Comparative assessment of road runoff harvested water quality and that of other water sources: A Case of Makueni County, Kenya

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Abstract

The research was aimed at analyzing the differences in physical-chemical water parameters of road runoff harvested water compared to water obtained from other sources. A case study was done in Makueni County. Specific objective is to gain insight in whether and how road runoff water has different water quality characteristics compared to water not coming from a road. Focusing on trends in physical and chemical parameters of water related to the different types of use. Furthermore possible purification methods are identified in case this proved needed. Overall this adds insight in the potential of the harvesting and storage of road runoff water for different purposes of use.

Data collection involved use of structured questionnaires, interviewing key personnel and photography. Triplicate samples of water (samples before, during and after the rains) were collected from the six sites and analyzed. The water parameters were compared to the world health organization (WHO) standards and guideline values. The water samples over the six sites had significant differences in the total hardness, calcium hardness, electrical conductivity, TDS, fluoride, chlorine, Iron and the turbidity. Comparison with road runoff and other sources revealed that different parameters exceeded with fluctuations across the seasons. However, with simple measures of treatment, these water sources, also from road runoff are suitable to use for agricultural and domestic purposes.

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List of Acronyms

WHO	World Health Organization
KEBS	Kenya Bureau of Standards
TDS	Total Dissolved Solids
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
SS	Suspended Solids
DO	Dissolved Oxygen
FAO	Food and Agriculture Organization
ASALS	Arid and Semi Arid Lands
KNBS	Kenya National Bureau of Statistics
SODIS	Solar Disinfection System
DS	Dissolved Solids
RRHW	Road runoff harvested water
HH	Household
SAR	Sodium Adsorption Ratio
NA	Not Applicable

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CHAPTER 1: INTRODUCTION

Road runoff water is an excellent opportunity as an alternative water source to people living in Arid and Semi-Arid lands (Van Steenbergen, *et al*., 2018). Makueni County is listed as an Arid and Semi Arid Land (ASAL) and therefore the community can adopt the technique of harvesting of the road runoff water for agricultural irrigation and livestock purposes, as well as for domestic use. The water quality is of importance for all these uses. Therefore, this research is of importance as it will find out whether the road runoff water quality is sufficient for the different purposes as outlined above. Its findings will also help the people of Makueni County and others living in ASAL regions of Kenya to increase their water supply to sustain their livelihoods.

Since water is an essential component of human life and a fully functional ecosystem, its quality parameters need to be addressed. The quality of water is defined by the physical, biological, chemical and aesthetic characteristics of the water. A heath ecosystem, which the water characteristics are sufficient, is organized by a varied rich set of flora and fauna (Goldman, Charles R & Horne, Alexander J; 1983).

The potential to scale up the harvesting of road runoff water is enormous especially when you look at ongoing investment in road building globally. Regarding tapping into the potential in road water management, every area has its own specific best solutions. At present, the construction of roads typically leads to social displeasure with local flooding, gulley erosion, water logging, dust and sedimentation at the centre stage (Gunawardena, J. M*et al.*, 2018). Yet this can be turned around so that roads and water, rather than being enemies can become friends.

When roads are put in place in a multi-functional manner, taking water management into account from early stages, this can result into a triple win (Sui, X, 2018). First, road damage can be prevented, while longevity and reliability are increased. Second, the direct environment can be safeguarded, reducing erosion damage, re-greening and groundwater levels recharged. Third, roadside communities benefit from increased water availability for agricultural production. Beyond the scope for harvesting water with roads, there is also another compelling argument: if done well, harvesting water with roads will reduce road damage and simply maintenance. Consequently, this will also enhance road access to the local communities along the roads (www.roadsforwater.org; accessed online on 19th Feb/2017).

Rural roads construction linked to poverty and groundwater development is a matter which has been overlooked by governments, donors and international organizations. Road construction when combined with water harvesting can benefit ground water resources for poor local communities, namely for small scale irrigation, animal watering and for household activities such as nursery gardens. Groundwater has played a key role in boosting agricultural production and thus reducing poverty in many parts of the world, particularly in Asia (Shah, 2010).

According to the Kenyan Constitution 2010, every person has the right to clean and safe water in adequate quantities (GOK, 2010); therefore, having clean water is of primary importance for our health and economy. Clean water provides recreation, commercial opportunities, fish habitat, drinking water, and adds to the beauty of our landscape. All benefit from clean water and therefore have a role to play in making and keeping our lakes, rivers, streams, marine and ground waters free from pollution of all kinds.

This study will be of great importance since it will reveal the various physical and biological contaminants present in road runoff water. With this kind of knowledge, the resultant impacts can easily be highlighted and the proper mitigation measures can be put in place to avoid negative impacts of various contaminants to humans and even domestic animals.

Road runoff water provides an alternative source of water to people who live in ASALs. This water is needed by people to sustain and become climate change resilient. There is need to analyze the water quality of road runoff water for it is important for people's livelihoods as this has not been determined yet relative to its suitability for the different types of use.

With this information people will be able to make informed decisions on the usage of road runoff harvested water and apply treatment in case of need. This will ensure people can use the potential of road runoff as an alternative water source in ASALs, for agricultural and domestic purposes. Therefore, this research is important to find out the water quality characteristics and its suitability for different purposes. In this way, the results can help people to increase their water availability to sustain their livelihoods.

CHAPTER 2: BACKGROUND INFORMATION

This chapter explores broadly the water situation in Africa and how it has impacted public health mostly in Sub-Saharan Africa. The chapter also critically looks at Kenya's geography and its water situation with emphasizes on the Arid and Semi-Arid Lands (ASALS) in the country. The background to which the research is grounded is also discussed therein.

2.0 Water situation in Africa

Africa faces huge challenges with multiple issues that adversely affect its public health. One of the major challenges is the inability for both rural and urban Africans to access a clean water supply. According to the WHO (2006), only 59% of the world's population had access to adequate sanitation systems, and efforts to achieve the Millennium Development Goal, falling way below the set target at 75% by the year 2015.

The situation of access to clean water and sanitation in rural Africa is even more dismal than the previous statistics imply. The WHO (2006) stated that, in 2004, only 16% of people in sub-Saharan Africa had access to drinking water through a household connection. Not only is there poor access to readily accessible drinking water, even when water is available in these small towns, there are risks of contamination due to several factors. When wells are built and water sanitation facilities are developed, they are improperly maintained due to limited financial resources. Water quality testing is not performed as often as is necessary, and lack of education among the people utilizing the water source leads them to believe that as long as they are getting water from a well, it is safe. Once a source of water has been provided, quantity of water is often given more attention than quality of water (Awuah *et al.*, 2009).

There are limited sources of water available to provide clean drinking water to the entire population of Africa. Surface water sources are often highly polluted, and infrastructure development to pipe water from fresh, clean sources to arid areas is too costly of an endeavor. Groundwater is the best resource to tap to provide clean water to the majority of areas in Africa, especially rural Africa. Groundwater has the benefit of being naturally protected from bacterial contamination and is a reliable source during droughts. However, the high costs associated with drilling for water, and the technical challenges in finding sources that are large enough to serve the population in need, present challenges that limit tapping the resource. Groundwater is not a fail-safe resource either when it comes to providing clean water. There may be contamination of the water with heavy metals, and bacteria may be introduced by leaking septic systems or contaminated wells. For these reasons, it is important that groundwater be monitored frequently, which is costly and requires technical abilities that may not be present in rural areas (Awuah, *et al.*, 2009).

The implications of lack of clean water and access to adequate sanitation are widespread. Young children die from dehydration and malnutrition, results of suffering from diarrheal illnesses that could be prevented by clean water and good hygiene (Metwally *et al.*, 2006). Diseases such as cholera are spread rampantly during the wet season. Women and young girls, who are the major role-players in accessing and carrying water, are prevented from doing income-generating work or attending school, as the majority of their day is often spent walking miles for their daily water needs. They are also at an increased risk for violence since they travel such great distances from their villages on a daily basis, and are even at risk when they must go to the edge of the village to find a private place to relieve themselves.

Urban areas face a whole different host of challenges to providing clean water and sanitation. Rapid growth of urban areas, especially in sub-Saharan Africa, has led to large volumes of water being extracted from existing sources. The influx of water, in addition to the influx in human waste, has outpaced the development of wastewater management systems, which has led to pollution of natural water bodies, unintentional use of wastewater in irrigated agriculture, irregular water supply, and environmental concerns for aquatic life due to the high concentration of pollutants flowing into water bodies (Van Rooijen *et al.*, 2009).

Overcrowding in urban slums makes it even more difficult to control sanitation issues and disease outbreaks associated with exposure to raw sewage. It has been reported that underprivileged urban populations pay exorbitant amounts of money for water, which is often not even suitable for consumption, while resources allocated to those living in the wealthy urban areas are heavily subsidized, meaning the wealthy pay less for cleaner water and better sanitation systems (Fotso *et al.*, 2007).

2.1 Kenya

Kenya lies between 5°N and 5°S of the Equator. It is a country that has a very diverse relief with a short, low coastal plain on the Indian Ocean shore, extensive inland plateau regions between 1000M and 1500M, and several mountain ranges and peaks such as Mount Kenya (Kalungu, J. W., & Leal Filho, W., 2018).

The Kenyan climate is divided broadly into two: The Arid parts comprising of regions such as Isiolo, Wajir, Mandera, and Turkana among other parts and the Semi-arid regions such as Laikipia, Makueni, Machakos, and Kitui among other parts.

