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List of Abbreviations

AC – Alternating Current
BTS – Base Transmission Station
DC – Direct Current
DNI – Daily Normal Irradiance
GHI – Global Horizontal Irradiance
GoK – Government of Kenya
GPS – Global Positioning System
JORC – Joint Ore Reserve Committee
Kcal – Kilocalorie
KEFRI – Kenya Forestry Research Institute
KFS – Kenya Forestry Service
KfW – Kreditanstalt für Wiederaufbau (German Development Bank)
Km –Kilometer
KMD – Kenya Meteorological Department
kW – Kilowatt
KWS – Kenya Wildlife Service
LED – Light Emitting Diode
LOWASCO – Lodwar Water and Sanitation Company
MCA – Member of County Assembly
MEENR – Ministry of Energy, Environment and Natural Resources
NEMA – National Environmental Management Authority
PPA – Power Purchase Agreement
PPM – Parts Per Million
PV – Photovoltaic
REA – Rural Electrification Authority
REMP – Rural Electrification Master Plan
RET – Renewable Energy Technology
RTI – Radar Technology International
SREP – Scaling Up Renewable Energy Programme
SWERA – Solar Wind Energy Resource Assessment
TCG – Turkana County Government
Preface
I am pleased to present this context analysis of Natural resources found in Turkana County. We should develop the abundant natural resources for the social and economic development and therefore an enhanced quality of live for our people. It is the policy of my government to enhance the welfare of the people of Turkana County and make them self reliant. This is what informed my Government to map all natural resources found in Turkana and plan how best they can be exploited for the benefit of the present and future generations. I encourage both local and foreign investors to tap these rich natural resource potential found in Turkana County for employment and wealth creation. From this mapping exercise it was found out that the County is rich in mineral resources like oil and gas, gold, graphite, garnets, gypsum, iron ore, sapphire, silver, asbestos, barytes, bentonite, beryl, bornite, calcite, chromite, corundum, galena, quartz and magnesite. These resources should be developed in a coordinated approach for the benefit of the people of Turkana County. In the energy sector there is huge potential for wind, solar, biomass and geothermal which have been dubbed green energy as they are renewable sources of energy. Potential areas for geothermal are found in Eliye spring, Koyasa, Lomonakipi spring, Muruatapa spring, Lobiritit Spring and Kapedo spring. There is rich potential for forestry expansion in Loima hills and along the rivers. The invasive Prosopis should be used extensively for commercial production of charcoal, animal fodder and bio-fuel. To enhance wildlife conservation game parks, should be delineated and gazetted, especially the Loitikipi game reserve. There is a lot of potential in fish industry on Lake Turkana which should be exploited. To ensure sustainable exploitation of the identified natural resources, relevant policies and legislation shall be drawn for water, minerals, flora and fauna, invasive species and energy which shall be the key driver in exploiting all enlisted resources.

H.E JOSPHAT N NANOK, Governor Turkana County
Forward

The Ministry of Energy, Environment and Natural Resources is mandated by the County Government of Turkana to sustainably manage all the natural resources and the environment of Turkana County, and develop renewable energy sources found within our borders like wind, solar and geothermal.

It is in this regard that the ministry deemed it necessary to map all the natural resources found in Turkana and develop relevant structures to guide sustainable exploitation of these resources for the benefit of the local community. The ministry is grateful to the Turkana County Government for making available the resources to undertake the mapping exercise. I wish also to thank the consultants, Think Right Associates, for completing this exercise on time.

I also thank all relevant stakeholders who participated in this mapping exercise especially the Energy and Environment committee of the County Assembly of Turkana County, all sub-County and Ward administrators and all local leaders across the breadth and width of the County. Finally I am grateful to my ministry staff for initiating and coordinating this important exercise which will help us plan our destiny in natural resource management.

RHODA LOYOR

CEC-Member, Ministry of Energy Environment and Natural Resources
Acknowledgement

The execution of this very strategic assignment was made possible by the entire leadership of Turkana County Government and in particular the guidance and direction of the County Executive for Energy, Environment and Natural Resources, the Chief Officer, Directors, Deputy Directors and the dedicated field officers.

The County Executive, at a strategy session at Eliye Springs, underscored her commitment to ensuring sustainable use of natural resources by the current and future generations.

We wish to acknowledge the kind support of the six major sub sectors that closely work with the Ministry: National Environmental Management Authority (NEMA), Kenya Meteorological Department (KMD), Kenya Forestry Service (KFS), Kenya Forestry Research Institute (KEFRI), Department of Renewable Energy and Kenya Wildlife Service (KWS).

Their contributions through interviews provide the very much needed broader perspective on the issues surrounding sustainable use of natural resources in Turkana County.

We recognize the input by the Catholic Diocese of Lodwar. Their contribution in especially issue of ground water was of great value and indeed helped during the actual mapping of water resources. Father Albert of Missionaries of St. Paul the Apostle made immense contribution, especially on the experience in boreholes and rock catchment in Turkana North.

The Water Resource Management Authority (WARMA) shared the latest developments, especially in regard to the planned activities for Lotikipi Basin geared towards validation the resource information using National Youth Service equipment.

We salute all the Members of County Assemblies (MCA) who made time to share very useful information on the natural resources available in their respective counties. They were led by Hon. Patrick Napion, the Chair of the Energy, Environment and Natural Resources Committee at the Turkana County Assembly and the MCA for Kaeris ward). Others were Hon. Moses Lomobong (Lake Zone), Hon. Jacob Nakuwa (Kibish) and Hon. Nicholas Ewoi (Nakalale), who was represented by his personal assistant, Mr. David Essinyen.

This list cannot be complete without recognizing the very kind support of the Sub County Administrators for their time to attend interviews with the team of consultants and offer guidance on the future of exploitation of natural resources in Turkana County.
We further register our deep appreciation for the commitment exhibited by the Ward Administrators. They indeed played a most critical role in facilitating the consulting team access their respective areas and indeed get the required cooperation by the great people of Turkana County.

The Chiefs and Assistant Chiefs across the entire county did a remarkable job by ensuring that the resource mapping teams were accorded seamless security throughout the exercise.

After the draft report was ready, the same was presented to a team of stakeholders, drawn from government, private sector, public benefit organizations, community based organizations and faith based organizations. The participants of the validation workshop held at Sand Fields Hotel on 21st May 2015 greatly contributed to the augmentation of this final report. We recognize the worthy and invaluable contributions of all the stakeholders. We register our deep appreciation to the Chief Officer, Director for Environment & Natural Resources as well as the Director for Energy for guiding the validation workshop and indeed producing minutes for the deliberations of the workshop.

And finally, to all those who facilitated the mapping process in one way or the other, we say a big THANK YOU!
Executive Summary

This report covers the details of the natural resource mapping and context analysis conducted for Turkana County in the months of April and May 2015. The report gives a detailed background on critical details relating to Turkana County. Turkana County is the second largest among the forty seven counties of Kenya and yet the poorest, with 92% poverty level. It is important to note that the mapping of natural resources was a strategic initiative of the Ministry of Energy, Environment and Natural Resources to ensure that Turkana County becomes a globally competitive and prosperous county.

This report addresses the critical and pertinent issues of water for Turkana County in great detail. The reason for the emphasis on this all important resource is because there shall not be any meaningful development in the County until the dragon of perennial and persistent water shortage is slain. This report gives a detailed coverage on both service and ground water.

Mineral resources exist in abundance in Turkana County. This report gives an exhaustive perspective of the various minerals found within the County, their relevant geology, economic use and indeed their respective locations. It is important to make the cautionary note that this report does not offer in-depth insights as to the quality and the quantity of the mineral reserves. That would require huge expenditure and engagement of internationally recognized resource assessors to issue JORC certified reports as necessary.

A natural resource mapping exercise would be incomplete without insights into the flora and fauna of the County. Chapter six gives an overview of the flora and fauna, with recommendations on necessary future actions to ensure conservation and sustainable use of the flora and fauna.

As Turkana County works at being a globally competitive and prosperous county, energy then becomes a core component in order to facilitate growth for agriculture, mining, processing and manufacturing sectors. This report dwells on the opportunities and the way forward in regard to renewable energy, with special emphasis on wind, solar, geothermal and biomass. Turkana has an awesome opportunity to invest in modern and green energy projects, buoyed by the solar irradiance, good wind speeds and existence of hot springs across the County.
Chapter 1: Introduction

Turkana County is the second largest of the forty seven (47) counties in the Republic of Kenya, covering an area of 77,000 square kilometres and lies between Longitudes 340 30’ and 360 40’ East and between Latitudes 10 30’ and 50 30’ North.

The County is located in the north-western most county in Kenya. It is bordered by the countries of Uganda to the west; South Sudan and Ethiopia, to the north and northeast; and Lake Turkana to the east. To the south and east, neighbouring counties are West Pokot, Baringo and Samburu Counties, while Marsabit County is located on the opposite (i.e. eastern) shore of Lake Turkana. Its administrative headquarters and largest town is Lodwar.

Turkana County is emerging to be a major source of electric power in Kenya. Kengen's Turkwel Hydro Power Plant, situated on the southwest of Turkana County, produces hydroelectric power which is connected to the national power grid at Lessos. The county is current subject of crude oil exploration in Block 10B and Block 13T and has potential for geothermal, solar and wind energy.

Turkana County leadership envisions “a prosperous, peaceful and just county with an empowered community enjoying equal opportunities” In order to inspire the resilient people of Turkana achieve the vision, the mission statement for the County is “to facilitate socio-economic transformation of Turkana through sustainable use of resources to ensure a high quality of life for the people of Turkana County”. It is on the basis of the Vision and the Mission statements that the Ministry of Energy, Environment and Natural Resources (MEENR) decided to facilitate the mapping of natural resources within the borders of the county. It is a well-established principle that the world over, the quality of the life of any community is dependent upon the capacity and capability of the community to tap into its natural resources in a sustainable manner.

Turkana County is considered the poorest of the forty seven counties in Kenya. Statistics from the Commission of Revenue Allocation indicate that nearly 92 percent of the population lives below the poverty line, earning less than two US dollars per day. According to the Kenya Population and Housing Census (KPHC) 2009 results, the County population stood at 855,399. It was projected to have a total population of 1,036,586 in 2012 and 1,427,797 in 2017. These projections are based on a population growth rate of 6.4 percent assuming constant mortality and fertility rates. The increase in the overall population will call for more investment in economic and social facilities such as health
services, educational facilities, agriculture and livestock sectors to provide food and employment opportunities.

Lodwar Town has the highest population projected to be 54,978 in 2012. The high number in these urban centres is attributed to more influx of people seeking employment and the availability of infrastructure and social amenities. According to the Cities and Urban Areas Act of 2012, only the above three urban centres qualify to be classified as Towns. There is need for improved infrastructural facilities and social amenities in these towns.

The physiographic features in the county include low lying open plains, mountain ranges and river drainage patterns. Lake Turkana is at an elevation of 360 meters (1,181 feet) while the surrounding basin is anywhere from 375-914 meters (1,230-3,000 feet).

The main mountain ranges of the county are Loima, Lorengippi, Mogila, Songot, Kalapata, Loriu, Kailongol and Silale mountains. The mountain ranges, because of their high elevation, are normally green, covered with dense bushes and high woody cover. The ranges support important economic activities like honey production, grazing during the dry season, wood production, and charcoal production. There are also water catchment sources thus supporting gum Arabica growing and small household shambas. The hills in the county consist of Tepes Hills in Kibish Division, Lokwanamor Hills and Lorionotom Hills in Kaikor Division, Pelekech Hills in Kakuma Division and Loima Hills in Loima Division which are characterized by large forests.

The open lying plains consist of the Kalapata and Lotikipi Plains. The plains form part of the arid area in the County and receive the lowest amount of rainfall of around 180 mm per annum. These plains are dominated by dwarf shrub and grassland, which provide forage for livestock during and shortly after the rainy season. However, this forage dries rapidly at the onset of the dry season. Rivers Tarach, Kerio, Kalapata, Malimalite and Turkwel are the major rivers in the county making them the most important with a potential of producing large amounts of food for the county, if properly utilized.

Lake Turkana is the largest and most saline of the Rift Valley lakes. There is no outlet, and with reduced inflows and high evaporation, this results into depositing of salt in the soil and capping on the surface. The water level is subject to three to four metres seasonal fluctuations. In total, the water level dropped 10m between 1975 and 1992. River Omo from Ethiopia, which is permanent, drains into Lake Turkana. The lake is situated on the eastern part
of the county, has northern island, and is endowed with a variety of wild animals namely: hippos, crocodiles and waterfowls. Fishing is the major activity for the people living near the lake.

Lake Turkana, which is a world heritage site, has a number of rivers that flow into the lake. These include Rivers Turkwel and Kerio among others that are seasonal. The County also has several springs which are scattered across the county especially parts of the lake zone, the North, the West and the East.

