvesting during the rainy season should be encouraged in the study area. The water harvested should then be stored and utilized during the dry season, which will help in alleviating water scarcity that is often experienced in the study area during the dry seasons.

Estimated Cost in Extending the Depth of the Wells

In Figure 2, the period that experienced highest increase in the number of wells drilled was 2000 -2010. Moreover, it can be noted in Table 3 that most households extended the depth of their wells during the same time period. These wells were extended because they could not provide enough water for the households, indicating that there were causative agents that caused a significant drop of ground water level or increased demand for water use resulting to most households drilling wells in order to access ground water.

Due to water scarcity, households were forced to incur costs by either extending the existing wells or drilling new wells in order to meet their water demands. There are many factors that could be responsible for the dropping of the water table and these include; climate change and watershed degradations which are often accelerated by human activities, excessive withdrawals of ground water due to population pressure and general environmental degradation (Epstein, 1999; Pounds & Puschendorf, 2004; FAO, 2010). Therefore, human actions that contribute to a drop in ground water level can be considered to be bringing about cost to households.

Table 3: The Extensions of the Wells in Feet and the Cost Incurred by the Households

Year of extending the well	**Number of Households that extended the well**	**Average depth extended by the households (feet)**	**Cost incurred by households in extending the wells (Ksh)**	**Cumulative frequency of the total depth extended by households (feet)**
2000	2	4.5	159.47*9.0 = 1,435.23	9.0
2001	4	3.8	159.47*15.0 = 2,392.05	24.0
2002	0	0	159.47*0.0 = 0.0	24.0
2003	12	3.7	159.47*44.4 = 7,080.47	68.4
2004	3	4.1	159.47*12.3 = 1,961.48	80.7
2005	9	3.6	159.47*32.4 = 5,166.83	113.1
2006	1	3.0	159.47*3.0 = 478.41	116.1
2007	24	3.2	159.47*76.8= 2,247.30	192.9
2008	14	3.4	159.47*47.6 = 7,590.77	240.5
2009	14	3.6	159.47*50.4 = 8,037.23	290.9
2010	15	3.7	159.47*55.5 = 8,850.59	346.4
2011	8	3.2	159.47*25.6 = 4,082.43	372.0
2012	6	3.1	159.47*18.6 = 2,966.14	390.6
Total	112	3.49	62,288.98	390.6

Table 3 shows that the total depth of the wells that were extended by the households was 390.6 feet, equivalent to about 34,752.6 litres of water gained from well extensions. The total cost that was incurred by the households in extending wells could be used as replacement cost, which can then be equated to the value for ecosystem variability. The estimated total cost for well extension was obtained by obtaining the product average cost of drilling the well per foot (Ksh. 159.47), and the total depth of the extensions (390.6 feet). Therefore, the estimated total cost of well extension in the study area was Ksh. 62,288.98. On average, the cost incurred per household to extend their wells was Ksh. 556.15, which can be deduced to be willingness to pay amount. Hence, this value could be used as the replacement cost or damage cost as a result of decrease in water supply or willingness to pay value per household in order to access ground water for household utility.

Conclusion

Human activities are responsible for disrupting the ecological function resulting to environmental degradation. Degradation of the environment and/or over use of water resources has led to a drop in ground water level resulting to limited water supply. This has been accelerated by increase in population growth that has led to a higher demand for water to be used for various uses and thus more ground water drawn. Moreover, when water supply declines and the demand for water ensues, households are therefore forced to extend their wells so as to gain access to more water. In the process of extending the wells to improve water supply, the households incur costs which could increase with time as the demand for water goes up and ground water level decline. It is therefore recommended that more trees be planted in the study area, the wetlands be conserved, soil conservation measures be put in place especially in agricultural lands, cultivation on sloppy areas be avoided and last but not least the water resources available should be utilized in a more efficient manner. Additionally, in order to supplement the ground and surface water, rain water harvesting should be encouraged in the study area.

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