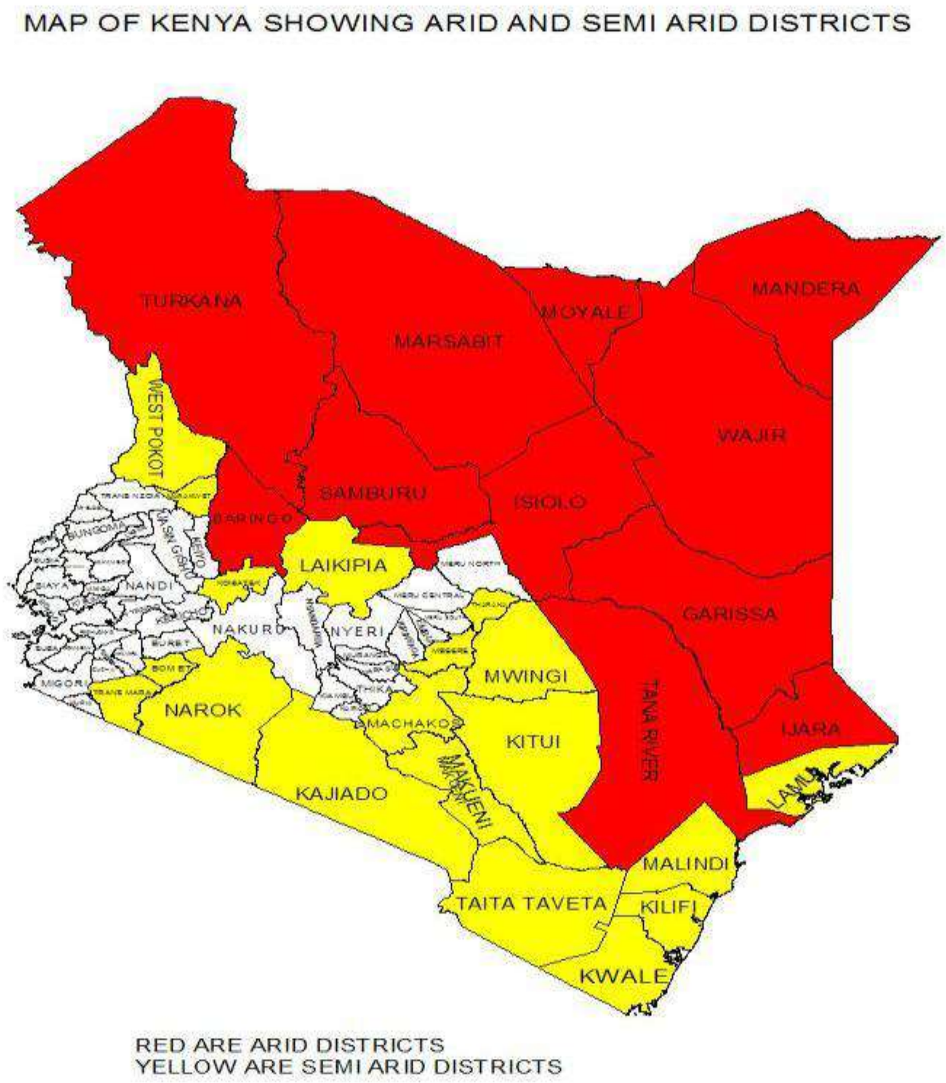


Figure1: Map of Kenya showing climate distribution (Google map, 2017)

2.1.1 Agro-climatic zones of Kenya

The table below shows the agro-climatic zones of Kenya showing the relevant rainfall amount, excluding areas above 3000m altitude (Biamah, 2005). Makueni County is a semi arid area and lies under the climatic zone (V).

Table 1: Agro-climatic zones of Kenya (Biamah, 2005)

Zone	R/E_o* (%)	Classification	R (mm)	E_o (mm)
I	> 80	Humid	1100 – 2700	1200 – 2000
II	65-80	Sub-humid	1000 - 1600	1300 – 2100
III	50-65	Semi-humid	800 – 1400	1450 – 2200
IV	40-50	S.humid -S.arid	600 - 1100	1500 – 2200
V	25-40	Semi-arid	450 - 900	1650 – 2300
VI	15-25	Arid	300 - 560	1900 – 2400
VII	< 15	Very arid	150 - 350	2100 – 2500

Notes: * R – Average rainfall; E_o- Average annual evaporation.

2.2 Makueni County- case study location

Makueni County is located in the southern part of the formerly Eastern Province. It borders four counties with Kitui to the East, Taita Taveta to the south, and Kajiado to the west and Machakos to the North. It has a total area of 8034.7sq km (Omollo, E. O *et al.*, 2018).

The county has varied climate conditions ranging from the hilly Mbooni and Kilome constituency, to the lowlands plains of Kalawa, Kitise, Kathonzweni and Kibwezi among others. This difference leads to the county’s advantage in production of dairy and beef animals, mangoes, paw paws, oranges and horticulture in the higher and cooler areas of the county. Temperature ranges within 12-28 deg. Centigrade, rainfall ranges from 150-650 mm/ year, typical of ASALS in Kenya.

The county has an estimated population of about 884527 persons (Government of Kenya, 2009).

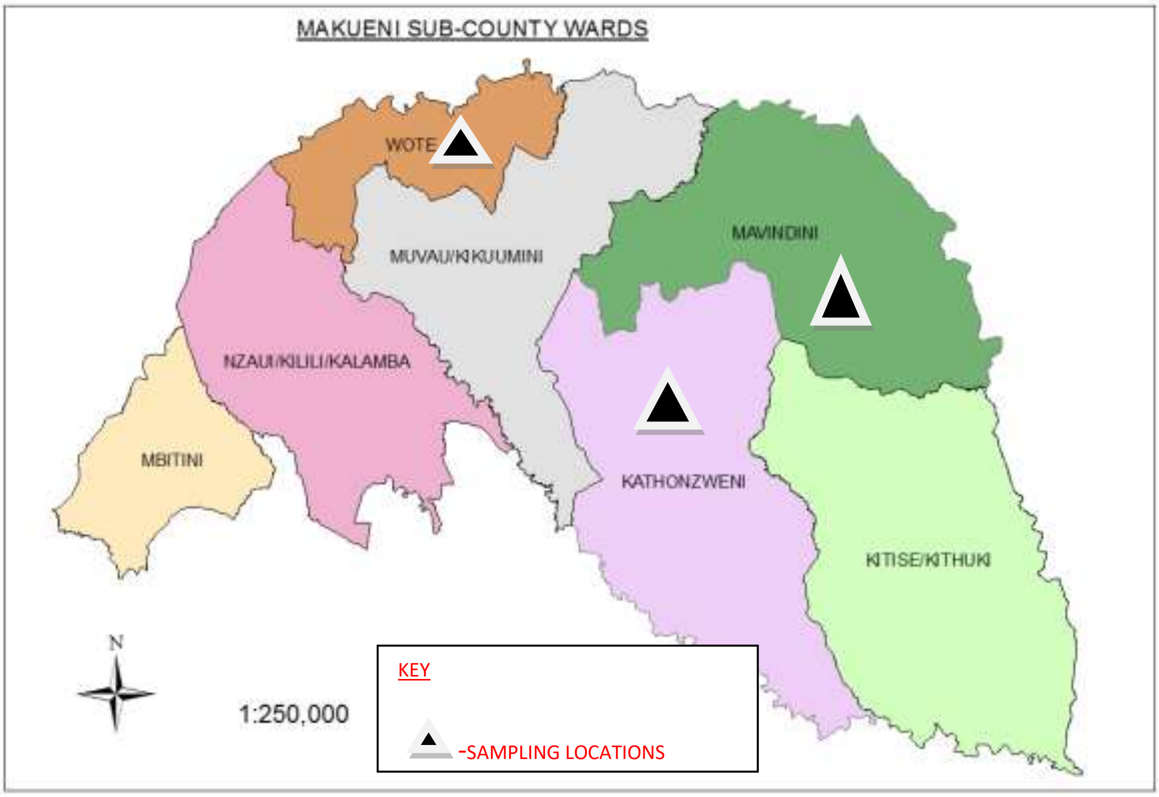


Figure 2: Study area map (GIS produced, 2018)

2.2.1 Climate

Makueni County is mainly semi-arid; it is characterized by extreme rainfall variability resulting in prolonged droughts from time to time. There are two rainy seasons in Makueni County: with the long rains occurring from March to May with the peak season experienced during March/April and short rains occurring during October to December with the peak being November/December. The most reliable rains for crop production are the short rains. The topography of Makueni County greatly influences the amount of precipitation in different parts of the county.

The hilly parts of the county (Mbooni and Kilungu) receive higher rainfall ranging from 800-1200 mm of rainfall per annum, the medium zone receives up to 750 mm of rainfall and the low-lying zone has an average of 500 mm of rainfall per year.

The erratic rainfall in Makueni County is complicated by the fact that most typically good seasons are interspersed with extremely dry seasons and variations in the onset of rain season, thereby undermining food production. The net effect has been perennial food shortages that have become the hallmark of the county.

The mean temperature ranges between 20-25 degrees Celsius. The high temperatures experienced in the low-lying areas of the county cause high evaporation rates that limit plant growth and therefore lead to massive crop failure most of the seasons.

Makueni County has also been affected by adverse effects of climate change. The increasingly unpredictable and unreliable rainfall coupled with increased human activity has led to drying up of springs, streams and rivers across the county (makueni.go.ke/sites/default/files/makueni%20county%20vision%202025.pdf).

2.2.2 Agriculture

The county is largely arid and semi-arid and usually prone to frequent droughts. The lower side, which is very dry, receives little rainfall ranging from 300mm to 400mm.The depressed rains in the lower part of the county hardly sustain the major staple food of maize and beans. Traditional crops which are drought tolerant have largely been abandoned. This means livestock rearing remains the common viable economic activity being undertaken by the local people in the lower region. This condition has negatively affected agriculture which is the main economic activity in the county; hence, people have opted to shift into other economic activities such as sand mining.

2.2.3 Water resources

Makueni County being one of the dry counties in Kenya faces water shortages more so during the dry spell (Mganga, K. Z *et al.*, 2018). This makes the residents to trek for long distances to access clean water. It is estimated that the average distance for most households to a water point is 8 kilometers. This is attributed to periodic cyclical droughts and shrinking water sources due to encroachment and degradation of water watersheds/towers, uncontrolled sand harvesting and, limited awareness on water harvesting and management techniques among the populace. The County faces limited resource allocation for water development and inadequate institutional capacity to manage and explore the available water resource potential.