Turkana County is arid and semi-arid and is characterized by warm and hot climate. The temperatures range between 20ºC and 41ºC with a mean of 30.5ºC. The rainfall pattern and distribution is erratic and unreliable with both time and space. There are two rainfall seasons. The long rains (akiporo) usually occur between April and July and the short rains between October and November and ranges between 52 mm and 480 mm annually with a mean of 200 mm. The driest periods (akamu) are January, February and September. The rainfall is distributed on an east-west gradient with more rainfall in the western parts and other areas of higher elevation. The rainfalls in brief violent storms resulting in flush floods. The surface runoff and potential evaporation rates are extremely high.

Due to the low rainfall and high temperatures there is a lot of evapo-transpiration resulting into deposition of salt in the soil and capping on the surface. As a result, only about 30 per cent of the county’s soil can be rated as moderately suitable for agricultural production. These moderately fertile soils are found at the central plains of Lorengippi, the upper Loima, the lowlands of the Turkwel, Nakaton and Kawalathe drainage along the lake at the lower Kalokol, Turkwel and Kerio rivers and a portion of the Loriu Plateaus.

The county road network is poorly developed. The county has a total road network of 5,496.2 km of which 488.5 km are bitumen, and 5007.7 km earth surface. The challenges faced by this sub-sector include seasonal rivers that cut through roads and poor soils that increase the cost of road construction and maintenance. As a result, a number of roads are rendered impassable during the rainy seasons. Air transport in the county is not developed as well. There is only one airport in Lokichogio and 22 air strips across the county. Lodwar air strip runway is tarmacked while the rest are just leveled grounds whose runways are not tarmacked.

The main wildlife found in the county are; lions, cheetahs, zebras, hyenas, elephants, gazelles, dik diks, and many other small animals. These are mainly found in the game reserve in Turkana South District. There are also hippos
and crocodiles in the lake in addition to the various fish species in the lake. There exists various bird species, key among them the flamingos in Lake Turkana.

The main water sources in the county are hand dug shallow wells, piped water and river water. The access to quality water is still a big problem for the county although through the GOK/UNICEF WASH Programme, the community has largely benefitted from water dug for schoolchildren because of the high yields experienced in some areas.

The main water sources in the county are rivers; hand dug shallow wells, water pans, boreholes and rock catchment. There also exists several springs. The distance to and from the nearest water points are varied depending on the areas but on average is between 5-10 kilometres. In urban centres and some market centres, different Water Users Associations have managed to pipe water closer to settlements thus reducing the distance to the nearest water points. However, in far flung areas like Kibish, Lorengipi, Lomelo and Mogila, distances covered is much higher ranging from 10-20 kilometres.
Chapter 2: Rationale for Natural Resource Mapping in Turkana County

Natural resources are things that are available in natural state and that can be used for economic gain. Indeed, natural resources are things that are simply free un-captured gifts of nature that are useful to man. Turkana County has its natural resources and the leadership of the county government invested in mapping the same in order to positively impact on the quality of life for the great people of Turkana. The mapping of the natural resources is a critical step towards developing a natural resource management framework whose core pillars shall be responsible exploitation of the natural resources in a sustainable manner.

Natural Resource Management therefore refers to the administration of resources such as land, water, soil, plants and animals, with specific reference to how it affects the quality of life for both present and future generations as stated by the concept of sustainable development. Turkana County government intends to embrace the concept of sustainable development and ensure wise global land management and environmental governance to conserve and preserve natural resources. It is prudent to note that the demand for natural resources far outstrips the supply. This state of perennial shortage has contributed to vicious conflicts and indeed instability in many parts of the world. Turkana County government is alive to this fact and indeed plans to have an all-inclusive approach in making decisions on the best practices in the use of the identified natural resources.

The Ministry of Energy, Environment and Natural Resources envisions emerging the best in environmental conservation, technological development, weather forecasting and sustainable utilization of energy and other natural resources. In order to realize that vision, the Ministry shall facilitate accessible and reliable meteorological information and services, conservation of environment and natural resources through sustainable management and utilization of forest, wildlife and renewable energy with supervision and coordination of environmental matters, conducting research and disseminating corresponding findings for stability and socio-economic development.

In order to put in place critical, practical and relevant strategies in the management of the natural resources, MEENR commissioned the mapping of the natural resources. Given the broad nature of the assignment, and the two months period to conduct the assignment, it was agreed that the assignment would focus on mainly water and minerals, the flora and fauna as well as the potential for renewable energy.
This report therefore focused on mapping the following natural resources:

a) Water
b) Minerals
c) Forests
d) Wildlife
e) Other natural resources of commercial value to the County.

Overall, Turkana County Government achieved the following deliverables through the natural resource mapping assignment:

i. Identified and mapped indications for precious and non-precious minerals within Turkana County;
ii. Identified and mapped water sources within Turkana County and documented their current status and economic potential.
iii. Identified and mapped key wildlife and forest resources within Turkana County and a brief on economic potential.
iv. Evaluated the current and future potential for exploitation.
v. Identified the factors that worked for the exploitation of the existing resources and enlisted the gaps that hindered the community from benefiting from the existence of such resources.
vi. Developed a roadmap that shall guide Turkana County government on the best approaches for engagement with the private sector / potential investors in order to leverage on the established natural resource base.
vii. Recommended the establishment of cooperatives and other community based groups in order to have a sustainable vehicle for well-coordinated, strengthened and harmonized approach in rendering services by the local community as actors in natural resource exploitation in Turkana County.
The consultancy assignment achieved the following core deliverables:

- This report gives a clear and detailed inventory of all key natural resources within Turkana County. The detailed inventory included but not limited to the following: exact location, the relevant GPS coordinates, the nature of the resource, any potential for exploitation, recommended future interventions, etc. In mapping the resources, historical evidence for any exploitation was captured.

- Existing activities of natural resource exploitation are analyzed for purposes of impact on both the population and the environment. There have been notable artisanal activities especially in regard to gold, gemstones, dimension stone, gypsum, etc. and these specific areas were mapped and actual commercial viability of those resources examined as a revenue stream for Turkana County government.

- Existing gaps / challenges to effective and quality resource management were identified and are covered at a later stage in the report. While the assignment took inventory of the gaps and challenges, equal effort was applied to explore the strengths/assets that existed and that would facilitate the local communities tap into economic activities tied to the identified natural resources.

- Guidelines and operational strategies to establish a county specific approach in the management of natural resources for the greatest benefit of both the county and the national governments as envisaged in the constitution of Kenya.
Figure 1: Gold bearing quartz veins in Oropoi
Figure 2: A view of the Mogila Hills and its vegetation
Chapter 3: The Natural Resource Mapping Process

The natural resource mapping process was conducted over a period of forty two days. This was conducted by a team of twenty three geologists and covered twenty seven wards out of the thirty wards covering Turkana County. The wards not covered were Township and Kanamkemer because of their urban nature and Kapedo/Napeitom which was largely due to the fluid security situation at the time of the mapping exercise.

In order to elicit the desired results, the geologists were given two templates, one to cover geology and water and a second one to help understand vegetation across the county. The templates helped the geologists gather samples and data that was then analyzed and used to map the identified natural resources. It is important to note that while the geologists offered the technical assistance, the local people were of extremely great help in assisting identify unique rocks and structures as well as ground water information. They too helped in regard to getting the local names for the various vegetation types and their respective use by the community.

The community was especially resourceful in helping the geologists map important features such as hot springs hitherto not reported or captured in reports covering the geology of northern Kenya. It is critical to take further note that the community remains the single most accurate and reliable source of information in regard to matters of geology, water and vegetation.

The templates used for collecting information in regard to geology, water and vegetation, as well as an implementation matrix on the key activities of the mapping exercise are annexed at the end of this report.

This report did not engage in mapping of oil and gas as those were not within its scope, given the limited time and resources. It is important to note that Tullow Oil was contacted and indeed shared very useful information on the progress achieved as at the time of production of this report.

For example, information made available revealed that at the end of March 2015, Tullow Oil had engaged twenty three (23) contractors who delivered a wide range of services. The 23 contractors had 2,741, among them 1,776 being from Turkana County. Tullow oil is committed to the aspect of local content and this has transcended into tangible benefits for the local communities.
In 2013, the company spent Kshs. 6.1 billion (USD. 71 million) on stakeholder payments, taxes to Kenya government, expenditure with local suppliers and discretionary investment in community projects. Besides employment, Tullow oil continues to partner with Turkana County government through investments in infrastructure (schools and health facilities), water, environment, bursaries for education, solar installations, etc. Tullow Oil has an estimated 600 million barrels of discovered recoverable resource (gross) in South Lokichar basin. This is a testimony to the fact that with about five large exploration companies, the economy of the county would get a big boost and many more lives would be transformed in Turkana County.

Figure 3: One of the boreholes drilled at Lotikipi Plains
Chapter 4: Water Resources

4.0 Water Resources Availability and Potential

The main sources of water in rural parts Turkana County are unprotected dug wells, streams, boreholes and boreholes. More than half (61%) of rural households in Turkana County (n= 103,827) use unimproved water sources with majority relying on unprotected wells and streams. However the majority of these households are found in Turkana North district where 60% (n= 43,792) of rural households rely on unimproved water sources (GOK/ UNICEF WASH PROGRAMME, 2013). Water resources Potential for the county is not yet known for example no proper monitoring installations in permanent rivers and the presumed availability of groundwater only along riverlines as attested by shallow wells and boreholes drilled in the county

Access to water greatly affects food security i.e. Level of livestock production, crop production, sanitation, health and nutrition—thus consequently human productivity

4.1 Groundwater Resources

Groundwater is water that is in subsurface and only accessed by wells/boreholes and otherwise by springs when the water table reaches the ground level. Because groundwater is unseen it is commonly misunderstood for example maybe not available or maybe saline. Groundwater tapping has an initial capital resource input thus not readily accessed but is dependable with right investments.

Groundwater is a key source of water to be considered in the County which happens to located in the ASAL areas of Kenya. It is the only source of portable water in the county.
Turkana County presents all types of the major geological formations ranging from the basement mostly of metamorphic nature, igneous rocks of both volcanic and plutonic nature. It is important to note that with this kind of geology (see figure1a) all nature of groundwater potential is expected (see figure1b). This ranges from high to moderate to low and even poor groundwater potential.

The following geological formations behave in their specific ways of groundwater holding and potential;

**Geologic Formation as Aquifers**

Many types of geologic formations serve as aquifers in the world and equally are available for assessment in the Turkana County.

**Alluvial Deposits**

Probably 90% of all developed aquifers in the world consist of unconsolidated rocks, chiefly gravels and sands related to the deposits made by flowing water; washed away from one place and deposited in another. An example in the county is Lotikipi Plain which is a major basin of alluvial material and Napuu aquifer located in highly permeable strata bordering the Turkwel River, thus presents wells which are producing large quantities of water, as infiltration from the river augments groundwater supplies. The recharge of Lotikipi plains aquifer needs to be established, with Napuu facing the same, though suspected to be recharged from the Turkwel River.
**Limestone**

Limestone varies widely in density, porosity and permeability depending on the degree of consolidation and development of permeable zones after deposition. Openings in limestone may range from microscopic original pores to large solution caverns forming subterranean channels sufficiently large to carry the entire flow of a stream. The term lost river has been applied to a stream that disappears completely underground in a limestone terrain. Dissolution of calcium carbonate by water causes hard groundwater to be found in limestone areas. Also by dissolving the rock, water tends to increase the pore space and permeability with time. Karst terrain, characterized by solution channels, closed depressions, subterranean drainage through sinkholes and caves are common in limestone areas.

The county has massive reported deposits of limestone ranging from Metamorphosed limestone (marble), pure limestone and kankar limestone. All these formation of lime presents potential aquifers which calls for investigations and assessments. These areas of interest include some parts of Lokiriama for crystalline limestone, Kaeris for kankar limestone and parts of Kaptir for metamorphosed limestone.

**Volcanic rocks**

Volcanic rocks can form highly permeable aquifers; basalt flows in particular often display such characteristics. The type of openings found in basalts include: interstitial spaces at the tops of flows, cavities between adjacent beds, shrinkage cracks, lava tubes, gas vesicles, fissures resulting from faulting and cracking after rocks have cooled and holes left by the burning of trees overwhelmed by lava. An excellent example of a highly permeable volcanic rock is in Nicaragua, where a circular lake contained in an extinct crater, serves as the major municipal source and yields 75 000 m3/day. There is no surface
inflow and evaporation exceeds precipitation; hence, the lake, fed entirely by groundwater acts as a large natural well.

The volcanic areas of Kawalathe, and Katilia are formations of Upper Miocene which presents minimal faulting thus are likely to have moderate groundwater potential. Nabulukuk area presents highly faulting volcanic rocks thus are high groundwater potential formations.

**Sandstone**

Sandstone and conglomerates are cemented forms of sands and gravels. As such, their porosity and yield have been reduced by the cement. However, sandstones can yield water if they are fractured and jointed. Sandstone and conglomerates otherwise referred to as Turkana grits which from the geological mapping and structural geology presents a highly fractured and jointed nature. This place covered by these includes areas around Gold (junction) in Nakalale ward. One of the Key aquifers mapped by ITR is found in this area.