The main sources of water for the population are: seasonal and permanent rivers; springs; boreholes and wells; and dams and roof catchment (Oguge, N., &Oremo, F. (2018). The current water production in the County is 14,489.911 m^3/Day against a demand of 40,794.39 m^3/Day leaving a water deficit of 26,304.47 m^3/Day. This translates to water coverage of 35.6 per cent against national water coverage of 52 per cent. The projected water demand by 2025 will be 45,934 m^3/Day. Inadequate investment in water resources is a major contributor to poor water access in the County (Musee, S. B. (2018). Even where springs and river water sources are available, the water is mainly harvested but not treated and therefore, it is considered unsafe source of water. 64.3 per cent of the population in the County relies on unimproved sources of water compared to a National average of 47.4 per cent. There is a high potential for roof water catchment with 86.6 per cent of the households having corrugated iron sheets roofing.

2.3Research background

This chapter looks at what already has been done in the past in relation to research problems and reviews relevant aspects noted in relation to the need of the present study. Study of past literature is intended to identify gaps which this study may fill or propose for further research. This chapter will therefore describe results from previous studies on water quality characteristics, its effects for utilization and link this to water runoff pollutants and characterization.

2.3.1 Water quality

Water quality refers to the chemical, physical, biological and radiological characteristics of water consisting of suspended and dissolved solids, dissolved gases, heat and microorganisms in given water body (Ralph A. Wurbs and Wesley P. James 2010). In nature, a myriad of impurities enters and leaves water throughout the hydrological cycle. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human purpose or need. Water quality describes the conditions of the water with respect to its sustainability for a particular purpose such as drinking or irrigation.

Water quality is measured by several factors such as the concentration of dissolved oxygen, bacterial levels, the amount of salt (salinity) or the amount of suspended materials in the water (turbidity). In some bodies of water, the concentration of microscopic algae and quantities of pesticides, herbicides, heavy metals and other contaminants may also be measured to determine water quality. Although scientific measurements are used to define water quality, it is not a simple thing to say that “water is good” or “water is bad”, so the determination is typically made relative to the purpose of the water. Poor water quality can pose a health risk for people and ecosystems. Pollutants such as metals, oils, pesticides, fertilizers runoff from land into waters can cause excess algae growth and other harmful impacts (www.int/water-sanitation-health/resourcesquality/wqmchap2.pdf).

Environmental pollution with poisonous and dangerous heavy metals is a main concern in modern societies (Chang et al., 2000). By developing several mechanisms these metals remove the balance in living beings, especially humans, and result in wide range of consequences and disorders (Chong et al, 2000). The most important of these consequences include carcinogenicity, effects on the central and peripheral nervous system, skin diseases, blood disorders, cardiovascular diseases, and kidney harm among others. Metal ions accumulate in the environment and enter food chains (Vole sky and Schiewer, 2000). There are several methods to remove heavy metals from the environment which mainly involve physical, biological and chemical ways (Zhang et al, 2007). Current physical methods include: physical and membrane filtration, reverse osmosis, coagulation-flocculation and floatation (Kurniawan et al., 2006).

2.3.2 Storm runoff pollution

Immense quantities of pollution enter streams without ever flowing through pipes, sewers, treatment plants or storm water outfall structures. Such waste water sources are characterized as nonpoint sources pollution. Storm runoff occurs when precipitation falls on urban environment, highways and picks up pollutants, both natural and man-made, and deposits them into surface waters or introduces them into ground waters. The water carries with it all wastes and chemicals from buildings, streets, construction sites, oils, gasoline from automobiles, insecticides, herbicides and fertilizers. Nonpoint sources include agricultural areas, abandoned and active mine sites, urban areas and highway facilities among others (Chen. L*et al.*, 2018).

The most common nonpoint source pollutants are sediment and nutrients. These wash into water bodies from agricultural lands, small and medium-sized animal feeding operations, construction sites and other areas of land disturbance. Other common nonpoint source pollutants include pesticides, pathogens, salts, oils, grease, toxic chemicals and heavy metals. Highway nonpoint pollution is created when chemicals, debris, fertilizers, automotive oils, debris from wearing parts and litter are washed off roadways and bridges during rainstorms and carried as run off to streams, rivers, lakes, bays and roadside pond collection(Min, J., & Shi, W., 2018).

The most common pollutants in highway runoffs are heavy metals, inorganic salts, aromatic hydrocarbons and suspended solids which accumulate on the road surface as a result of regular highway operation and maintenance activities. Ordinary operations and wear and tear of motor vehicles also result in oil, grease, rust, hydrocarbons, rubber particles and other solid materials dropping onto the highway surface. These materials are often washed off the highway during rain events (U.S Environmental Protection Agency, 1995; 1997).

2.3.3 Water quality standards and guidelines

Water quality standards and guidelines are the international set of water parameters which should be adhered to in order to be termed of enough quality for the different types of usage. It looks at the recommended concentrations of organic compounds, inorganic compounds, pesticides, and disinfectants among other compounds which are regarded safe for different levels of utilization (Markovic, M et al., 2018).

WHO produces international norms on water quality and human health in the form of guidelines that are used as basis for regulation and standard setting world-wide (Björklund, K et al., 2018).The guidelines for drinking water quality promote the protection of the public health by advocating for the development of locally sound standards and regulations and the adoption of preventive risk management approaches.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

This chapter describes the procedures that were used in conducting the research. Firstly, the research designs including the problem statement, objectives and research questions. Furthermore, it describes the research methodology in regards to the techniques of data collection, sampling procedures and data analysis applied during the study.

3.1 Problem statement

There is need for alternative sources of water due to the scarcity of the resource overtime. Road water harvesting by roadside communities can be used for domestic and agricultural purposes. However, it is not clear whether the quality of road runoff water is high enough for the different types of utilization thus there is a need for assessing it. This research identified the gaps in water quality parameters from road run offs and compared them to those from other sources not recharged by road runoffs.

3.2 Research questions and objectives

3.2.1 Research questions

The main research question is: What are the water quality characteristics of harvested road runoff water, compared to other water sources, and is this water of sufficient quality regarding its usage?

Sub-questions:

1. What are the major physical and chemical water pollutants in road runoff, compared to water from other sources?
2. What are the origins and effects of these pollutants?
3. Is the water quality of harvested road run off sufficient regarding its different types of usage?

3.2.2 Objectives

The general objective of this research was to gain more understanding in water quality characteristics of water storage reservoirs which are filled up by road run off for different types of use.

This was further guided by the following specific objectives:

a. To gain insight in whether and how road runoff water has different water quality characteristics compared to water not coming from a road.
b. To gain insight in the water quality standards for different types of use; the trends in physical and chemical qualities of water.
c. To identify the major physical and chemical water pollutants.
d. To identify possible purification methods.
e. To gain insight in the potential of the harvesting and storage of road runoff water for different purposes of use.

3.3 Research methodology

The research employed a case study research design in finding the characteristics of road run off harvested water compared to water from other water sources. The sites of interest, i.e. water reservoirs recharged by road runoffs along with a representation of water from other water sources were identified for comparison. Makueni County was the case for the research. It best represents ASAL regions since it is prone to droughts, and water scarcity is a major challenge. The findings of the research were generalized for other ASAL regions.

3.3.1Water sampling

In order to determine the trends in the physical-chemical parameters of the water reservoirs, the research was carried out in three phases; before the onset of rains, during the rainy period and after the rainy period. This allowed for the comparison of the water parameters in the reservoirs over the seasons to be done thus determining trends. In actual sampling of the water samples for analysis, information-oriented sampling method was adopted. The sampling method allowed data collection from only sites which had reservoirs of interest. Triplicate water samples from six selected sites were taken as a representative of other reservoirs of the same type. The samples were analyzed for the physical-chemical parameters of water and compared in order to achieve the objectives of the research. The parameters analyzed were: PH, Calcium hardness, total hardness, conductivity, iron, sulphates, nitrates and nitrites. This is because the values of these parameters are the key indicators of water which meets the standards for domestic development when within the recommended WHO values.

3.3.2 Interviews and observations

Formal and informal interviews were administered to the relevant key stakeholders; Water and Agricultural Officers, and farmers to extract their views and opinions regarding road runoff harvested water. In order to get a broad-spectrum conceptualization of water quality characteristics and the epidemiology of water borne diseases, data from Health Centers were retrieved. During the fieldwork, the method of observation was conducted in order to cross-check and verified information that was communicated.

The questionnaires were designed in a simple and clear manner. They were distributed to the target population which mainly was the households at a radius of 5 km from the sampling locations. Random sampling was used to get the number and the names of the respondents within the sampling area. The aim of the questionnaire was to get people's opinions, views and perceptions about water quality characteristics of road runoff harvested water compared to that from other sources.

Key informant interviews were conducted to Health Centers (Wote Level 5 hospital and Kathonzweni health center), Ministry of Water and Ministry of Agriculture. In order to obtain data on water related diseases, the water quality parameters, the role of stakeholders and community in water purification and also measures in place on road water harvesting related to livestock and agricultural production, the key informant interviews were therefore vital.

3.3.3 Data analysis and presentation

Data collected from the field was cross-checked, cleaned, validated, bench-checked and analyzed using SPSS version 20 and MS Excel. The laboratory results of water analysis from the various water reservoirs were compared with the WHO guideline values. The data is presented in this report in form of graphs, tabulations and narrations.

CHAPTER 4: RESULTS AND DISCUSSION

Though Makueni County is largely categorized as ASAL, it is endowed with a number of water resources. The water resources in the county range from seasonal to permanent sources including rivers, boreholes, and wells among others. Although there are various water sources in the study area, water demand is high with insufficient supply often due to a combination of increasing rainfall intensity in shorter time spans and unreliable rainfall distribution. Thus, rainfall comes in a short time, though often ceases before it suffices the land and the people. This often induces difficulties with water supply in the following dry season. Also, the frequency of droughts has increased over the last decades. Therefore, people have constructed artificial water reservoirs to supplement the natural sources for the residents to meet their daily water demands. From the study findings, there was a relative equal distribution of the different sources, borehole, river, pond, dam, tap, well and rain water harvesting, as shown in figure 3.