**Igneous and Metamorphic rocks**

In solid form, they are relatively impermeable and hence serve as poor aquifers. However, where weathering or fracturing have taken place, the weathered or fractured materials can serve as good aquifer depending on the degree of weathering and fracturing. Precambrian intrusives in this county are found western bordering Uganda.

The areas of Kaptir are majorly of Mozambique belt of crystalline limestone and quartzites, areas between Lokichar and Loichangamatak hills presents formations of Mozambique belt of gneisses and schists. The schist forms good aquifers but the gneisses and quartzites highly depend on level of weathering and fractures.
Clay

Clays are generally porous, but their pores are so small that they may be regarded as relatively impermeable. The areas between Koyasa and Kibish present such clay formations. Surveying there is indicative groundwater potential but on drilling, one gets mud, thus this calls for specialized surveying to be able to distinguish clay or mud from water, for the two behaves almost the same on resistance to current.
Figure 4: Geological Map of Turkana County
Figure 5: Ground Water Potential Map - Overlaid on Geological Map of Turkana
4.1.1 Borehole and Well Location Surveys

With the advent of Global Positioning System (GPS) equipment and software, well location surveys have become easier and more accurate. Using the GPS receiver, employees can locate wells and other objects within 2 to 5 meters of their actual position.

The latitude and longitude collected by the GPS receiver is corrected to this high accuracy using data from one of the three NC Geodetic Survey’s GPS base stations. Well locations are used in maps, cross-sections, and ground water flow models produced by the Section.

Water level data is useless unless we can accurately fix the position of the monitoring well from which it came. For this purpose, we utilize Global Positioning Satellite (GPS) units to derive accurate coordinates of our monitoring well locations. GPS works by triangulating locations on the earth using three to five GPS satellites.

The above exercise of well and borehole locations enabled the team to understand and project the groundwater resources accessibility per ward in the county.

The spatial distribution of the water accessibility by wells and boreholes is as discussed below. This also equally covers areas where there has been rock catchment development in the county.

The groundwater abstraction of the county through the use of shallow wells and boreholes is majorly guided by geological structural orientation. This structural orientation determines the topography and hence surface water flow direction.

Groundwater by wells is either by having shallow wells dug in the river bed or dug by the river. The shallow wells dug in the river are only useful during the dry season thus temporal. The ones dug by the river are permanent sources
but tend to dry up with prolonged drought. This can be seen from the skewed nature of distribution of the wells across the county (see figure 6).

The distribution of boreholes as indicated by the figure 1d is largely showing that the boreholes are dug on fault zones. These happen to be same zones controlling the surface water flow. Thus most of the boreholes are dug near river lines.
Figure 6: Distribution of Shallow Wells across Turkana County
Figure 7: Distribution of Boreholes in Turkana County
The groundwater accessibility by use of shallow wells is restricted to river lines and in areas where there are settlements. This limits access of water to grazing communities and their livestock. Consequently, this necessitates walking of long distances to get water for livestock accessing pastures in areas away from the settlements. The boreholes have also been used in the ward in a sparse way to access groundwater. Most are also confined to river lines and by the roadsides. A few have also been drilled by considering the geological structural orientation of the areas, for example the Nadome borehole of coordinates Lat. 4.2045653 and Long.34.3810955, Kalapata primary school waypoint of coordinates Lat.2.332382 and Long.35.836723., Kaikor mission borehole of coordinates Lat.4.516645 and Long. 35.422629908124., Naodos water point of coordinates Lat. 3.691547345 and Long. 34.934441 and Kang’amanang’it water point of coordinates Lat.3.73664875 and Long.34.943066., Kadokornyang water point coordinated Lat. 3.45195743 and Long. 35.78279906. The distribution of the shallow wells and boreholes is shown in Figures 6 and 7.

4.1.2 Groundwater Potential

The groundwater potential is evaluated by determining Boreholes Specific Capacities (S), Transmissivities (T) and Specific Yields/Storage Coefficients, Hydraulic conductivity (K) and these have roughly been determined in appendix 2.

4.1.2.1 Boreholes Specific Capacities (S), Transmissivities (T) and Specific Yields/Storage Coefficients

The boreholes specific capacities have been calculated based on the formula $S = \frac{Q}{s}$ (Driscoll, 1986), where $Q$ is the yield during the pump test and $s$ is the drawdown i.e. PWL-WRL. Transmissivity on the other hand is calculated using the formula $T = 0.183 \frac{Q}{s}$. However, this formula is applicable where well test data is available in log scale.
However, the available data from the Ministry of Environment, Water and Natural resources only provides data in summary of form, and thus the above formula is of little use. It is however possible to estimate the transmissivity using the Logan’s formula (Logan, 1964) i.e. $T=1.22 \frac{Q}{s}$. A drawback of this estimate is that it may lead to overestimation of the Transmissivity; nevertheless it gives a fair indication of the same.

The Modified Non-Steady State flow equation relies in a change in drawdown on a laminar scale with the log cycle of time and is independent of the magnitude of the drawdown. Thus, $T=2.3\frac{Q}{4\pi\Delta s}$, where $T=$Transmissivity, $\Delta s=$Drawdown per log cycle. Reliable data was not available from boreholes for proper analysis of the test pumping parameters within the surveyed area.

4.1.2.2. Hydraulic Conductivity (K)

Hydraulic conductivity and groundwater flux can only be accurately determined by time-consuming and expensive methods like pumping tests or sampling, isotope methods and laboratory investigations. The results are confined to few locations, and they depend on the scale of the investigation method. Measurements on rock samples in the laboratory can differ significantly from well test result. The paucity of the data available from the Ministry of Water and Irrigation further complicates the situation. However, a simple estimation of hydraulic conductivity can be derived from the formula $T=kD$ which can be rearranged to $k=T/D$, where $k$ is the hydraulic conductivity, $T$ is the transmissivity, and $D$ is the aquifer thickness. A drawback to this estimation in this case however is the cumulative aquifer thickness which is recorded at the strike point rather than as an interval.
1.2 Surface Water Resources

1.2.1 Rivers

Surface water availability is achieved by establishment of rock catchments. These are distributed as shown in the map of figure 1.2a.

Figure 8: Rock Catchments in Turkana County
These are concentrated in the northern part of the county where the area is well endowed with mountain ranges and thus forms gorges which have been utilized effectively. The water has been controlled by concrete weirs and is useful in serving the community.

Notably, surface water from the seasonal rivers is accessed by the community during the rainy season, and also accessed by digging holes in the sandy areas of riverbed to access water during the dry season. This water is not portable and hence the communities as exposed to water borne diseases. Despite the dry nature of the county in most parts of the year, there are a few permanent rivers including the Turkwel river, Kerio river, Elelea irrigation canal, Nabwanyang river, Nawoyawoi river.

Thus important abstraction points exist on these rivers purposefully for irrigation and are presented in table 1 and figure 9. These river abstractions are key to irrigation and a case of that potential is shown in table 2. The process of water movement to irrigation farms is user friendly in that it is achieved by gravity and hence there should be an effort to encourage the communities living around the river to practice irrigated farming.

Table 1: Name of Water Source / Point and Division

<table>
<thead>
<tr>
<th>Division</th>
<th>Name of water source/point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lokori</td>
<td>Elelea irrigation canal</td>
</tr>
<tr>
<td>Turkwel</td>
<td>Kalemunyang irrigation scheme</td>
</tr>
<tr>
<td>Kakuma</td>
<td>adome water point</td>
</tr>
<tr>
<td>Turkwel</td>
<td>Nabwanyang river abstraction point</td>
</tr>
<tr>
<td>Turkwel</td>
<td>Nawoyawoi river abstraction</td>
</tr>
<tr>
<td>Oropoi</td>
<td>Letea water absraction</td>
</tr>
<tr>
<td>Lokori</td>
<td>Lokuba irrigation scheme</td>
</tr>
<tr>
<td>Lokichohio</td>
<td>Nanam water point</td>
</tr>
<tr>
<td>Turkwel</td>
<td>Naremit</td>
</tr>
<tr>
<td>Lokori</td>
<td>Kerio river</td>
</tr>
</tbody>
</table>
Table 2: Irrigation Potential at Several Locations along Turkwel River

<table>
<thead>
<tr>
<th>Intake location</th>
<th>Water Abstracted</th>
<th>Source of water</th>
<th>Method of intake</th>
<th>Irrigation Area</th>
<th>Major crops</th>
<th>Year initiated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalemunyang</td>
<td>0.0374 m³/sec</td>
<td>Turkwel river</td>
<td>Gravity</td>
<td>160 (ha)</td>
<td>Sorghum,</td>
<td>1985</td>
</tr>
<tr>
<td>Kabulokor</td>
<td>0.0534 m³/sec</td>
<td>Turkwel river</td>
<td>Gravity</td>
<td>135 (ha)</td>
<td>Cowpeas,</td>
<td>2004</td>
</tr>
<tr>
<td>Nanyee</td>
<td>0.0884 m³/sec</td>
<td>Turkwel river</td>
<td>Gravity</td>
<td>60 (ha)</td>
<td>Green grams</td>
<td>1997</td>
</tr>
<tr>
<td>Napeikar</td>
<td>0.0454 m³/sec</td>
<td>Turkwel river</td>
<td>Gravity</td>
<td>48 (ha)</td>
<td></td>
<td>2005</td>
</tr>
<tr>
<td>Kangalita</td>
<td>0.0454 m³/sec</td>
<td>Turkwel river</td>
<td>Gravity</td>
<td>100 (ha)</td>
<td></td>
<td>2005</td>
</tr>
<tr>
<td>Nakamane</td>
<td>0.0534 m³/sec</td>
<td>Turkwel river</td>
<td>Gravity</td>
<td>144 (ha)</td>
<td></td>
<td>2010</td>
</tr>
<tr>
<td>Nadapal</td>
<td>0.0303 m³/sec</td>
<td>Turkwel river</td>
<td>Gravity</td>
<td>40 (ha)</td>
<td></td>
<td>2011</td>
</tr>
<tr>
<td>Naoros</td>
<td>0.0433 m³/sec</td>
<td>Turkwel river</td>
<td>Gravity</td>
<td>80 (ha)</td>
<td></td>
<td>2011</td>
</tr>
</tbody>
</table>
Figure 9: Water Abstraction Points from Permanent Rivers for Irrigation Purpose
1.2.2 Springs

A spring is any natural situation where water flows from an aquifer to the earth's surface. It is a component of the hydrosphere. There are different types of springs including Seepage or filtration spring. The term seep refers to springs with small flow rates in which the source water has filtered through permeable earth. Fracture springs, discharge from faults, joints, or fissures in the earth, in which springs have followed a natural course of voids or weaknesses in the bedrock. Tubular springs, in which the water flows from underground caverns.

Turkana County presents several springs running from cold to warm to hot springs. The warm springs include; Eliye Springs, also known as Ille Springs. This is a remote village on the western shore of Lake Turkana in Kenya, near the mouth of River Turkwel. Nearby the spring is the Eliye Spring Resort. It is located 50 kilometres east of Lodwar and 40 kilometres south of Kalokol. Koyasa warm spring is found in the North in Kibish ward.

The hot springs include; Lomonakipi spring hot spring in Kibish, Muruatapal hot spring, Lobiritit hot spring and Kachapo hot spring in Latea and the Kapedo hot springs.

The county also presents a number of cold springs, for example one in Nakurio in Kerio Delta.

1.2.3 Lake Turkana

Lake Turkana is the largest lake in the eastern portion of the Rift Valley and the fourth largest lake by volume in Africa (Beadle 1981). Lying in a low closed basin at approximately 365 m above sea level, the lake is situated primarily in northwestern Kenya, with only its northernmost end, the Omo Delta, inside Ethiopia. Of the twelve principal rivers that feed Lake Turkana, the River Omo is its only perennial tributary, supplying over 90% of the lake’s inflow (Beadle 1981). The Omo River drains the southwestern portion of the Ethiopian Massif and flows through the Rift Valley into Lake Turkana. Of the seasonal rivers that flow into the lake, the Turkwel and Kerio Rivers are the largest contributors and enter the lake along its western edge and in its southern half (Hughes & Hughes 1992).
1.3. County Water Salinity

The salinity of Lake Turkana is higher than that of any other large African lake. This is due to the fact that the lake has no outlet, and that it has contracted in volume over the last 7,500 years. Very recent volcanic activity in the basin has also contributed to the high salinity of the lake (Beadle 1981). Water samples taken between 1931 and 1975 record salinity as ranging from 1.7-2.7‰ (Hughes & Hughes 1992; Spigel & Coulter 1996). The mean conductivity is about 3500 µS/cm, with an estimated rise of about 0.45 µS/cm/yr (Ferguson & Harbott 1982). Due to the volcanic origin of the catchment area the water chemistry is dominated by sodium (more than 95% of the cations by weight) and bicarbonate, which generate a high alkalinity (pH > 9.3). The seasonal inflow of water, coupled with strong diurnal wind patterns, keep the waters of Lake Turkana productive and well mixed. In fact, the oxygen content of Turkana’s deepest water is never less than 70% (Beadle 1981).