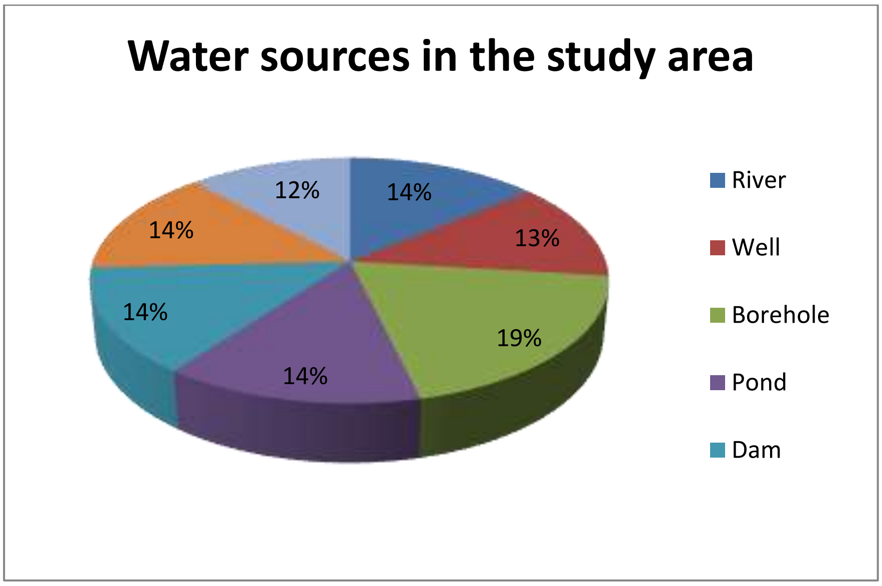


Figure 3: Water sources in Makueni County (field data, 2017)

4.1 Results of the water analysis

In this chapter, the results of the water analysis for the six different sites are discussed and compared. First, each of the six results is presented and discussed. In the last paragraph, a comparison is made of the values of the major pollutants.

4.2 Water from a borehole

The results obtained for the water analysis from a borehole are shown in table 2. The values highlighted in green are the parameter values which are far below the WHO values while the values highlighted in red are the parameter values which were above the WHO values.

Table 2: Results of water analysis from a borehole (lab data, 2017)

Parameter	During the rains	After the rains	WHO	Units
P^H	7.08	7.44	6.5-8.5	-
Apparent color	5	5	-	^OH
True color	5	5	-	^OH
Conductivity	**1098**	889	<800	µ/S/CM,mg/l
Turbidity	1.4	1.2	<5(NTU)	F.T.U
Calcium hardness, $CaCo_3$	132	380	50	Mg/l
Total hardness, $CaCo_3$	444	520	<500	Mg/l
Total alkalinity, $CaCo_3$	208	172	-	Mg/l
Carbonate alkalinity	0	0	-	Mg/l
Iron	0.2	0.2	0.3	Mg/l
Fluorides	0.32	0.51	1.5(p.p.m)	Mg/l
Sulphates	480	430	500	Mg/l
Dissolved Oxygen	6.1	5.6	-	p.p.m
Nitrates	0.5	0.6	50	Mg/l
Nitrites	0	0	50	Mg/l
Chlorides	188	186	-	Mg/l
Dissolved solids	1160	900	-	Mg/l
Suspended solids	0	0	-	Mg/l
Total solids	1160	900	-	Mg/l

From the analysis of the water samples from a borehole, high parameter values of conductivity, calcium hardness and total hardness were detected. These values were above the WHO guideline values. The high values of conductivity, calcium hardness and total hardness can be directly linked to the geology of the region. The region is clay-soiled and heavy ionization from the minerals present contributed to this. Noteworthy to find were the low parameter values of nitrates and nitrites which were below the WHO values. The values were low because the borehole is not fed by runoff water which could have carried nutrient-rich silt which would have eventual effect on high nitrite and nitrate values. The water in the borehole was found to be slightly alkaline as depicted by the PH values and hydrogen ions concentration in the water.

4.3 Water from a shallow well

The results obtained for the water analysis from a shallow well are shown in table 3. The values highlighted in green are the parameter values which are far below the WHO values while the values highlighted in red are the parameter values which were above the WHO values.

Table 3: Results of water analysis from a shallow well (lab data, 2017)

Parameter	During the rains	WHO	Units
P^H	7.13	6.5-8.5	-
Apparent color	5	-	^OH
True color	5	-	^OH
Conductivity	246	<800	µ/S/CM,mg/l
Turbidity	3.9	<5(NTU)	F.T.U
Calcium hardness, $CaCo_3$	36	50	Mg/l
Total hardness, $CaCo_3$	80	<500	Mg/l
Total alkalinity, $CaCo_3$	116	-	Mg/l
Carbonate alkalinity	0	-	Mg/l

Iron	0.3	0.3	Mg/l
Fluorides	0.35	1.5(p.p.m)	Mg/l
Sulphates	5.0	500	Mg/l
Dissolved Oxygen	4.6	-	p.p.m
Nitrates	1.0	50	Mg/l
Nitrites	0	50	Mg/l
Chlorides	46	-	Mg/l
Dissolved solids	140	-	Mg/l
Suspended solids	80	-	Mg/l
Total solids	220	-	Mg/l

The following parameter values were below the recommended WHO values: Calcium hardness, Sulphates, Nitrates and Nitrites. This is because the well does not receive water input directly from the surface runoff. Most often, the surface runoff leads to higher parameter values of nutrient related water quality than if the runoff passes through regions where heavy agricultural activities are practiced. All the other parameter values analyzed were within the accepted WHO values. The water was slightly alkaline as evidenced by the P^H value and hydrogen ion concentration in it.

Plate 1: A dried up well during the dry spell (Researcher, 2017)

4.4 Water from a river

The results obtained for the water analysis from a river are shown in table 4. The values highlighted in green are the parameter values which are far below the WHO values while the values highlighted in red are the parameter values which were above the WHO values.

Plate 2: A section of Kaiti River where water samples were collected (Researcher, 2017)

Table 4: Results of water analysis from a river (lab data, 2017)

Parameter	Before rains	During the rains	After the rains	WHO	Units
P^H	6.55	6.74	7.29	6.5-8.5	-
Apparent color	5	5	10	-	^OH
True color	5	5	5	-	^OH
Conductivity	605	400	3240	<800	μ/S/CM,mg/l
Turbidity	1.1	1.0	2.6	<5(NTU)	F.T.U
Calcium hardness, $CaCo_3$	66	50	368	50	Mg/l
Total hardness, $CaCo_3$	184	168	514	<500	Mg/l
Total alkalinity, $CaCo_3$	86	118	408	-	Mg/l

Carbonate alkalinity	0	0	0	-	Mg/l
Iron	0.3	0.3	0.3	0.3	Mg/l
Fluorides	0.14	0.41	1.11	1.5(p.p.m)	Mg/l
Sulphates	**275**	**110**	**480**	500	Mg/l
Dissolved Oxygen	5.2	5.3	5.2	-	p.p.m
Nitrates	0.5	0.9	1.0	50	Mg/l
Nitrites	0	0	0	50	Mg/l
Chlorides	260	134	2240	-	Mg/l
Dissolved solids	500	290	2900	-	Mg/l
Suspended solids	70	40	60	-	Mg/l
Total solids	570	330	2960	-	Mg/l

Conductivity, calcium hardness and total hardness are the water parameter values which were above the WHO guideline values for this water body after the rains. Conductivity value was high after the rainy season. The high value could be a result of water temperature since the samples for analysis were taken during the hot seasons of the year. High temperatures result to increased ion mobility and salinity which are contributes to high conductivity. Nitrates and Nitrites were below the WHO guideline values for this water body over the seasons. In spite the fact that the river volume could have significant water volumes coming from the surface runoff, the values of nitrates and nitrites were low. This phenomenon can be explained on basis of dilution. The nitrite and nitrate contents had been highly diluted hence the low values. Before the rains, the value of calcium hardness was above the recommended WHO value. Large discrepancies in values of chlorides, dissolved solids and total solids were noted over the seasons. The values were high after the rainy season. This resulted from the changing water volumes which affects the concentration of the sediment load and the continual downwash of the particles along the river continuum over time.

4.5 Water body in a rock catchment

The results obtained for the water analysis of a water body in a rock catchment are shown in table 5. The values highlighted in green are the parameter values which are far below the WHO values while the values highlighted in red are the parameter values which were above the WHO values.

Table 5: Results of water analysis from a reservoir in a rock catchment (lab data, 2017)

Parameter	During the rains	After the rains	WHO	Units
P^H	6.90	7.23	6.5-8.5	-
Apparent color	40	20	-	^OH
True color	30	15	-	^OH
Conductivity	175	68	<800	µ/S/CM,mg/l
Turbidity	59	6.5	<5(NTU)	F.T.U
Calcium hardness, $CaCo_3$	40	22	50	Mg/l
Total hardness, $CaCo_3$	94	62	<500	Mg/l
Total alkalinity, $CaCo_3$	88	54	-	Mg/l
Carbonate alkalinity	0	0	-	Mg/l
Iron	1.6	0.3	0.3	Mg/l
Fluorides	0.20	0.09	1.5(p.p.m)	Mg/l
Sulphates	5.0	5	500	Mg/l
Dissolved Oxygen	3.5	4.87	-	p.p.m
Nitrates	0.9	1	50	Mg/l
Nitrites	0	0	50	Mg/l
Chlorides	58	34	-	Mg/l
Dissolved solids	**340**	100	-	Mg/l
Suspended solids	100	40	-	Mg/l
Total solids	**440**	140	-	Mg/l

From the analysis of the water from this reservoir, it was noted that there were high values of iron concentration during the rainy season which exceeded the recommended WHO values. The high level of iron concentration was possibly from the surface runoff from areas of high iron concentration to the water reservoir. Low values of calcium hardness, nitrates and nitrites were detected. The low parameter values of nitrates and nitrites were due to low-level agricultural activities in and around the region. However, the agricultural activities significantly impacted the water turbidity. As a result of sediment load entering the reservoir due to storm water runoff, the turbidity of the water increased. A huge discrepancy in values of dissolved solids and total solids was noted over the season in this reservoir. The values of dissolved solids and total solids were high during the rainy season. During the rainy season, the storm water flow is high and carries a lot of sediments. After the rains, there is low or no storm water flow thus low sediment load. This makes the water to have high parameter values of dissolved and total solids during the rains compared to values registered after the rains.

4.6 Road runoff from a dirt road (murram)

The results obtained for the water analysis of road run off from a dirt road (murram) are shown in table 6. The values highlighted in green are the parameter values which are far below the WHO values while the values highlighted in red are the parameter values which were above the WHO values.

Table 6: Results of water analysis from a reservoir recharged by a dirt-road (lab data, 2017)

Parameter	Before rains	During the rains	After the rains	WHO	Units
P^H	6.68	7.08	6.71	6.5-8.5	-
Apparent color	40	15	70	-	^{O}H
True color	30	10	60	-	^{O}H
Conductivity	105	98	62	<800	µ/S/CM,mg/l
Turbidity	50	8.8	250	<5(NTU)	F.T.U
Calcium hardness, $CaCo_3$	12	16	20	50	Mg/l
Total hardness, $CaCo_3$	46	38	46	<500	Mg/l
Total alkalinity, $CaCo_3$	58	48	36	-	Mg/l
Carbonate alkalinity	0	0	0	-	Mg/l

Iron	0.4	0.4	5	0.3	Mg/l
Fluorides	0.11	0	0	1.5(p.p.m)	Mg/l
Sulphates	5.0	10	5	500	Mg/l
Dissolved Oxygen	5.1	5.3	2.80	-	p.p.m
Nitrates	0.8	1.0	0.5	50	Mg/l
Nitrites	0	0	0	50	Mg/l
Chlorides	42	54	38	-	Mg/l
Dissolved solids	220	160	360	-	Mg/l
Suspended solids	40	20	340	-	Mg/l
Total solids	260	180	700	-	Mg/l

High water parameter values of iron concentration which exceeded the WHO guideline values were noted. This results from the surface runoff and continual accumulation in the reservoir. The soils, over which the runoff passed most, probably have high iron contents, hence the detected high value. Low values of sulphates, nitrates and nitrites were detected, while there was huge discrepancy in values of suspended and dissolved solids after the rainy season from other seasons. Since there are no heavy agricultural activities which take place around this region, the runoff had little nutrient content thus the low parameter values of the sulphates, nitrites and nitrates. The high iron value indicates that the water body is polluted from iron.

High turbidity values were detected after the rains. The reservoir serves both people and domestic animals as source of drinking water during the dry spell. As the animals take water, there is induced agitation in the water reservoir thus causing the turbidity values to greatly increase.

Plate 3: A reservoir recharged by dirt-road runoff (Researcher, 2017)

4.7 Road runoff from tarmac road

The results obtained for the water analysis of tarmac run off are shown in table 7. The values highlighted in green are the parameter values which are far below the WHO values while the values highlighted in red are the parameter values which were above the WHO values.

Table 7: Results of water analysis from a reservoir recharged by tarmac runoff (lab data, 2017)

Parameter	Before rains	During the rains	After the rains	WHO	Units
P^H	6.56	6.87	6.80	6.5-8.5	-
Apparent color	5	35	33	-	^{O}H
True color	5	30	30	-	^{O}H
Conductivity	114	76	56	<800	µ/S/CM,mg /l
Turbidity	0.9	52	70	<5(NTU)	F.T.U
Calcium hardness, $CaCo_3$	18	10	20	50	Mg/l
Total hardness, $CaCo_3$	58	32	42	<500	Mg/l
Total alkalinity, $CaCo_3$	62	32	40	-	Mg/l
Carbonate alkalinity	0	0	0	-	Mg/l

Iron	0.3	0.3	1.2	0.3	Mg/l
Fluorides	0.75	0.16	0	1.5(p.p.m)	Mg/l
Sulphates	2	0	5	500	Mg/l
Dissolved Oxygen	6.3	5.3	2.91	-	p.p.m
Nitrates	1	0.9	0.3	50	Mg/l
Nitrites	0	0	0	50	Mg/l
Chlorides	38	36	46	-	Mg/l
Dissolved solids	130	160	120	-	Mg/l
Suspended solids	0	10	100	-	Mg/l
Total solids	130	170	220	-	Mg/l

The water parameters calcium hardness, sulphates, nitrates and nitrites were below the recommended W.H.O guidelines over the different seasons of the year. High turbidity values were detected after the rains. The reservoir serves both people and domestic animals as source of drinking water during the dry spell. As the animals take water, there is induced agitation in the water reservoir thus causing the turbidity values to greatly increase.

Significant was the elevated value of iron noted after the rains, which exceeded the W.H.O guidelines on standards for domestic water purposes. The traces of iron can be attributed to wear and tear of automobiles, which is down washed and accumulated in the ponds, thus magnifying the values. According to Environmental Protection Agency, iron is a secondary contaminant that carries bacteria that feeds off the iron to survive. This bacterium is harmful to human health when digested. Iron overload, which occurs due to mutation in the gene that digests the iron, can also occur when the water is consumed. This leads to hemochromatosis which can lead to liver, heart and pancreatic damage. Water with iron does not blend well with soap, causing issues when showering and washing. This can be dangerous when cleaning with such water as it can lead to clogging of the skin pores leading to build up of oils in the skin.

Plate *4*: A farmer fetching water from a reservoir recharged by tarmac runoff (Researcher, 2017)

4.8 Comparison of the major pollutants

Table 8 below shows the major water pollutants identified for the six different water reservoirs at different times of the year. Further discussion of the pollutants is done showing how the pollutants compared across the seasons in the reservoirs.

Table 8: Research findings of the major pollutants (lab data, 2017)

Water source	Ca hardness (Mg/l)			Total hardness(Mg/l)			Iron(Mg/l)			Conductivity(u/S/Cm,Mg)			Turbidity(FTU)			Chlorides			Dissolved solids		
Borehole	-	**132**	**380**	-	**444**	**520**	-	**0.2**	**0.2**	-	**1098**	**889**	-	**1.4**	**1.2**	-	188	186	-	1160	900
Shallow well	-	**36**	-	-	**80**	-	-	**0.3**	-	-	**246**	-	-	**3.9**	-	-	46	-	-	140	-
River	**66**	**50**	**368**	**184**	**168**	**514**	**0.3**	**0.3**	**0.3**	**605**	**400**	**3240**	**1.1**	**1**	**2.6**	260	134	2240	500	290	2900
Rock catchment	-	**40**	**22**	-	**94**	**62**	-	**1.6**	**0.3**	-	**175**	**68**	-	**59**	**6.5**	58	34	-	340	100	-
Dirt road	**12**	**16**	**20**	**46**	**38**	**46**	**0.4**	**0.4**	**5**	**105**	**98**	**62**	**50**	**8.8**	**250**	42	54	38	220	160	360
Tarmac road	**18**	**10**	**20**	**58**	**32**	**42**	**0.3**	**0.3**	**1.2**	**114**	**76**	**56**	**0.9**	**52**	**70**	38	36	46	130	160	120
WHO		50	<500						0.3	<800			<5 NTU			NA			NA		

Key:

a. – Indicates that no parameter values were taken
b. Figures in black colour indicates parameter values for samples taken before the rains
c. Figures in green colour indicates parameter values for samples taken during the rains
d. Figures in red colour indicates parameter values for samples taken after the rains

The PH values for the different water bodies were slightly different during different times of the year (i.e. before, during & after the rains). The differences in P^H were a result of sediment load, composition and deposition into the reservoirs. The reservoirs were recharged by runoffs emanating from diffuse geographical locations thus different soil chemistry. The differences in P^H within a body over seasons (i.e. before, during & after the rainy seasons) were due to sedimentation and accumulation.

High parameter values of calcium and total hardness were detected in a borehole and river. However, the high values of total hardness were high after the rainy season as opposed to the Calcium hardness which was exceeding the recommended WHO values across the seasons. Although water hardness has no health issues documented, it is not fit to be used for washing purposes. Hard water is important in body systems as it adds to the body's mineral supplements. When used in washing, it does not lather easily with soap leading to wastage of the soap thus not economical.

Conductivity values were high in samples which were taken from a borehole and river. Most withstanding difference was that for borehole, the conductivity values were high in all the seasons of the year. The only season when conductivity value was high in a river was after the rains.

Noteworthy to find was the high values of iron concentration which were detected in road run off harvested water reservoirs and in the reservoir with a rock catchment. From the other water reservoirs, the iron concentration values were either below or at the recommended WHO values.

Extremely high parameter value of turbidity was detected in a reservoir recharged by dirt road runoff after the rainy season. Other reservoirs where high parameter values of turbidity were high were the ones recharged by the tarmac runoff and that in a rock catchment.

Calcium hardness, total hardness, conductivity, turbidity and iron were the water parameter values which were noted to be exceeding the recommended WHO values in most of the water reservoirs. Therefore, it’s noteworthy to conclude that in all the water reservoirs, they are major water pollutants. Interestingly to find was that all parameter values for a shallow well were within WHO guideline values, though this could only be measured during rainfall. This cannot guarantee its quality once the water level in the well goes down and most likely become more concentrated with the various parameters. For all the other sources there was either one or more of the parameters exceeding the WHO limits. For road runoff water this mainly was because of high iron concentration and high turbidity values, for borehole, rock catchment and river sources this was mainly due to calcium and overall hardness levels and the conductivity rates.

CHAPTER 5: WATER QUALITY ANALYSIS FOR ITS PURPOSES

This chapter critically discusses the internationally set standards on the water quality parameters and the reasons why the standards were established.