The salinity of the other sources like rivers, shallow wells and boreholes could not be established.
Chapter 5: Mineral Resources

5.1 Background Information

Turkana County share almost similar geological formations and structure with the neighbouring countries: Uganda, Ethiopia and Sudan. This is so because the structural evolution, tectonics and volcanism which culminated in the present rock types and structures took place almost at the same time span. The county is traversed by the extensive Eastern African Rift System, which equally traverses through Tanzania and Ethiopia on the east and through Uganda on the west. It is no wonder then that it is within this structure and deep basins of sedimentary deposits outside it that some prospects of oil and gas deposits are manifested. The cratonic masses bordered by this huge rift structure take the share of many types of metallic and non-metallic mineral deposits and materials.

This report is a synthesis of works of reviewing the geology and deep analysis of the metallic and non-metallic minerals and gemstone occurrences in Turkana County.

5.2 Geology of Turkana County

5.2.1 Basement

The crystalline rocks of the Basement System cover wide areas of the country, and are particularly extensive in the eastern half. They comprise principally various types of sediments-grits, sandstones, limestone and shale that have been metamorphosed into gneisses, schist and marbles by heat and pressure or by impregnation by pervading fluids. Other types are derived from lavas and volcanic fragmental rocks.
Igneous rocks are relatively scarce and consist of granite sheets and dykes, and sills of epidiorite and amphibolite derived from originally doleritic or allied rocks, and some ultrabasic rocks. Some are apparently of later date than the metamorphism of the sedimentary hosts, but are probably Precambrian in age.

The variety of rocks in the sedimentary series is extensive and includes, besides widespread mica- and mica-hornblende schists and gneisses, such types as graphite schists, kyanite gneisses, garnet gneisses and schists, sillimanite gneisses, pyroxene granulites, quartzites and crystalline limestones. Other and rare kinds include actinolite schists, anthophyllite schists, and epidolite schists and gneisses. In some areas there are considerable developments of migmatites, which have arisen by the injection of granitic magma into the gneisses and schists, or by their permeation by granitic fluids. Several granites of northern and northwestern Kenya are considered to be the products of granitization of metasediments. Pegmatites of various types are frequently associated with the Basement System rocks, particularly where metasomatic action has been prominent.

The crystalline limestones form notable bands and lenses, often of considerable thickness and length, though some are small. A series of outcrops extends discontinuously through the central part of the county.

**5.2.1.1 Gneisses**

i. Pelitic gneisses

a. Biotite-kyanite gneisses

This is most abundant and distinctive rock type and passes laterally from a semi-pelitic biotite gneiss in the south to a kyanite-bearing biotite gneiss. The hand specimen is a grey brown, fine-grained rock with large blades of kyanite
set in a quartzo-felspathic matrix, with a foliation produced by numerous plates of biotite with lesser amounts of muscovite arranged in parallel layers.

The thin section contains only small crystals of kyanite oriented parallel to the biotite. Orthoclase, which is the most abundant leucocratic mineral, is accompanied by quartz and rare albite, and magnetite and apatite are accessory. Large blades of kyanite associated with yellowish quartz noted at the eastern bank of the Kabokuli River.

A garnetiferous variety of kyanite-biotite gneiss is found as a lens within biotite gneiss on the south bank of the Loolung River. It is a friable rock, of reddish-brown colour due to iron staining. Small garnet porphyroblasts and blades of kyanite deflect the foliation which is picked out by flakes of biotite.

Under the microscope the garnet is seen to occur chiefly as porphyroblasts, with smaller grains enclosed in the quartzo-felspathic layers. The garnets are chloritized along cracks and contain inclusions of quartz-felspar and iron ores.

The kyanite occurs as 'large porphyroblasts elongated parallel to the foliation and unaffected by other constituents. The quartz and felspar, mainly orthoclase with a little oligoclase, form small iron-stained patches with a granulose texture. It is this feature as much as the porphyroblasts which gives the rock its nodular appearance and friable character.

In some places epidote is abundant as an accessory and magnetite occurs most frequently near the garnet crystals, while chlorite patches enclosed by iron staining may represent altered garnets.

b. Sillimanite Gneisses

This group occurs only in thin discontinuous bands in the biotite-kyanite gneisses, especially towards their base. It is a silver-grey, medium-grained friable rock, the foliation of which is produced by layers of mica, chiefly biotite,
and felts of sillimanite needles. The leucocratic layers consist of quartz with some orthoclase and a little albite; magnetite is accessory.

ii. Biotite Gneisses

The rocks included in this group are well foliated, fairly fine-grained gneisses with a conspicuous development of dark biotite on foliation surfaces. Biotite gneisses and related types are the most abundant of the Basement System rocks and show a considerable variation in grain size, nature of foliation, in the quantity of biotite present and the degree of granitization.

Accessory minerals include epidote, muscovite, apatite and iron ore and secondary calcite is also present.

iii. Hornblende-Biotite Gneisses

This group of semi-pelitic gneisses is represented in the area by one thin band outcropping at the trigonometrical beacon of Tukum. The rock lacks foliation and is fine grained, grey in colour but speckled with darker ferromagnesian minerals. Sphene, epidote and apatite are accessory.

iv. Hornblende Gneisses

Are medium-grained rocks with alternating bands of hornblende and quartzofelspathic minerals which are more distinct than those of the average plagioclase amphibolites. Epidote and sphene are important as accessories in with a small amount of magnetite, which is more abundant where apatite is found.

v. Granitoid Gneiss

The only granitoid gneiss exposed in the area is that which farms a roughly circular area same 25 square miles in extent just south-east of Perra and includes the rugged tar af Emurucharod. Foliations within the granitoid gneiss are uncommon and rather vague, while the relationship between the margin af
the granitaid gneiss and the surrounding rocks is not known, due to lack of contact exposures. Although the mapped boundaries of the granitoid gneiss must be generally regarded as approximate there is no linkage of the granitoid gneiss with the banded Basement System rocks to the south but it occupies a stratigraphical position analogous to the pelitic gneisses of the Karsit-Morundirin group. The Emuruchorod granitic or granitoid gneiss can alternatively be regarded as an intrusion into the Basement System.

vi. Pegmatites

Pegmatites mostly occur in the eastern part of the area, especially to the east of the Turkana fault. Intrusive cross-cutting pegmatites greatly predominate over smaller concordant ones, most of which are identical petrologically. Under the microscope the most abundant feldspar is seen to be altered and sericitized orthoclase with subsidiary clearer albite and a little microcline. Some small grains of quartz are interstitial to the feldspar and small flakes of biotite sometimes accompany the muscovite. Small quantities of magnetite and epidote are accessory.

For the more sodic pegmatities, sericite and disseminated iron ores are contained within the feldspar while there are some larger grains of accessory magnetite.

vii. Amphibolites

Are dark green, fine-grained rocks composed mainly of laths of hornblende whose orientation gives a good foliation. Under the microscope the hornblende is seen to be a pale green variety which is less pleochroic than that of the plagioclase amphibolites. The small grains of plagioclase which are interstitial to the hornblende were determined as calcic andesine. Sphene, magnetite and apatite are accessory.
ii. Psammitic gneisses

The rocks which are included in this section are those which are believed to have been formed from arenaceous sediments, mainly sandstones and arkoses, which are represented by quartzites and quartz-felspar gneisses respectively.

5.2.1.2 Turkana Grits

Are a series of pebbly conglomerates, felspathic grits and sandy shales. In the Lorugum area Turkana Grits are exposed on the west bank of the Turkwel River about 16 miles south-east of Lorugum and in the bend of a small river cutting three miles to the west of the Kabarat Hills north of Lorugum.

The Turkana Grits appear to have been derived completely from Basement System rocks, and would thus agree with Mason and Gibson's definition of their lower group of sediments. A typical specimen, from the Turkwel exposure, is a coarse conglomeratic grit mainly composed of quartz, microcline and sodic plagioclase in carbonate cement. Accessory minerals include hornblende, epidote, garnet and augite.

Occurring within the Turkana Grits on the Turkwel River there is a small circular patch of basalt which appears to be of intrusive origin.

Also wide spread of the Turkana grits is observed in Nakalale area where they are the hosts of gold deposits.

5.2.2 Volcanic

i. Augite and Analcime Basalts

These are the oldest volcanic rocks which are generally fine-grained basalts which overlie the Turkana Grits. This volcanic series of basalts tend to weather fairly rapidly by mechanical breakdown on joints and fractures, which reduce much of the mass of the exposed rock to small boulders and cobble which in
their turn suffer surface weathering and alteration. For this reason the topography of outcrops of the lower basalts is generally a series of low rolling hills.

Examination of the outcrops of the basalts showed analcime in the groundmass. Augite occurs as phenocrysts within the groundmass composed of andesine-labradorite, enstatite-augite and magnetite, with a small amount of interstitial analcime.

Geodes ranging in size from a fraction of an inch to several feet across are found in the basalts, particularly at lower levels. Such geodes consist of calcite, quartz and semi-crystalline or amorphous silica minerals such as agate and chalcedony. Calcite and silica minerals also occur as nodules and veinlets, and their occurrence, together with the characteristic deep weathering of the basalt, is thought to be due largely to submersion beneath the lake in which the intravolcanic sediments were deposited.

**ii. Phonolites and Nephelinites**

These formations are found as pockets in the south central part of the project area. A typical phonolite rock found in the area is medium grey in colour with no visible phenocrysts. In thin section it is seen to contain rare microphenocrysts of nepheline, partly altered to sodalite, and turbid anorthoclase feldspar set in a fine-grained groundmass of green aegirine-augite, anorthoclase and nepheline.

Southern part of the area is a series of plugs, with minor lava flows, which are almost circular in outline, which have been forced upwards through the lower basalts. The rock of the plugs is distinctive in having a much lighter colour, being of various shades of grey and greenish grey, occasionally buff and light red.
These rocks as observed in a plug near Kanukurdio has rare glassy phenocrysts of anorthoclase in a medium-grained ground mass of anorthoclase, aegirine-augite, riebeckite and cossyrite, again with interstitial nepheline.

The nephelinite is of medium grain, with an off-white groundmass supporting spherical clusters 2 to 3 mm. across of greenish grey mafic minerals. The groundmass of this rock is of nepheline and replacive sodalite, with enstatite-augite and green aegirine-augite and small amounts of sphene and magnetite. The other type of nephelenite found in the area is a black coarsely porphyritic rock, which in thin section shows phenocrysts of purple-grey titanaugite with sphene and magnetite, in a groundmass rich in euhedral crystals of nepheline with laths and grains of green pyroxene and subhedral magnetite. The whole is stained with red-brown iron oxide.

**iii. Olivine Basalts**

These type of rocks are widespread in the northern part of the area and the outcrops of olivine basalts are generally coarsely porphyritic. Regular and well-marked jointing is locally a feature of the olivine basalts. It is believed that the olivine basalts represent a locally developed basic phase occurring towards the end of the extrusion of the older basalt series, and that olivine basalts were locally being extruded on an already eroded surface of the lower basalts. The olivine basalts are of medium to coarse texture, dark blue-grey or black in colour, with phenocrysts up to 0.5 cm. across of pyroxene, olivine and plagioclase.
iv. Rhyolites

These are acid lavas which tend to be more resistant to local conditions of erosion, with the result that they often form protective caps on hills of basalt and pyroclastics. Fault scarps in rhyolitic lavas tend to be vertical or near-vertical due to the breaking away of sheets of rock at strong vertical joint planes. The rhyolites of the area of study area are found to the northern central and these are found capping all the major mountain ranges of the area. The rhyolites are always of a light colour, in shades of buff, yellow or pale grey, sometimes stained red-brown by iron oxides. Alteration of the lavas in the form of iron ore replacement of much or all of the coloured minerals is widespread. In some instances in thin section the coloured minerals of the groundmass are completely altered to a black or dark chocolate brown iron mineral in mossy aggregates.

5.2.3 Tertiary and Younger Sediments

i. Lake Beds

These rock formations are found to the eastern part of the County, but this part was not covered during the sampling time. These are sediments of the Lake Rudolf basin (Lake Turkana) and according to Walsh and Dodson (1969) the formations comprise a series of lacustrine deposits dating from the Pleistocene and continuing into the recent period.

ii. Superficial Limestone

Various localities flanking the Lodwar-Lokitaung road ideally from Kanukurdio to Kaeris are broad flat expanses of nodular pea-sized kunkar limestone of varying shades of off-white and pink, sometimes with a heavy admixture of soil and sand but more often virtually pure limestone. This rock formation was sampled as M33 from point of UTM coordinates 36N 0773500, UTM 0431835.
iii. **Sandy Soils**

These deposits are divisible into two main groups, deep red, often well compacted, sandy soils derived wholly from Basement System rocks, and generally buff to grey, occasionally light red, fine-textured and powdery sandy soils derived mainly from lavas.

The mapping exercise was akin to identifying the mineral occurrence in Turkana County as per the collected data. Discussed below is a broad list of minerals of which their levels of occurrence indicates potential that warrants further detailed work to establish their quantities and hence their economic potential.

**5.3 Mineral Occurrence**

Mineral occurrences have a close relationship with geology, historical occurrences like metamorphism, volcanicity, faulting and folding, not forgetting sedimentation processed from weathered and eroded materials. Thus mineral will be formed as primary or secondary. The igneous process induces primary mineral forming process. Metamorphism and sedimentation induces the secondary process of mineral formation. The minerals adduced from the natural resources mapping exercise originates from the three rock forming processes. Some mineral are related to igneous activity, some to sedimentary rock formations and equally some from metamorphism. The minerals mapped are in figure 10. A summary of some key coordinates are detailed later in Table 3.
Figure 10: Mineral Map for Turkana County
I. **Asbestos**

There are several minerals which may be considered under this heading but only one, anthophyllite, occurs in Turkana County.

Asbestos is a commercial and industrial term describing a group of specific silicate minerals that forms bundles of long, very thin mineral fibres. The form and structure of these fibres is called asbestiform. In addition to asbestos, there are additional minerals that are asbestiform including winchite and richterite that are not technically considered asbestos.

A characteristic shared by all the minerals of the asbestos group is the fibrous nature of the crystals. In some varieties, but not anthophyllite, these may have sufficient length and tensile strength to be spun into thread for use in the manufacture of fabrics having good fire-resistant and heat-proof properties.

Asbestos is most commonly found in three rock types: serpentinites, altered ultramafic rocks, and some mafic rocks. Other rock types known to host asbestos include metamorphosed dolostones, metamorphosed iron formations, carbonatites, and alkalic intrusions. Contributing to asbestos formation is the faulting and fracturing of these rocks with increased temperatures, pressures, and the presence of water. The amount of asbestos or asbestiform minerals in these rocks can range in size from commercial-grade ore bodies to thin impure veinlets or low-grade occurrences.

Occurrence: Anthophyllite here is associated with metamorphosed carbonatites found in the southern part of Lokichar. Anthophyllite in the county is found associated with metamorphosed dolostones, metamorphosed iron formations, carbonatites, and alkalic intrusions. Contributing to asbestos formation is the faulting and fracturing of these rocks with increased temperatures, pressures,
and the presence of water, and the faulting is observed from the geological map.

The chief use for anthophyllite is as an ingredient in insulated boiler coverings, fireproof paints and, mixed with cement, in the production of asbestos-cement roofing-sheets, pipes and similar goods. In recent years much research has been done into its uses as a filter aid. The serpentine bodies are also found in the Loperot area.

**Impacts of Mining Asbestos** - If products containing asbestos are disturbed, the tiny fibers are released into the air. When they are breathed in, they can become trapped in the lungs and stay there for many years. Over time these fibers can accumulate and lead to serious health problems, including: Asbestosis, an inflammatory condition of lungs that can cause shortness of breath, coughing, and eventually scarring of the lungs that makes it hard to breathe. Mesothelioma, a rare cancer that affects the lining of the lungs, chest cavity, or abdomen and Lung cancer. Other lung problems, including pleural plaques (changes in the membranes surrounding the lungs), thickening of the membranes that surround the lungs, and pleural effusions (abnormal collections of fluid between the lungs and the inside wall of the chest.

II. **Barytes**

This is the name given to natural barium sulphate, a heavy white mineral used in the manufacture of paints, drilling muds, as filler, and as an ingredient in glass making.

Barium, which is slightly harder than lead, has a silvery white lustre when freshly cut. It readily oxidizes when exposed to air and must be protected from oxygen during storage. In nature it is always found combined with other
elements. The mineral is found in the south of County in the Lokichar area associated with sulphates found south like the gypsum terrain.

The metal is used as a getter in electron tubes to perfect the vacuum by combining with final traces of gases, as a deoxidizer in copper refining, and as a constituent in certain alloys. The alloy with nickel readily emits electrons when heated and is used for this reason in electron tubes and in spark plug electrodes.

**Bentonite**

The name bentonite is applied to a variety of clays, buff to olive-green in colour, characterized by their property of adsorbing water to a greater extent than ordinary plastic clays, and by a much greater capacity for base-exchange than that possessed by kaolinitic clays.

Bentonite is defined as a naturally occurring material that is composed predominantly of the clay mineral smectite. Most bentonites are formed by the alteration of volcanic ash in marine environments and occur as layers sandwiched between other types of rocks. The smectite in most bentonites is the mineral montmorillonite, which is a dioctahedral smectite but occasionally other types of smectite may be present. It is the presence of smectite which imparts the desirable properties to bentonites, although associated factors such as the nature of the exchangeable cations in the interlayer also affect properties. For example naturally occurring bentonites with Na+ as the interlayer cation can have very different properties to bentonites where the interlayer cation is Ca++. Most commercial bentonites contain more that 80% smectite, however, a wide variety of other minerals may occur as impurities. The image on this page shows a geosynthetic liner with bentonite granules as fill.

The main uses of bentonite are for drilling mud, binder (e.g. foundry-sand
bond, iron ore pelletizer), purifier, absorbent (e.g. pet litter), and as a groundwater barrier. (As of around 1990, almost half of the US production of bentonite was used for drilling mud).

The adsorption of water by certain bentonites is accompanied by a considerable increase in volume and the formation of a gelatinous mass. This property is utilized for controlling the viscosity of oil-well drilling muds. Other uses include its employment as an emulsifying agent for asphaltic and resinous substances; in soap, paints, and pharmaceutical products; as a plasticizer in ceramic bodies and in the refining of petroleum products, vegetable oils fats and greases.

**III. Beryl**

Beryl is a relatively rare silicate mineral with a chemical composition of Be₃Al₂Si₆O₁₈. It is found in igneous and metamorphic rocks. The beryl here is contained in the Precambrian metamorphic rocks carbonaceous shale, limestone, and marble have been acted upon by regional metamorphism. The beryl resource is found in the proximity of LOICHANGAMATAK HILLS in the southern part of Lodwar town.

The major economic interest in beryl today is its use as a gemstone. It is one of the most important gem minerals, and the gems are named by their color as emerald (green), aquamarine (greenish blue to blue), morganite (pink to orange), red beryl (red), heliodor (yellow to greenish yellow), maxixe (deep blue), goshenite (colorless), and green beryl (light green). Emerald and aquamarine are the most popular. This mineral is an alumino-silicate of beryllium with chemical composition Be₃Al₂Si₆O₁₈ and constitutes the chief ore of the metal, which is an important element in certain alloys which have the hardness of steel but which are non-magnetic and non-sparking. They are used extensively for making bearings, marine propeller blades, watch and clock springs, cams, and a variety of products demanding a material of high tensile strength,
hardness, and absence of elastic creep. Beryl itself may be used directly in the production of certain specialized ceramics having high electrical resistance and capable of withstanding strong mechanical shock.

Emeralds are gem-quality specimens of beryl that are defined by their green colour. Aquamarine is the second most popular gem beryl. Like emerald, its identity is defined by its colour. Aquamarine has a distinct greenish blue to blue colour. Morganite, also known as “pink beryl” and “rose beryl,” is a rare variety of beryl that ranges in colour between yellowish orange, orange, pink, and lilac

IV. **Bornite**

This mineral is a sulphide of iron and copper and is an important ore of the latter metal. In colour it is copper-red to brown with a metallic lustre, but is usually tarnished. It has been identified together with other copper minerals in Basement System rocks. Indications of heavy copper staining was seen in amygdaloidal basalt and conglomerates in some of the areas like as noted in sample M30 (36N 0788743, UTM 0415542) which is a rock sample brownish and greenish intercalation suspected to be iron-copper ore. Occurrence of copper mineral is documented at Kaakelae, at Kaaleng-Kaikor border.

Modern uses of copper are many and varied. Much of the pure metal is absorbed by the electrical industry in the form of wire bar and sheet. It is the basis of numerous industrial alloys such as brass, gunmetal, speculum, bronze, and bell metal. Cupro-nickel is widely used in "silver" coinage, e.g. the East African shilling. So-called "copper" coinage consists chiefly of copper with small quantities of zinc and tin. Powdered copper is used extensively in powder metallurgy and as a constituent of anti-fouling paints. In agriculture, copper sulphate and other copper compounds are used as fungicides and insecticides.
Bornite and chalcopyrite disseminations in quartz veins are recorded from one mile south of LOKICHAR in Turkana. Further to the north in KARASUK copper indications occur in the Kamila Valley. The copper minerals, bornite accompanied by secondary cuprite, covellite, azurite and malachite, were found disseminated in quartz veins, amphibolites and talc-chlorite schists.

Copper is one of the most ductile metals, not especially strong or hard. Strength and hardness are appreciably increased by cold-working because of the formation of elongated crystals of the same face-centred cubic structure that is present in the softer annealed copper. Common gases, such as oxygen, nitrogen, carbon dioxide, and sulfur dioxide are soluble in molten copper and greatly affect the mechanical and electrical properties of the solidified metal. The pure metal is second only to silver in thermal and electrical conductivity.

The levels Mined- 0.15% copper (Cu) at Munni Munni (WA); 0.07% Cu at Panton (WA) both in Australia; against measured- 775ppm, 416.55ppm, 397.15 ppm, 369.96ppm in the county specified areas.

V. Calcite

Vast quantities of calcite (Calcium Carbonate, CaCo3) occur as the main constituent of economically important calcite. Some occur as marble which is can be quarried for ornamental stone and lime products. Calcite veins of late hydrothermal type is rampart in the areas of Kaputir and Kaeris which happens to host gold. Impure calcite called kunkar limestone is also present in areas of Kaeris, Kalapata, and Turkwel. Also noticed during the exercise of sampling is kunkar limestone. This was of varying shades of off-white and pink, sometimes with a heavy admixture of soil and sand.

Crystalline limestones are fairly abundant in the area, being exposed east of Amuton, at Emuroy and Kirkinie, and near the Uganda border at Looya. Of these exposures the most accessible are at Emuroy and Kirkinie. Commonly
the limestone found in the south contains bands of calc-magnesium silicate minerals as well as small flakes of graphite.

VI. **Chromite**

This is the chief ore of chromium, a hard silver-blue metal used extensively in chromium plating to give a protective coating to metals such as steel which are susceptible to rusting or other forms of corrosion. Its main use, however, is in the manufacture of corrosion-resistant alloys of which stainless steel is one example. For such purposes the ore must be of a metallurgical grade for which consumers demand a minimum Cr2O3 content of 48 per cent and a chromium-iron ratio of at least 3:1.

The mineral is in the study area in Lokichar is associated with an intrusion of dunite altered to serpentinous carbonate rocks, talc and chlorite schists, with veins of magnesite, aplite and pegmatite.

Chromite itself is employed in refractory products for lining furnaces. The specifications of the refractory grade mineral vary with the different manufacturers but, in general, a low silica value is preferred (up to 5 per cent) and sometimes the iron content, too, is limited (up to 10 per cent). The percentage of Cr2O3 is usually required to exceed 40. The mined levels - 4-5.2% chromium (Cr) at Weld Range – Parks Reef (WA); against measured-1547.91ppm, 878.59 ppm, 866.07ppm, 754.88 ppm in the county.

VII. **Corundum**

This is the name given to naturally occurring aluminium oxide. Next to diamond, it is the hardest mineral known and the common varieties find wide application as abrasives. Emery, which is of a greyish black colour due to an admixture of magnetite and hematite, is familiar as the coating of emery cloth.
Transparent red and blue-coloured varieties are equally familiar as the gemstones ruby and sapphire respectively.

Natural and synthetic corundum are used in a wide variety of industrial applications because of their toughness, hardness, and chemical stability. They are used to make industrial bearings, scratch-resistant windows for electronic instruments, wafers for circuit boards, and many other products. Crushed corundum is processed to remove impurities and then screened to produce uniformly sized granules and powders. These are used for grinding media, polishing compounds, sand papers, grinding wheels, and other cutting applications.

VIII. Galena

This is lead sulphide and constitutes the chief source of the metal. It is used in the manufacture of storage batteries, water pipes, roofing sheets, solders, and coverings of electric cables. It is the starting point in the production of lead compounds employed in the chemical, paint and glass industries.

**Lead Poisoning** Lead poisoning (also known as plumbism, colica pictorum, saturnism, Devon colic, or painter's colic) is a type of metal poisoning and a medical condition in humans and other vertebrates caused by increased levels of the heavy metal lead in the body. Routes of exposure to lead include contaminated air, water, soil, food, and consumer products. Occupational exposure is a common cause of lead poisoning in adults

IX. Gold

Gold particles which accumulate in the sands and gravels of streams and rivers give rise to "alluvial" gold deposits. Extraction from these is relatively simple, and usually involves gravitational concentration followed by amalgamation. Alluvial gold derived from the Suk and Karasuk hills is possibly present in the
Turkwel River. In some places, the gold is recovered by panning.

Throughout the entire goldfield’s area of Nakalale and Sesame, the commonest and most characteristic products of mineralization are auriferous quartz veins. These are lenticular in habit and vary in strike length from tens of 1 feet to over 2,000 feet, and in width from an inch or two up to 30 feet. Persistence at depth is commonly greater than the surface strike. Economically interesting concentrations of gold have been found in more or less well-defined shoots rather than throughout the entire bulk of the veins.