The chapter also explores the origins and the effects of the water pollutants which were found from the analysis of the water samples. The findings of the origin and the effects are based from the laboratory results of the water samples analyzed and data collected from the farmers in Makueni County, which was the case study for this research. For each of the pollutant identified, the possible treatment measures are also discussed.

A discussion of the purification techniques is also put forth which is extracted from the literature review. This ranges from simple techniques which can be adopted at the household or farm level to very sophisticated techniques, which are largely adopted by manufacturing and processing companies to manage their waste water.

5.1 WHO Guideline Standards on Water Quality Parameters

The WHO's water quality standards and guidelines are the international set of water parameters which should be adhered to in order to meet the quality standards for the different types of usage. It looks at the recommended concentrations of organic compounds, inorganic compounds, pesticides and disinfectants, among other compounds which are regarded safe for different levels of utilization (drinking, cooking, and irrigation among others).

WHO produces international norms on water quality and human health in the form of guidelines that are used as basis for regulation and standard setting world-wide (Björklund, K et al., 2018).The guidelines for drinking water quality promote the protection of the public health by advocating for the development of locally sound standards and regulations and the adoption of preventive risk management approaches.

Table 9: W.H.O water quality standards and guidelines

Element	Symbol	Normally found in fresh/surface/groundwater	Health based guidelines by WHO
Aluminum	Al	-	0.2mg/l
Ammonia	NH4	<0.2mg/l(upto0.3mg/l in	No guideline

		anaerobic waters)	
Antimony	Sib	<4ug/l	0.005mg/l
Arsenic	As	-	0.01mg/l
Asbestos	-	-	No guideline
Barium	Ba	-	0.3mg/l
Beryllium	Be	<1ug/l	No guideline
Boron	B	<1mg/l	0.3mg/l
Cadmium	Cd	<1ug/l	0.003mg/l
Chloride	Cl	-	250mg/l
Chromium	Cr+3/Cr+6	<2ug/l	0.05mg/l
Copper	Cu	-	2mg/l
Cyanide	CN-	-	0.07mg/l
Dissolved oxygen	O2	-	No guideline
Fluoride	F	<1.5mg/l up to 10	1.5mg/l
Color	-	-	Not mentioned
Hardness	mg/l CaCO3	-	No guideline
Hydrogen sulfide	H2S	-	No guideline
Iron	Fe	0.5-50mg/l	No guideline
Lead	Pb	-	0.01mg/l
Manganese	Mn	-	0.5mg/l
Mercury	Hg	<0.5ug/l	0.001mg/l
Molybdenum	Mb	<0.01mg/l	0.07mg/l
Nickel	Ni	<0.02	0.02mg/l
Nitrate/Nitrite	NO3-/NO2-	-	50mg/l total Nitrogen
Turbidity	-	-	Not mentioned
PH	-	-	No guideline
Selenium	Se	<0.01mg/l	0.01mg/l
Silver	Ag	5-50ug/l	No guideline
Sodium	Na	<20mg/l	200mg/l
Sulfate	SO4-	-	500mg/l
Inorganic tin	Sn	-	No guideline
Uranium	U	-	1.4mg/l
TDS	-	-	No guideline
Zinc	Zn	-	3mg/l

(Source: WHO guidelines; water quality 2006)

5.2 Essential agricultural water quality parameters

Both irrigation water quality and proper irrigation management are critical to successful crop production (Shukla, S. K *et al*., 2018). The quality of the irrigation water may affect both crop yields and soil physical conditions, even if all other conditions and cultural practices are favorable/optimal. In addition, different crops require different irrigation water qualities (Adviento-Borbe, M. A *et al*., 2018).

Therefore, testing the irrigation water prior to selecting the site and the crops to be grown is critical. The quality of some water sources may change significantly with time or during certain periods (such as in dry/rainy seasons), so it is recommended to have more than one sample taken, in different time periods.

The essential parameters which determine the irrigation water quality are:

Salinity - The main problem related to irrigation water quality is the water salinity. Water salinity refers to the total amount of salts dissolved in the water but it does not indicate which salts are present in it. High level of salts in the irrigation water reduces water availability to the crop (because of osmotic pressure) and causes yield reduction. Above a certain threshold, reduction in crop yield is proportional to the increase in salinity level. Different crops vary in their tolerance to salinity and therefore have different thresholds and yield reduction rates.

The most common parameters used for determining the irrigation water quality, in relation with its salinity, are Electrical conductivity and Total dissolved solids.

TDS ppm or mg/L	EC dS/m	Salinity hazard
<500	<0.8	Low
500 – 1000	0.8 - 1.6	Medium
1000 – 2000	1.6 - 3	High
> 2000	> 3	Very high

Sodium hazard and irrigation water infiltration - The parameter used to determine the sodium hazard is SAR - Sodium Adsorption Ratio. This parameter indicates the amount of sodium in the irrigation water, in relation to calcium and magnesium. Calcium and magnesium tend to counter the negative effect of sodium. High SAR levels might result in a breakdown of soil structure and water infiltration problems. Soil tends to seal and to become hard and compact when dry.

Alkalinity is the sum of the amounts of bicarbonates (HCO3-), carbonates (CO32-) and hydroxide (OH-) in water. It is expressed as mg/l or meq/l CaCO3. Alkalinity buffers the water against sudden changes in pH. If the alkalinity is too low, any addition of acidic fertilizers will immediately lower the pH. In container plants and hydroponics, ions released by plant roots may also rapidly change the pH if alkalinity is low.

5.3 Origins of the pollutants

After the analysis of the field data was obtained, the views and opinion of the farmers were distilled in combination. As a result, the following were origins of the pollutants as established from the field data:

Animal contamination; Both domestic and wild animals took water from the same reservoir where people drew from. The major water sources in the study area were open sources; earth dams and rivers which were not fenced from animals, which are carriers of diseases. Animals also lead to induced agitation of the reservoirs from which they took water from. Therefore, turbidity in the water systems increases.

Dumpsite leachate; A substantial number of the respondents complained of the contribution of Wote dump site to the water quality. It is located a few meters from the Kaiti River, which is a major water source in the area. There lies a research gap to identify the actual elements which may have impacts on the river water quality, such as presence of heavy metals, or any of the most prevalent elements.

Wear and tear of automobile parts; The traces of iron can be attributed to wear and tear of automobiles. Then, as a result of downwash by the road run off and accumulation in the ponds, the values magnify. Humans could have also contributed to the high values of iron detected in the reservoirs from the use of the vessels to fetch water with.

Geology and climate; Calcium and total hardness was present due to geology of the underlying rocks. The soil types in all the six different sampling sites posed differences in the water hardness. Conductivity resulted from the geology of the regions, coupled by the climate. High temperatures lead to increased ionization and evaporation thus the high conductivity values were detected.

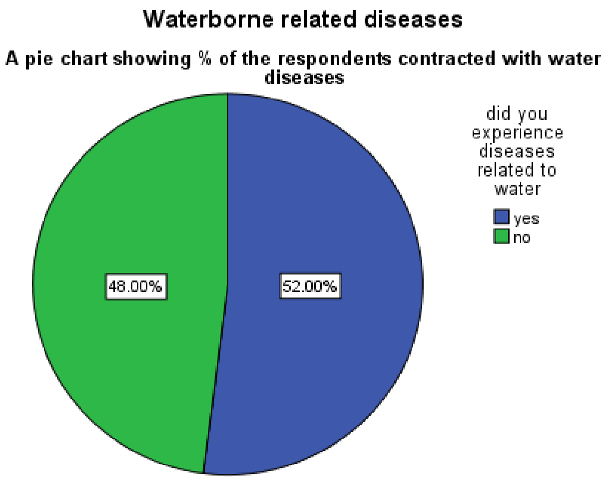
5.4 Effects of the pollutants

This section exposes the effects of the water pollutants to human and animal health. The section discloses the effects the farmers rose, which are attributed from the use of water without establishing whether its quality is sufficient enough for the use. A discussion of the implication of usage of such water is made.

According to Environmental Protection Agency, iron is a secondary contaminant that carries bacteria that feeds off the iron to survive. This bacterium is harmful to human health when digested. Iron overload, which occurs due to mutation in the gene that digests the iron, can also occur when the water is consumed. This leads to hemochromatosis, which can lead to liver, heart and pancreatic damage. Water with iron does not blend well with soap, causing issues when showering and washing. This can be dangerous when showering with such water as it can lead to clogging of the skin pores, leading to build up of oils in the skin.

The respondents also complained of suffering from water borne diseases, which can be directly attributed from the consumption of the raw water. Out of the total respondents interviewed, 52 % professed to have suffered from waterborne related diseases. The waterborne diseases which were profoundly quoted are cholera and amoeba. Only 48% said they have never experienced waterborne related diseases.

These were attributed to the respondents drawing water from open surfaces, such as earth dams and wells, where animals took from. No pre-treatment was done for the water from the reservoir. This increases the chances of contracting the water borne diseases more so than if the water body was invested by the diseases' causative agents.



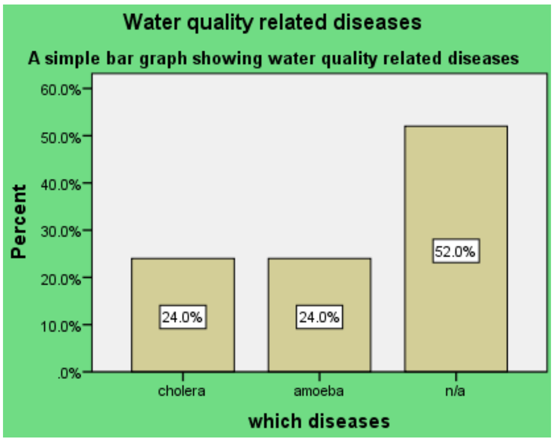


Figure 4: A bar graph representing water borne related diseases in the study area (field data, 2017)

5.5 Treatment measures for the major pollutants

This section looks at the best simple measures that can be adopted to remedy the water quality status. The discussion is inclined towards unearthing the potential of taping water that goes to waste as runoff. The detected water quality issues can be alleviated by use of simple best methods, which the communities in ASALS can implement and increase resilience during the dry spell.