Calcite veins of late hydrothermal type is rampart in the areas of Kaputir and Kaeris which happens to host gold. Other minerals associated with the gold include sericite, tourmaline, calcite, pyrite, arsenopyrite, chalcopyrite, and galena. As the depth of mining operations increased it was found that the proportion of free gold diminished while the proportion of gold in a refractory condition as sulphides increased. It is of interest to note that the greatest depth reached in mining operations was about 550 feet and that the ore bodies were strong and showed a persistence of gold values.
Figure 11: A gold dealer at work in Naduat (Nakalale)

The Mined levels-0.2 g/t gold (Au) at Munni Munni (WA); 0.31 g/t Au at Panton (WA) both in Australia: against measured locally- 15.82ppm, 15.15ppm, 15.1ppm, 15.08 ppm.

X. Graphite

This mineral is a crystalline form of elemental carbon and is usually found associated with impurities such as quartz, mica, calcite, pyrite, etc. which must be removed before the mineral can be sold. In commerce the term graphite is applied to the crystalline flake mineral, plumbago implies the massive variety, whilst black-lead refers to the apparently amorphous type The Kenya variety is crystalline flake graphite.

The chief uses for graphite are for foundry facings and moulds, graphite crucibles, lubricants, paints, dry batteries, brushes for electric motors and generators, stove polishes, electrodes, explosive and pencils. The mineral is used also in the fields of nuclear power and missile construction.
Graphite has, however, been successfully exploited on a commercial scale from sources in the Basement System where it occurs as a constituent of kyanite-schists, graphitic limestones and felspathic gneisses.

Graphite was reported from gneiss in the EPEIYELEL area of Karasuk and is of low grade ore, coupled with the hardness of its matrix making extraction difficult.

**XI. Garnet**

Garnet is the name used for a large group of rock-forming minerals. These minerals share a common crystal structure and a generalized chemical composition of $A_3B_2(SiO_4)_3$. In that composition $A$ can be Ca, Mg, $Fe^{2+}$ or $Mn^{2+}$, and $B$ can be Al, $Fe^{3+}$, $Mn^{3+}$, $V^{3+}$ or $Cr^{3+}$.

These minerals are found throughout the world in metamorphic, igneous, and sedimentary rocks. Most garnet found near Earth’s surface forms when a sedimentary rock with high aluminium content, such as shale, is subjected to heat and pressure intense enough to produce schist or gneiss. Garnet is also found in the rocks of contact metamorphism, subsurface magma chambers, lava flows, deep-source volcanic eruptions, and the soils and sediments formed when garnet-bearing rocks are weathered and eroded.

**Garnet** is chiefly found in the amphibolites and plagioclase amphibolites but is of local occurrence and the crystals themselves are small and of poor quality, as are those in the kyanite-garnet gneisses. *Mica* is ubiquitous in the rocks of the Basement System but generally occurs as small flakes in hard rocks and so would be unsuitable for working. Some large flakes of suspected vermiculite were tested but proved to be biotite.
This name covers a family of minerals, which are silicates of iron, calcium, aluminium, magnesium and chromium. They vary considerably in some of their physical properties and only the hardest members find a use in industry, where they are employed as abrasives.

Most of the garnet is crushed for use in the preparation of garnet paper and cloth, the remainder being employed in the form of loose grains. Its abrasive properties depend, in addition to its hardness, upon the way in which it fractures; on crushing it should break sharply into angular fragments with round or curved edges. Thin slivery pieces are undesirable since they either do not adhere well to cloth and paper or they quickly break down and shorten the useful life of the product. Large crystals that have been badly weathered or shattered, or contain embedded impurities, are not good raw material because they tend to crumble to dust on crushing. Granular garnet is also unsuitable since it tends to break into rounded rather than angular fragments. Colour is, or should be, unimportant, but most trades are prejudiced against any colour other than red.

The pie diagram above shows the most common industrial uses of garnet minerals.

Areas mined in the county are in Lokiriama and some areas of Lokichar.
XII. **Gypsum**

Gypsum is an evaporite mineral most commonly found in layered sedimentary deposits in association with halite, anhydrite, sulfur, calcite and dolomite. Gypsum (CaSO₄·2H₂O) is very similar to Anhydrite (CaSO₄). The chemical difference is that gypsum contains two waters and anhydrite is without water. Gypsum is the most common sulfate mineral.

In composition gypsum is hydrated calcium sulphate, and is used in the cement industry, in fertilizers, as filler in various materials such as paper and paint, and in the manufacture of Plaster of Paris.

There are two major occurrences in the County of Turkana, one is in Kapua area of Kalokol ward towards the lake from Lodwar and the other major sources in the south are Nakaale in Kalapata ward and Naposimoru in Lokichar ward.

Gypsum is abundantly scattered about along some stretch on the road and sample was picked at coordinates 36N 0773500, UTM 0431835. The gypsum on the surface is of variable sizes and opaque to nearly transparent may be free of impurities as observed from quarried areas. The material from here is of sufficiently high quality to find a use in cement manufacture, building and agriculture.
XIII. **Iron Ores**

The olivine basalts of Turkana County are indicative of much opaque iron ore. Some in the thin section phenocrysts of olivine are abundant and numerous small inclusions of augite and two or three per cent of magnetite in groundmass. The rhyolites sometimes stained red-brown by iron oxides are noticed. Alteration of the lavas in the form of iron ore replacement of much or all of the coloured minerals is widespread. In some instances in thin section the coloured minerals of the groundmass are completely altered to a black or dark chocolate brown iron mineral in mossy aggregates.
Next to aluminium, iron is the most widely distributed and abundant metallic element in the earth’s crust, of which it constitutes about 4.6 per cent. The chief ores of iron are magnetite, Fe3O4, containing 72.4 per cent Fe; hematite, Fe2O3 containing 70 per cent Fe; limonite, 2Fe2O3.3H2O, containing 59.9 per cent Fe; and the carbonate siderite, FeCO3, containing 48.3 per cent Fe. Less important ores are the sulphides, pyrite, FeS2, and pyrrhotite, FeSn+1.

Fe-Ti oxides only include magnetite and ilmenite and are present in these rocks. There seems to have a general but not absolute tendency that magnetites predominate ilmenites in alkali basalts whereas elongated ilmenites predominate magnetites in tholeiites. There is recorded potential for iron in Lokichar ward 36N 0786992, UTM 0261942, Kaaleng ward 36N 0788294, UTM 0476726 and Lapur ward 36N 0803925, UTM 0474117.

The main uses of iron ores are for the production of iron and steel. Although iron itself may be employed in the form of castings, wire, rod, sheet, etc. for the engineering and building trades there are many purposes for which steel is more suitable. This is made by alloying iron with varying amounts of other metals or non-metallic elements, and subjecting it to various forms of heat treatment. Depending on how it is made and the metals used the resultant steel has properties which, for many uses, render it superior to iron.

XIV. **Kyanite and Mullite**

Kyanite, a typically blue silicate mineral, commonly found in aluminium-rich metamorphic pegmatites and/or sedimentary rock. Kyanite in metamorphic rocks generally indicates pressures higher than four kilobars. Although potentially stable at lower pressure and low temperature, the activity of water is usually high enough under such conditions that it is replaced by hydrous aluminosilicates such as muscovite, pyrophyllite, or kaolinite. Kyanite is also known as disthene, rhaeticite and cyanite.
Likewise in Karasuk, north of the KAKEP PASS in the Loiya-Lorugum area kyanite is present in a thick series of garnet-kyanite gneisses in which it forms large bladed crystals up to four inches in length. There are no workable segregations and it never constitutes more than a few per cent of the rock. Kyanite has been used as a semiprecious gemstone, which may display cat's eye chatoyancy, though this use is limited by its anisotropism and perfect cleavage. Colour varieties include recently discovered orange kyanite from Tanzania.[citation needed] The orange colour is due to inclusion of small amounts of manganese (Mn3+) in the structure. Kyanite is one of the index minerals that are used to estimate the temperature, depth, and pressure at which a rock undergoes metamorphism.

Kyanite is present in a fairly thick series of pelitic garnet-kyanite gneisses occurring in the synclinal belt east of the Kakep Pass. The kyanite, which forms large-bladed crystals up to three or four inches in length, never makes up more than a few per cent of the host rock and no kyanite segregations were noted. Occasionally kyanite concentrations of loose crystals are formed by weathering in hollows or at the foot of slopes but these are always of only very small extent.

Kyanite, is found in Lokichar in the Precambrian metamorphosed rocks.. It is a silicate of aluminium, Al2O3.SiO2, which upon heating to 1,450°C. undergoes conversion to mullite, 3Al2O3.2SiO2 and vitreous silica. In this calcined form the mineral is very suitable for refractory products, chiefly bricks for furnace linings, as it shows little or no softening below its melting point of 1,810°C. In addition mullite has good insulation characteristics, even at high temperatures, and its needle-like structure confers high mechanical strength and high resistance to thermal shock.
XV. **Magnesite**

This is magnesium carbonate, MgCO3, and may be used in the manufacture of magnesium metal, magnesium salts and by-product carbon dioxide. The most important uses of magnesite however, are for refractory bricks, furnace linings and crucibles. It is also employed in the manufacture of special cements, in the paper and sugar industries, and as a fertilizer. There is little demand in industry for raw magnesite since most of the uses to which the mineral is put demand the calcined oxide as the starting point for manufacture.

A little magnesite was found in the area south of LODWAR where several intrusive ultrabasic bodies are cut by anastomosing veins up to 2 inches thick.

XVI. **Manganese Minerals**

Manganese is found in form of Psilomelane which is an oxide of manganese commonly found in association with pyrolusite, which it resembles in colour but is much harder. Indications of manganese were found at Kerio Delta. Other areas included Kaaleng ward.

The chief demand is for the oxide minerals, which are used in the production of such alloys as spiegeleisen and ferromanganese, containing from 15 to 80 per cent manganese, and silico-manganese containing from 10 to 20 per cent silicon, all of which are of importance in the steel industry. Pyrolusite itself is used directly for a number of purposes such as the decolourization of glass, as a dryer in the manufacture of paint and varnish, and in dry batteries.
XVII. **Oil**

Crude petroleum, naphtha, and mineral oil are all names given to what is generally understood to be naturally occurring oil. This is a black or brown liquid of variable viscosity possessing a powerful and disagreeable odour. Many different organic chemical compounds are contained in it and to separate these the crude oil must be treated in a refinery. By fractional distillation various oils are obtained which, in order of increasing boiling points, are known as petroleum ether, petroleum spirit, kerosene or paraffin, diesel oil, lubricating oil and fuel oil. The black or brown pitchy substance remaining when all these oils have been driven off is known as asphalt or mineral pitch.

Crude oil has been discovered in Lokichar area and also rocks, soil and water samples containing oil were infrequently observed in the northern areas especially at the Lomanakipi spring. A discussion with Tullow oil Community Communications Coordinator indicated that intensive work has been done in areas of Lokichar and Lokori and consequently wells drilled had an excess of 600,000M barrels of oil discovered. Works done in Turkana North lead to discovery of gas.

XVIII. **Pyrochlore**

This mineral is a naturally occurring form of calcium niobate and is of economic interest by reason of its niobium (columbium) content. The resource is found in Lapur and Kalapata wards. Although pyrochlore may be weakly radioactive it is described separately from the radioactive minerals because of its much greater value as a source of niobium rather than of radioactive elements. It occurs typically as small yellow to brown or black octahedral crystals up to an eighth of an inch across.
XIX. Quartz

Silica, or silicon dioxide, is the most abundant constituent of the earth’s crust and is commonly found in the form of mineral quartz. When free from impurities it is colourless, glass-clear, and occurs typically in six-sided crystals. Such material finds use in industry chiefly in the production of fused silica ware and optical lenses, although specially selected crystals may have piezo-electric properties and are then cut into plates of suitable size for incorporation in wireless equipment as frequency controllers. This use however, is declining because the natural mineral is being superseded by artificially grown quartz crystals.

Silica is associated with Miocene formations in Loima areas and also the same formations spread to Turkwel ward. Likewise the resource is abundantly present in Lokiriama-Lorengipi ward.

Small quantities of various impurities give rise to a wide range of coloured varieties of quartz, some of which are of value as semi-precious stones.

XX. Radioactive and Rare Earth Minerals

Radioactive minerals are those, which contain the elements uranium, thorium, or radium. These elements have the property of emitting radiation, which may be detected by means of various instruments, the most familiar being the Geiger counter. The rare earth minerals contain certain unfamiliar or rare elements such as cerium, lanthanum, yttrium, europium, neodymium, praseodymium, and terbium to mention but a few. In addition to the rare earths, thorium, and in some cases uranium, may be present in small quantities resulting in weak radioactivity. For this reason it is convenient to consider the radio-active and rare earth minerals together.
In the current study Thorium and Uranium are the most common. They are found in good levels in Kibish at 36N 0768528, UTM0545498; Nakalale at coordinates 36N0749214, UTM0393788.

In practically every instance the minerals are employed as the raw material for the production by complex chemical processes of the particular metal or rare earth, which they contain. The uses to which the final products are put are many and varied and the list, which follows, is by no means comprehensive. Uranium became a familiar name as the result of the invention of the atomic bomb. Later, with the employment of nuclear energy for peaceful purposes, the metal and its oxides were used extensively as fuel in atomic piles for generation of electricity. Uranium oxide is used also for colouring glass and glazes on pottery; in the textile industry; in photography; and in analytical chemistry.

Thorium in the form of its nitrate is employed chiefly in the manufacture of incandescent mantles for gas and pressure-lamps. Small quantities of thorium compounds are used for refractories and polishing; as constituents of certain catalysts; and in the manufacture of carbon electrodes for producing ultraviolet radiation in sunray lamps. Metallic thorium is important as an alloying element in tungsten wire to which it imparts a greatly increased ductility. This facilitates its drawing into filaments for electric lamps and also improves its electron emitting qualities. Combined with copper and nickel the metal is used to produce the "guertler" series of alloys, which are claimed to be mechanically strong in addition to having good resistance to chemical action and high temperature.
XXI. Sapphire

The area is also famous of the blue sapphire which is casually picked by the locals and disposed to unorganized markets. This is common in areas of Nadung’a and around Kanurdio in Kaeris ward.

XXII. Sillimanite

This mineral is an aluminium silicate, $\text{A}_2\text{O}_3\cdot\text{SiO}_2$, and may vary in colour from grey to brown, green, or yellow due to the presence of small proportions of iron oxide. When heated to 1,545°C. It slowly changes to mullite, and at about 1,700°C, the change is rapid. In the refractory industry the name sillimanite is used to cover the products obtained by calcining the minerals kyanite, sillimanite, andalusite and dumortierite. The first three minerals have the same chemical composition, but differ in their physical properties and crystalline structure.

Natural sillimanite is not much used as a refractory as it is less easy to handle than kyanite or andalusite owing to difficulty in crushing. It is however, used in the ceramic industry where the finely ground mineral is added to kaolin or clay mixtures in order to reduce the shrinkage in firing, to increase the breaking strength and resistance to abrasion and to lengthen the sintering range of the ware. It is also used in some sparking plug porcelains

XXIII. Silver

The principal use for metallic silver is (as an alloy with copper) for coinage, plate, and jewellery. The second largest use is for the preparation of silver salts in the manufacture of photographic films and papers. It is used also in electrical engineering, electronics, chemical plant, and certain brazing alloys.
Silver is also an indicator mineral for gold. The following areas shows good indications; Song’ot 36N 0668666 UTM0455008; Kaeris ward 36N 0764069, UTM0470477 and Lokichar 36N 0790936, UTM 0264091.

XXIV. **Steam (Geothermal)**

This thermal energy can be tapped in areas where fissures in the rock at depth carry superheated steam, or where ground water is heated to high temperatures either by contact with hot rocks or by the transfer of heat from hot juvenile steam and gas. Such occurrences are commonly associated with areas of recent volcanic action which are cut by faults carrying the heated ground water to the surface where it emerges as hot springs, geysers, steam jets, etc.

In Kenya the Rift Valley is a good potential geothermal area and various manifestations of heat occur at intervals along it. In the Turkana County the principal occurrences are as follows: -

- **Eliye spring**  lat. 3.252478  long. 36.020673  Warm spring
- **Koyasa Spring**  lat. 4.973584  long. 35.485616  Warm spring
- **Lomonakipi spring**  lat. 5.018824  long. 35.591003  Hot spring
- **Muruatapa spring**  36N 0692538  UTM0389596  Hot spring
- **Lobiritit Hot Spring**
- **Kapedo Hot Springs**

In order to exploit natural sources of steam certain conditions must be fulfilled. Either superheated steam at depth must be located, or superheated ground water, which when tapped converts to superheated steam at pressures above 40 p.s.i. and at temperatures of between 250° and 500°F. Salinity of the ground water should be low to prevent fouling of the drill pipes and surface
installations with salts and minerals released by boiling. The water-body should be large enough to supply steam for a lengthy period and should occur at moderate depth, otherwise drilling costs are very high.

XXV. Talc

This mineral is essentially a hydrated silicate of magnesium and commonly occurs as a secondary mineral resulting from the alteration of other magnesium minerals such as serpentine, pyroxene, or tremolite. French Chalk, asbestine, steatite, and soapstone (but not the Kisii soapstone of Kenya) are names given to varieties of talc having slightly different physical properties or containing various impurities.

The bulk of commercial talc is either dry ground as mined or, to an increasing extent, wet ground and beneficiated. Its value lies in its extreme softness and smoothness, good lustre and sheen, high slip and lubricating properties, low moisture content, ability to absorb oil and grease, chemical inertness, high fusion point, low conductivity for heat and electricity, and good covering power as a pigment. As a consequence it has numerous industrial uses, large quantities being consumed in the manufacture of paint, roofing felts, rubber and ceramics. It is used as a filler in insecticides, soaps, linoleum, polishes and paper. In the textile industry fairly large quantities are employed for loading and bleaching certain goods such as cotton sacks for flour and sugar, cordage, rope and string. The ceramics industry uses increasing quantities of talc in floor and wall tiles and it is also used for electrical porcelains, enamels and refractories. Only relatively small quantities of high-grade white talc are employed in the manufacture of cosmetics. Massive talc or steatite is cut into blocks or otherwise shaped for various refractory uses such as lining certain kinds of furnaces. It is soft and easy to work but after firing becomes very hard. Talc in Turkana occurs in the Basement System of Precambrian and is associated with either banded magnesium-rich metamorphic rocks.
XXVI. Tourmaline

This mineral is a complex: silicate of boron and aluminium, and commonly occurs as well-developed crystals belonging to the hexagonal system. It varies in colour from red, green-blue and yellow to black. Rubellite is a red or pink variety, and schorl is the ordinary black opaque variety, which commonly occurs as aggregates of needle-like or columnar crystals. There are few uses for this mineral, although suitable stones of the rubellite variety are cut as gems.

The mineral Tourmaline is wide spread in the southern part of the county covering Lokichar, Lorugum, Nakatome and the Loiya-Lorugum area.

Figure 13: Petrified Wood Forest North of Kaeris
Figure 14: Bathroom Tiles made from Petrified Wood

Figure 15: Petrified Wood Table
### Table 3: Sample Mineral Coordinates

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Chapter 6: Endemic Flora & Fauna in Turkana County

Turkana County is endowed with various classes of fauna and flora some of which can be classified as threatened or endemic. This includes *Aloe turkanensis* species *Osiris lanceolata* species (sandal wood). Key environmental challenges facing endemic species are over exploitation due to high demand ready markets, land degradation, deforestation, degradation of aquatic ecosystems, erratic rainfall of mean annual average of 180 mm and high mean annual temperatures of 29°C and loss of wildlife habitats and biodiversity. Environmental degradation and loss of ecosystem services particularly affects the poor who are most vulnerable due to malnutrition and poverty hence lack alternative income generating activities.

6.1 Land Use and vegetation

Turkana is an arid and semiarid County characterized by scarce vegetation cover described as scrubland with a pastoral economy. The local community believes in keeping livestock in large numbers as a source of wealth and payment of dowry which has led to overstocking. This has the negative effect of overgrazing which leads to land degradation. On the onset of draughts they lose most of these livestock which affects the pastoral economy. The Turkana keep mainly the short horned zebu cattle, goats, donkeys and camels for milk and meat. They are herded separately according to their feeding regimes and water needs. Rapidly increasing population from 350,000 in 1999 to the current 850,000(GoK 2009) has had an impact on resource use and planning. This increases pressure on natural resources as more people become sedentary. During dry spells, herders moved freely across the borders of Ethiopia, South Sudan and Uganda in search of fresh pasture. However national and regional boundaries and the proliferation of small arms and cattle rustling have limited this free spatial mobility in search of animal forage and water. The county government should draw up and enforce policies to deter cattle rustling. These should be treated as robbery with violence. Boundaries should be clearly marked with beacons and where possible fenced to curb human conflict and cattle rustling.

Vegetation cover in Turkana is classified into three ecoclimatic zones which are influenced by climate, topography and soil structure. Rainfall increases with elevation while evaporation decreases hence higher elevations are significantly wetter than the low plains increasing vegetation cover and species composition.
The only exception is where groundwater in Aquifers, Rivers and Lakes influence vegetation densities and composition.

Ecoclimatic zone VI is the very arid parts of Turkana County found in the low plains of Turkana Central, Turkana East and Turkana South Sub-counties. These are rangelands of low agricultural potential characterized by dwarf grassland or shrub grassland with *Acacia reficiens* often confined to water courses and depressions with barren land in between.

Ecoclimatic zone V is the arid environment. The land is suitable for agriculture only where fertile soils coincide with very favourable distribution of rainfall or receive run off. These are typical rangelands dominated by Commiphora and Acacia woodlands. This zone is found in Turkana west Turkana North and Kibish Sub-counties.

Ecoclimatic zone IV is the semiarid lands of Turkana. This is the semi evergreen brushland of marginal agricultural potential mainly savannah woodlands characterized by *Acacia-Themeda –Brachystegia* woodlands. The County government should develop tree planting programmes in this area due to the high potential. Woodlots of Eucalyptus can be established in these three sub-counties to make Turkana a net importer of timber and firewood and to meet the ever increasing demand for fuel wood and building poles in Kakuma refugee camp in Turkana West sub-county.

Turkana is a low lying plain with high elevations in the North and West where mountain ranges rise to 4000ft above sea level. The highest elevation is Loima hills and the Puch Prasir plateaus characterized by tropical montane forests rich in species composition, formation and density.

In general soils in this County are not well developed due to aridity and constant water and wind erosion. They are often capped by stone mantles. Alluvial soils are generally reddish over the basement system and grey buff or white over the volcanoes. Aeolian soils are dune sands either active or fossil; Alluvial soils range from coarse sands to flash flood silts, while black or brown clays occur locally in areas of impended drainage. There is very high evapo-transpiration due to low rainfall and high temperatures resulting into deposition of salts in the soils and capping on the surface. As a result only 30% of the county soils can be rated moderately suitable for agricultural production (GoK, 2009).
These moderately fertile soils are found in the central plains of Lorengippi, upper Loima and the lowlands of Turkwel, Nakaton and Kawalathe drainage, along the lake at Todonyang plains, the lower Kalokol and Turkwel-Kerio River and a portion of Loriu plateaus. Therefore irrigation farming will transform pastoral landuse into agrosilvi pastoralism system which will enhance the socioeconomic development of the local communities in these very potential areas. The land should be zoned for agricultural production, fruit farming while the rest is demarcated for rangeland development where grass and fodder for livestock is produced. It is recommended that the fast growing and hardy grass species be introduced for pasture in this arid environment like *Syngras ciliaris*.

There is subsistence agriculture in this county where sorghum, maize, cowpeas and green grams are grown. Other crops include date palm, mangoes, local vegetables, kales, spinach, bananas and tomatoes. Food is imported from Kitale and Uasin Gishu counties since most pastoralists do not practice crop farming. The local people should be encouraged to raise food crops along rivers where canal irrigation can be practiced.

The vegetation cover map (figure 6.1a) shows that thick forest cover can be found around high elevations in mountain ranges (montane forests) and along the rivers (riverine forests). There was evidence of thick scrubs in the north western part of the county and swamp dependant vegetation in the vast Lotikipi plains. There was near-barren land mass in three characteristic areas namely: North of Lodwar due to lava flow, most parts of Lake Zone and Lotikipi plains due to sand deposits.

The crown cover of woody plants is 4.06%. Woody vegetation was dominated by *Acacia reficiens* while herbaceous cover was dominated by *Aristida mutabilis*, *Mallugo cerviana* and *Jatropha villosa*.

The second most important vegetation type in terms of productivity is dwarf shrubland. These woody plants are a major source of fodder and are heavily browsed. Woody plants were hardly more than one metre in height except in depressions where soils are deep and fertile. This type of vegetation is wide spread in the county.

The Lotikipi Plains and areas around Eliye Springs are extensively covered by grassland. The Lotikipi Plain gets flooded during heavy rains. Kibish Sub-county is green covered by tall trees and grass. The area is largely avoided by the local community due to aggressive cattle rustling from the neighbouring
Topotha of South Sudan and Dassanetch from Ethiopia their perceived enemies (*emoit*). Cattle rustling is an age old practice among pastoral communities but has become more violent and fatal due to proliferation of sophisticated weapons in the hands of the local people. Arms have proliferated due to civil wars that have been common in neighbouring Uganda and South Sudan.

There are riverine forests along the Rivers like Turkwel, Kerio and Tarach. In flood plains, riverine forests are extensive and *Maerua crassifolia*, which is an evergreen shrub, marks the extent of the floods. Dominant species are *Acacia tortilis* and *Ziziphus mucronata*.