From the findings of this research, the major pollutants identified were: Conductivity, Calcium and Total hardness, Iron and Turbidity. Each of the pollutant is discussed therein and a corrective mechanism also put forth.

Conductivity: Normal conductivity basically comes from the surrounding geology. Clay soils generally contribute to conductivity due to the ionization. Conductivity however, depends also on the temperature and TDS. Increase in temperatures will consequently lead to increase in conductivity. This is because temperatures increase ionic mobility as well as the solubility of salts and minerals. Seasonal variations in conductivity are affected by the average temperature and water flows. Agricultural runoff with high nutrient load often has high concentration of dissolved solids, which greatly influences conductivity. Heavy down pours can result to decrease in conductivity as it causes dilution in current salinity concentration.

Elevated dissolved solids can cause mineral tastes in drinking water and can also lead to elimination of some desirable food plants and habitat forming species. As a result, water with high conductivity is not fit for drinking and irrigation. However, it can be used for other economic purposes like making of bricks. High conductivity can be reduced through dilution. This involves mixing water of low salinity with water of high salinity.

Turbidity: Agitation of water systems, either induced or natural, impacts water quality. Construction, agricultural activities and mining can lead to high sediment levels entering water during the rainy season due to storm water runoff, hence impacting on turbidity. In drinking water, high turbidity levels increase the risk of people developing gastrointestinal diseases, mainly immune-compromising. Water with high turbidity can be used for irrigation, making of bricks and also for livestock.

High turbidity can be reduced by settling or filtration process. Sand filtration can be cheaply implemented and achieve desirable results of required turbidity levels. Stilling basins and also silt traps can be used to control turbidity. Increasing vegetation cover in areas where the water flows can trap sediments which increases turbidity in water systems hence controlling e.g. the vetiver grass.

Calcium and Total hardness: Calcium hardness generally increases due to evaporation. Water with calcium hardness is in fact the best for drinking purposes as it adds up to calcium in the body, which is essential for borne formation. It is also ideal to be used for irrigation, livestock and other economic activities like making of bricks. It should not, however be used for washing purposes. This is because it does not lather easily with soap, thus uneconomical. Calcium hardness is minimized by dilution or by use of a sequestering agent. A sequestering agent is a compound when added will chemically bond with calcium and other minerals to make them more soluble.

Iron: The major sources of iron in water are corrosion of steel pipes and other components of plumbing system. In wells, it can be controlled by extending the well casing to avoid water with high concentrations of iron.

5.6 Purification techniques from the existing literature

Past literature presents a number of simple to complex water purification techniques which can be adopted both at the household levels and even in big institutions, which are mandated for water purification processes. This section postulates a number of the techniques which can be used in water purification processes.

5.6.1 Solar disinfection

The principle underlying solar disinfection is that microorganisms are vulnerable to light and heat. One easy and simple way to treat water is to use the SODIS system (Solar Disinfection),which has been tested both in the laboratory and in the field. A transparent container is filled with water and exposed to full sunlight for several hours. As soon as the water temperature reaches 50°C, the inactivation process is accelerated and usually leads to complete bacteriological disinfection.

5.6.2 Boiling

Heating water is an effective way to kill the microorganisms in it. W.H.O recommends that the water be brought to a vigorous boil. This will kill, or inactivate, most organisms that cause diarrhea. High turbidity does not affect disinfection by boiling, but if the water is to be filtered, this must be done before boiling. For household use, water is mostly boiled in a pot on a stove. If it is not to be stored in the same pot in which it was boiled, the water should be poured into a clean storage container immediately after boiling, so that the heat of the boiled water will kill most of the bacteria in the storage container. Fuel costs, and the time involved in boiling and cooling the water, limit the usefulness of this method. A study in Bangladesh estimated it would cost 7% of the average family budget to boil all the water for the village (Gilman &Skill corn, 1985). Also, fuel prices continue to rise in most parts of the world.

5.6.3 Water chlorination at household level

Chlorination of water at household level can be used as an emergency measure or as part of everyday life. When water quality cannot be trusted, a carefully measured amount of concentrated chlorine solution is added to a container with a known amount of clear water. The mixture is stirred and left for at least 30 minutes, to let the chlorine react and oxidize any organic matter in the water. After this, the water is safe to drink. The amount of chlorine needed depends mainly on the concentration of organic matter in the water and has to be determined for each situation. After 30 minutes, the residual concentration of active chlorine in the water should be between0.2–0.5 mg/l, which can be determined using a special test kit. The concentrated chlorine solution can be made of clear water and chlorine-producing chemicals, such as bleaching powder, sodium hypochlorite, or organic chlorine tablets. It can be prepared at household level, but also in larger quantities and distributed among the households. A concentrated chlorine solution should be used within a relatively short time (defined according to the compound used) before it loses its strength.

In some cases, chlorine-producing chemicals are added directly to the water, without prior dilution. Some chlorine products come in combination with a flocculent to help settle suspended material in the water.

5.6.4 Storage and sedimentation

The quality of raw water can be improved considerably by storage. During storage, on-colloidal, suspended particles slowly settle to the bottom of a storage tank, and solar radiation will kill some of the harmful organisms in the water. Schist soma larvae, for example, will die after storage for at least 48 hours. In contrast, colloidal particles remain in suspension. The smaller the suspended particles, the longer the water needs to be retained in the reservoir. If the suspended matter precipitates very slowly, chemicals can be added to induce coagulation and flocculation.

5.6.5 Up-flow roughing filter

Roughing filters are often used to pre-treat water by removing suspended solids from the water that could rapidly clog a slow sand filter. Roughing filters can also considerably reduce the number of pathogens in the water, as well as the amount of iron and manganese. There are many types of roughing filters with different flow directions (down flow, up flow and horizontal flow filters), and with different types of filter medium (e.g. sand, gravel, coconut husk fiber). Up flow roughing filters are relatively cheap and easier to clean than down flow or horizontal flow filters. An up-flow filter box can be made of bricks, concrete or ferro cement. It can have around or rectangular shape, with vertical or partially inclined walls, and it is usually about 1.5 m deep. Water flows in through an under-drain system on the bottom, usually a perforated PVC pipe, which also permits rapid abstraction during cleaning when the flow direction is reversed (backwashing); (Galvis *et al*., 1993).

5.6.6 Slow sand filtration

The treatment of water by slow sand filtration combines biological, chemical and physical processes when the water slowly passes downwards through a bed of sand. Fine particles are filtered out, and in the sand and on top of the filter bed a population of microorganisms develops that feed on bacteria, viruses and organic matter in the water. The filter reservoirs have drains on the bottom covered with gravel and sand. Raw water slowly enters the filter through an inlet, and an outlet leads the clean water from the drains to the clean-water mains. During operation, the sand filter is covered with a water layer of 0.3–1.0 m. For the filter to work well, water must flow continuously at a rate of 0.1–0.3 m/hour.

5.7 Purification techniques adopted by the farmers at Makueni County-case study location

According to the findings of this research, the farmers have adopted household water purification techniques in their effort to treating the raw water from reservoirs.

Table 10: Water purification techniques adopted at the HH level (field data, 2017)

Water treatment approaches		
Treatment approach	**Frequency**	**% frequency**
Boiling	16	59.26
Use of water guard	9	33.33
Use of ash	2	7.41
	27	100

From the study findings, the respondents had adopted home approaches to treat water after harvesting. 59.26% of the respondents' boiled water, while 33.33% used water guards and 7.41 % used ash as treatment approach as shown in table 10 above.Boiling and use of ash are simple home methods which are affordable by all irrespective of the economic status.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From the analyses and findings of this research paper, the major physical and chemical water pollutants in RRHW were: iron and turbidity. Conductivity, calcium and total hardness were the major pollutants in reservoirs which are not directly recharged by the road runoffs.

In the RRHW, high turbidity resulted from induced agitation of the water systems, either natural or artificial. Humans and animals took water direct from the reservoirs during the dry periods thereby exciting the water systems. Also, as water flows during the rainy season, it collects sediments which are deposited in the water systems. Overall, human and animal behavior and the storm water flow, impacts on the turbidity of the water systems. Wear and tear of automobiles, steel pipes and plumbing system were the causes of the high levels of iron in water. In water reservoirs which are not directly recharged by the road runoffs, the high values of conductivity, calcium and total hardness was due to geology of the surrounding soils and climatic factors such as temperature. In few occasions the parameters exceeded the standards of the WHO on water quality, which can result to human health complications without treatment.

Road runoff water harvesting is an excellent opportunity for the communities living in ASALs to beef up their water availability and be more resilient during the times of drought. It presents a chance for the communities to tap the potential road runoff water, which is currently going to waste. Using this resource would mean an enormous boost for both agricultural production and domestic use. The several methods of treatments should be taken into account in order to guarantee a sufficient water quality standard. For domestic use the methods are various, adding to existing methods of boiling and the use of chlorine, people can try sand/ceramic filters and use solar disinfection systems for example. For agricultural use it is key to construct water diversions and storage reservoirs which have stilling basins and silt traps combined with vegetation to reduce turbidity and sedimentation.

So in conclusion the road runoff water proves a good alternative to other water sources in the area, in terms of water quality parameters the road runoff is often of higher quality compared to other sources like a river, borehole and rock catchment. Looking at the amount of water being drained away from the road, the potential is enormous. In order to realize the potential of road runoff harvesting one can invest in low-cost harvesting methods combined with water treatment.

6.2 Recommendations

The following recommendations are put forth in line with the findings of this research:

- The community should propose to the county government of Makueni to build a water treatment plant. This will ensure that the road runoff harvested water is treated and therefore of sufficient quality in regard to its usage.
- The community should be sensitized and mobilized on the adoption of road runoff water harvesting. This is because the research has established that the road runoff harvested water meets sufficient quality for most of the usage. This will increase the resilience of the community even during the dry seasons.
- The community should be educated on water quality standards and adoption of household water purification techniques postulated by the findings of this research. This will lead to improved health for the people and environmental conservation since due considerations will be made in regard to the usage of the water, depending on its quality.
- Roads should be designed in a way that there is maximum storm runoff flow directed towards farmers' shambas. This will reduce the cost and time they incur in implementing road runoff harvesting structures.
- Further research should be done on the implications of the communities taking contaminated water and the impact it has on the economy of the community.

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Appendix (i): WHO guideline values 2006-Organic compounds

Group	Substance	Formula	Health based guideline by WHO
Chlorinated alkanes	Carbon tetrachloride	CCl4	2ug/l
	Dichloromethane	CH2Cl2	20ug/l
	1,1-dichloroethane	C2H4Cl2	No guideline
	1,2-dichloroethane	ClCH2CH2Cl	30ug/l
	1,1,1-trichloroethane	CH3CCl3	2000ug/l
Chlorinated ethenes	1,1-dichloroethene	C2H2Cl2	30ug/l
	1,2-dichloroethene	C2H2Cl2	50ug/l
	Trichloroethene	C2HCl3	70ug/l
	Tetrachloroethene	C2Cl4	40ug/l
Aromatic hydrocarbons	Benzene	C6H6	10ug/l
	Toluene	C7H8	700ug/l
	Xylenes	C8H10	500ug/l
	Ethyl benzene	C8H10	300ug/l
	Styrene	C8H8	20ug/l
	Polynuclear aromatic hydrocarbon(PAHS)	C2H3N1O5P13	0.7ug/l
Chlorinated benzenes	Monochlorobenzene(MCB)	C6H5Cl	300ug/l
	1,2-dichlorobenzene	C6H4Cl2	1000ug/l
	1,3-dichlorobenzene	C6H4Cl2	No guideline
	1,4-dichlorobenzene	C6H4Cl2	300ug/l
	Trichlorobenzene	C6H3Cl3	20ug/l
Miscellaneous organic constituents	Di(2-ethylhexyl)phthalate(DEHP)	C24H38O4	8ug/l
	Acrylamide	C3H5NO	0.5ug/l
	Epichlorohydrin(ECH)	C3H5ClO	0.4ug/l
	Hexachlorobutadiene(HCBD)	C4Cl6	0.6ug/l
	Nitrilotriac acid(NTA)	N(CH2COOH)3	200ug/l

Source: WHO guidelines; water quality 2006

Substance	Formula	Health based guideline by WHO
Alachlor	C14H2OClNO2	20ug/l

Aldicarb	C7H14N2O4S	10ug/l
Aldrin and dieldrin	C12H8Cl6 $ C12H8Cl6O	0.03ug/l
Altrazine	C8H14ClN5	2ug/l
Bentazone	C10H12N2O3S	30ug/l
Carbofuran	C12H15NO3	5ug/l
Chlordane	C10H6Cl8	0.2ug/l
Chlorotoluron	C10H13ClN2O	30ug/l
DDT	C14H9Cl5	2ug/l
1,2-dibromo-3-chloropropane	C3H5Br2Cl	1ug/l
2,4-dichlorophenoxyacetic acid(2,4-D)	C8H6Cl2O3	30ug/l
1,2-dichloropropane	C3H6Cl2	No guideline
1,3-dichloropropane	C3H6Cl2	20ug/l
Ethylene dibromide(EDB)	BrCH2Br	No guideline
1,3-dichloropropene	CH3CHClCH2Cl	No guideline
Heptar and heptachlor epoxide	C10H5Cl7	0.03ug/l
Hexachlorobenzene(HCB)	C10H5Cl7O	1ug/l
Isoproturon	C12H18N2O	9ug/l
Lindane	C6H6Cl6	2ug/l
MCPA	C9H9ClO3	2ug/l
Methoxychlor	(C6H4OCH3)CHCCl3	20ug/l
Molinate	C9H17NOS	6ug/l
Pendimethalin	C13H19O4N3	20ug/l
Pentachlorophenol(PCP)	C6HCl5O	9ug/l
Permethrin	C21H20Cl2O3	20ug/l
Propanil	C9H9Cl2NO	20ug/l
Simazine	C7H12ClN5	2ug/l
Trifluralin	C13H16F3N3O4	20ug/l

Source: WHO guidelines-water quality 2006

Appendix (ii): Field work photographs

Plate 5: Water sample collection for physico-chemical analysis

Appendix (iii): Household questionnaire

Dear respondent,

I am a fourth year student at SEKU pursuing Bsc(Environmental science) carrying out a research on investigation to find out if the water quality characteristics of road run off harvested water is different from those harvested from other sources in Makueni County, with MetaMeta organization for road for water harvesting in arid and semi-arid areas.

This questionnaire aims at obtaining information about your perceptions, opinions and experiences on water quality aspects. Your contributions and assistance are highly valued.

Thank you.

Yours faithfully

…………………………………..

Fredrick Mulatya.

0714281034

fredmulatya13@gmail.com

INSTRUCTIONS: Tick where applicable and briefly fill in information where applicable

This research questionnaire seeks information particularly for educational purpose and all information given will be treated with utmost confidentiality.

Date of interview………………………Place of interview (GPS coordinates)……………………….

Interviewer……………………..Time of the interview………………………………….

SECTION ONE: General

1. Sex of the respondent, Male[ ] Female[ ]
2. Name (optional)…………………………………..
3. Age of the respondent[ ]yrs. old
4. Level of education

   None [ ] Primary [ ] Secondary [ ] Higher education [ ]

5. Total number of household members……………………
6. What is the name of this village?.....................................
7. For how long have you lived here?.............................

SECTION TWO: Water source and use

8. What is the source of water the you use?[river] [well][borehole] [pond/dam] [tap] [rain water harvesting system] [other, specify]
9. Mention some of the ways you use this water

   ………………………………………………………………………………

   ………………………………………………………………………………

   ……………………………………………………………………………...

   ……………………………………………………………………………….
10. What do you think of water quality?
11. Can you estimate the levels of :
    - Fluoride
    - Sediments
    - Metals
12. Do you think the water is safe for use in purposes you have mentioned? Yes[ ] No[ ]
13. If yes or no, give reasons why you think so

    ………………………………………………………………………………………

    ……………………………………………………………………………………….

    ……………………………………………………………………………………….
14. Did you experience any diseases related to water?
    - Diarrhoea?
    - Malaria?
    - Other?
15. What do you think is the main source of water pollution in your water source?
16. How do you/can treat water?
    - In the water reservoir?
    - In your home?

- In the conveyance system?

SECTION THREE: Road water harvesting

17. Do you use water harvested from road runoffs? [Yes] [No]

18. If yes, is the runoff from murram [ ] or tarmac [ ]

19. Mention some of the ways you use this water

…………………………………………………………………………….

…………………………………………………………………………….

……………………………………………………………………………

20. What do you think of water quality?

21. Can you estimate levels of?

- Fluoride
- Sediment
- Metal

22. Do you think the water is safe for the purposes you have mentioned? Yes [ ] No [ ]

23. If yes or no, give reasons why you think so

…………………………………………………………………………….

……………………………………………………………………………..

24. Did you experience any diseases related to water?

- Malaria?
- Diarrhoea?
- Other?

25. In your opinion, which water source do you think is safer than the other and why do you think so? Give reasons

…………………………………………………………………………………………

…………………………………………………………………………………………

Thank you

Appendix (iv): Key informants

a). Health institutions

Dear respondent,

I am a fourth year student at SEKU pursuing Bsc(Environmental science) carrying out a research on investigation to find out if the water quality characteristics of road run off harvested water is different from those harvested from other sources in Makueni County, with MetaMeta organization for road for water harvesting in arid and semi-arid areas.

This questionnaire aims at obtaining information about your perceptions, opinions and experiences on water quality aspects. Your contributions and assistance are highly valued.

Thank you.

Yours faithfully

…………………………………….

Fredrick Mulatya.

0714281034

fredmulatya13@gmail.com

INSTRUCTIONS: Tick where applicable and briefly fill in information where applicable

This research questionnaire seeks information particularly for educational purpose and all information given will be treated with utmost confidentiality.

1. Name of the health institution..
2. Level of the institution…………………………………………………………..
3. Name of the laboratory technician…………………………………………
4. For how long have you been in this health institution?..............
5. Do you encounter patients with water borne diseases? Yes[ ] No[ ]
6. If yes, mention the frequently attended water borne diseases

   ………………………………………………………………………………………....

   ……………………………………………………………………………………….

   ……………………………………………………………………………………….
7. Which seasons of the year do you experience high numbers of patient suffering from water borne diseases? Rainy season[ ] Dry season[ ]
8. In your opinion, where can you trace the source of these diseases

   ………………………………………………………………………………………………

   ………………………………………………………………………………………………
9. Apart from medication, are there efforts this institution making towards overcoming water borne diseases? Yes[ ] No[ ]
10. If yes, mention them

    ………………………………………………………………………………………………

    ……………………………………………………………………………………………...

    ………………………………………………………………………………………………
11. If no, what do you think can be done to alleviate these diseases?

    ………………………………………………………………………………………………

    ………………………………………………………………………………………………
12. Which water quality characteristics are the causes of water borne diseases?
13. How could you counter them?..

    ……………………………………………………………………………………………………….
14. What the other health risks when it comes to water quality?.....................

    ……………………………………………………………………………………………………….

15. What do you think of quality of water harvested from roads?....................

    …….

Thank you.

b). Agricultural officer/water officers

County: Makueni

Date of interview…………………………………

Interviewer…………………………………………..

GPS Coordinates……………………………………

1. Which authorities are concerned with water quality assessment in this County?
2. What are some of the methods used/which can be used in purifying water?
3. How can the local authority support in assessment of quality of water in the various water sources?
4. What constraints are associated with water quality assessment and purification?
5. In your opinion, how can the quality of water be enhanced for its different types of usage?
6. What roles can the private sector play in regard to enhancing the quality of water?
7. How does the water quality characteristics of road runoff harvested water compare to that from other sources?

Thank you.