Bushland vegetation is found in the south of the County and along the border with Uganda. It is also found around Lokitaung and in an area north of Lokori in south Turkana sub-county. *Acacia reficiens* is the dominant tree species here while the dominant perennial grass species is *Digitaria milanjiana*, *Panicum maximum*, *Sporobolus conjinis* and *Echinochloa haploclada*. Spatial distribution of vegetation is poor in most Wards visited like Nakalale and Kaeris. The county government should double their efforts to reafforest these regions with fodder species, fruit tree species for better nutrition, trees for timber, pole, posts and firewood working cycles. To this end Kenya Forest service (KFS) and KEFRI could advise on most suitable tree species. The vegetation cover in wards like Kibish, Kokuro, Lokichogio, Kakuma was higher due to better rainfall. Pastoralists find a lot of pasture in Kibish sub-county albeit fears due to cattle rustling from neighbouring Southern Sudan and Ethiopia.

The main challenge apart from the climate is charcoal burning. Nearly all sub-counties are involved in serious charcoal burning as a source of livelihood. Charcoal is supposed to be produced from dead and dry wood only. However there was evidence that most people are cutting live trees for charcoal production which is illegal. The KFS has legalized Charcoal production from dry vegetation in Turkana. The county government however encourages farmers to produce charcoal from the invasive *Prosopis juliflora*. There is need for the county government to double their efforts to continuously create public awareness to sensitize the community on the dangers of deforestation in drylands and the impacts it has on their livelihood and survival. Efforts should be made to increase tree cover from the current 4.06% to world standards of 10% which is also guaranteed in the constitution and the Forest Act 2005. The County government should construct workshops to manufacture improved
energy saving jikos as seen in Kakuma refugee camp. The Ministry should develop policies to govern the energy sector, charcoal production and utilization of Prosopis. The local people should form associations to help organize coordinate and regulate the Charcoal industry for improved income and increased revenue generation to the County government. These rangelands should be mapped and zoned to indicate no go zones for charcoal burning to protect water catchment areas, water Aquifers, Rivers and endemic species.

Figure 16: Ministry officials inspect illegal charcoal burning activities
Figure 17: Vegetation Map for Turkana County
6.2 Medicinal Plants

Turkanas have a wealth of indigenous knowledge in managing diseases especially among all rural population, who depend on traditional herbs to cure common ailments. The rural community had no access to modern medicine since hospitals and dispensaries are far away and the drugs too expensive to afford. The Turkana have an intimate knowledge of medicinal plants used to cure diseases among mankind poultry and livestock. Hence they have learned to protect medicinal plants. It is important to note that indigenous knowledge in trees and herbs for their medicinal value, knowledge on important species for integration in pest management, innovative ideas in ecological processes and land use are important in conservation initiatives. Most modern drugs and medicine are derivatives of plant material. *Aloe turkaniensis* is among many medicinal plants highly exploited among the local community.

![Aloe Turkanensis](image)

Figure 18: *Aloe Turkanensis*

Aloe is found growing in the wilderness in Turkana County. Some communities have started planting it for its economic value like community groups in Napak and Oropoi.

The sap from *Aloe Turkanensis* is used to cure poultry diseases like coccidiosis. The sap also makes good quality soap, shampoo, skin lotion. It is used to cure skin diseases.
Other plants exploited for their medicinal value are shown in the table below.

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<th><strong>Scientific name</strong></th>
<th><strong>Local name</strong></th>
<th><strong>Medicinal use</strong></th>
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<tbody>
<tr>
<td>1 Dobera glabra</td>
<td>Edapal</td>
<td>Roots used in treatment of colds and flu</td>
</tr>
<tr>
<td>2 Echorokong’u</td>
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<td>Cure of TB, cancer snake bites and is a painkiller</td>
</tr>
<tr>
<td>3 Aloe turkanensis</td>
<td>Echuchuka</td>
<td>Cure of many diseases</td>
</tr>
<tr>
<td>4 Cordia sinensis</td>
<td>Edome</td>
<td>Leaves used to treat eye sores</td>
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<tr>
<td>5 Balanites aegyptiaca</td>
<td>Ebeyi</td>
<td>Treating wounds</td>
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<td>6 Epuu</td>
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<td>Its milky sap used for treating sore eyes Treating measles</td>
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<td>7 Eroronyiti</td>
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<td>Stomachache</td>
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<td>8 Etesiro</td>
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<td>Treating wounds, removing thorns deep in the body</td>
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<td>9 Epeduru</td>
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<td>Appetizer</td>
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<td>10 Eroronyit</td>
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<td>Treating bloody intestinal wounds</td>
</tr>
<tr>
<td>11 Emus</td>
<td></td>
<td>Treating early pneumonia and tuberculosis (TB)</td>
</tr>
<tr>
<td>12 Sisal</td>
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<td>Treatment of snake bites, treating women</td>
</tr>
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</table>
### 6.3 Invasive Plants

Prosopis juliflora is an invasive tree species which was introduced in Turkana County in 1979 by NORAD. *Prosopis juliflora* is an evergreen shrub native to South America: regions between Mexico to Peru. It has become invasive in Turkana since it was introduced outside its ecological range with no natural predators. In Turkana District the plant was introduced by Turkana Rehabilitation project with support from NORAD (Norwegian Relief Agency for development) during the 1979-1980 famine period. The purpose was to mitigate desertification, fuel wood and fodder shortages in the Turkana ASALs.

Planting was intensified by this program through schools, NGOs, relief agencies, Forest department and all stakeholders who were keen in fighting desertification at that time. It has since colonized vast areas of the pastoral rangeland invading along the water courses heavily e.g. along Rivers Turkwell and Kerio and on the western shores of Lake Turkana. Prosopis has invaded

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<td>6.3</td>
<td>Invasive Plants</td>
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<tr>
<td>01</td>
<td>- Esekon: Teating chest pain, TB mouthwash, toothbrush, constipation, appetizer</td>
</tr>
<tr>
<td>02</td>
<td>- Lokimietta: Eyesores</td>
</tr>
<tr>
<td>03</td>
<td>- Lowurosuori: Fever</td>
</tr>
<tr>
<td>04</td>
<td>- Lokile: Treating wounds</td>
</tr>
<tr>
<td>05</td>
<td>- Esaajait: Roots used for treating stomachache</td>
</tr>
<tr>
<td>06</td>
<td>- Eegong: Roots for treating stomachache, activates vomiting and cleaning the stomach</td>
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</table>
many areas in Lokichogio, Letea and Kakuma. In Lokitaung it was found out to be a major source of fodder for goats, where the pods are collected and stored for use in drier periods.

The plant was preferred due to its resilience, drought tolerance, fast growth, source of fodder and fuel wood. It was easily imported into Kenya due to the poor phyto-sanitary regulations and enforcement policies of the 1960s to 1980s.

Figure 19: Barren land with limited vegetation cover

Further planting of the tree was stopped in the early 1990s when the weedy characteristics of the plant were noticed followed by public outcry. *Prosopis juliflora* has many potential uses in the ASALs. In general 95% of the households use *P. juliflora* as the main source of fuel wood and also produce charcoal for both domestic and commercial utility. Its fuel wood has a high calorific value of 4.2 Kcal/gram to 4.8 Kcal/gram higher than local species like Acacia. The species is a major source of fuel wood to the Kakuma refugee camp which uses tones of firewood per day. This has become a major economic activity of supplying Prosopis fuel wood to Kakuma refugee camp at a reasonable cost.
Women now have access to plenty of firewood which was previously a scarce resource. This has reduced the time spent and distances they walked in search of the scarce firewood.

*P. juliflora* is a highly flowering evergreen plant with bright yellow flowers that easily attract bees. Hence honey production under Prosopis stands has increased in this County. It has medicinal value. In Turkana it is used to cure ring worms and stomachache. The plant has helped control desert storms of the early 1980s reducing dust and air pollution. Ambient air quality based on the NEMA / WHO standards should not exceed 30 mg/l of dust. The plant has helped control desertification and soil erosion.
The plant provides poles and post for construction, Fencing material, shade and is habitat for fauna. The traditional Turkana houses are built using a lot of poles and withies (fito) as can be seen below hence Prosopis was just the answer.
However there are Socio-economic losses associated with *Prosopis juliflora* which are chiefly linked to the sharp and hardy thorns of this plant which are also poisonous. They inflict septic wounds. In Turkana it is sometimes derogatory referred to as *Msumari wa Norad*. Thorns pierce tyres of motor vehicles, motorbikes and bicycles increasing cost of maintenance and transportation. Thorns pierce, animal hooves limiting their movement in search of the scarce pasture and water in the ASALs. The thorns pierce hides and skins of livestock which affects animal health hence increased cost of treatment. This lowers the quality of hides and skins lowering their market value. This is a drawback to the economy of pastoralists. Pods of Prosopis are known to have very high sugar content which enhances activity of rumen bacterial cellulose which causes teeth decay especially in Goats. Hence goats lose their teeth and starve to death. This spells doom to the pastoral economy. Prosopis is an invasive weed which out-competes other plants growing around it. This is due to the hormone they produce called 5-hydroxyl-juglone which is a growth inhibitor. This has affected plant biodiversity in the ASALS which changes the ecology of these rangelands. This will eventually affect pastoralism.

Prosopis out-competes Acacia woodlots which are the mainstay of the pastoral economy in terms of charcoal, honey production and forage etc yet Prosopis leaves are not good forage for livestock due to high content of resin and tannin. Prosopis has reduced the pasture and forage in this rangelands hence animals need to move longer distances in such of pasture. Prosopis has now invaded wetlands like River Turkwell and Kerio and around Lake Turkana. It is also colonizing Lotikipi nature reserve where a water aquifer has been identified with sufficient water for the whole nation.

Prosopis forms thorny thickets which blocks infrastructure like access roads, markets, schools, playing fields, watering points, salt licks, cultural sites. Prosopis has been known to host pests like aphids which affect crop production and tsetse flies which affect livestock keeping. Cattle raiders have safe haven under Prosopis thickets. Prosopis is known to have deep rooting system which assists in competition of water. Some scientists claim its water consumption could be very high for the ASALs. It has strong rooting system which often cracks floors of houses.
6.3.1 Constraints in Managing Prosopis

a) Lack of biological control methods: bruchid beetles from South Africa be introduced

b) Land tenure system: In communal land ownership the environment suffers the tragedy of the commons. No one takes the responsibility to clear the invasive weed

c) Pastoral way of life. They are always moving in search of pasture and water

d) Mechanical control not viable since they regenerate (coppice) from cut stems and roots disturbance of the soil makes the many seeds underground to sprout.

e) Prosopis juliflora is a profuse seeder producing 60000 seeds per ha per annum

f) The weed is very thorny and stems are very hard to cut hence requires specialized equipment like power saws

g) Lack of Machinery to clear large areas mechanically with chain bulldozers while chemical control is not environmentally sound

h) The Turkana people keep a lot of livestock (overstocking is common) which feed on the Prosopis pods hence spread the seeds in their dung all over the grazing field helping in seed dispersal and germination as the seeds are not destroyed but are scarified through the natural digestion process and deposited in nutrient rich dung.

i) Seeds are washed down in flash floods helping in dispersal

j) Has deep rooting system up to 20M deep hence outcompetes others for water and nutrients and can regenerate from cut stems and roots (coppicing with over six stems per stool)
6.3.2 Recommendations

The Ministry of Energy, Environment and Natural Resources is in the process of developing the natural resource use policy and acts which will guide and govern management of Natural Resources, including the invasive species. The Turkana County Government has enhanced utilization of the many products and services from the plant since pastoralists rely only on livestock.

a) Encouraging charcoal processing through training installing modern charcoal kilns and purchase power saws to assist groups to cut down the thorny thickets and produce charcoal on a commercial scale. This will generate employment for the many Turkana youths. This is socioeconomic transformation of the County through sustainable utilization of the invasive Prosopis weed (Utilization for management).

b) The Ministry should set up Local Farmers Field Schools to train the locals on potential uses of Prosopis and show case best management practices like thinning to reduce stand densities, pruning, pollarding, ring barking

c) Enhance commercial utilization of *P. Juliflora* by removing trade barriers in charcoal production and transportation by issuing movement permits for *P. juliflora* charcoal. Support establishment of a plant to generate steam energy from Prosopis.

d) The County government should introduce non-invasive and thorn less *Prosopis chilensis* alongside commercial utilization of *P. juliflora*.

e) The Ministry should create awareness among communities and private entrepreneurs on other potential uses of the plant

f) The Ministry should purchase grinding mills to process animal feeds from the pods of Prosopis since they contain high levels of carbohydrates and proteins. This will provide high quality animal feed which earn the locals income. Crashing of these pods has a duo effect of reducing available seeds to germinate in the next season hence an excellent mechanical control.

g) Other potential uses of Prosopis is harvesting of wax for pharmaceutical companies and tapping the medicinal value of the tree.
h) The community should stop burning *P. juliflora* as it encourages re-sprouting from damaged stems, scarifies the dormant seeds and removes all valuable native plants from the ground. Moreover, it also releases carbon dioxide which contributes to global warming.

i) The National government can consider introducing biological control using the bruchid beetles imported from South Africa under quarantine. The dilemma is would it wipe out all Prosopis and then invade on the remaining acacias. What is the host specificity?

j) The Ministry should map the spread of Prosopis using aerial photography from DRSRS to determine area covered

### 6.4 Wildlife

Lake Turkana is an important site for water birds with up to 220,000 congregants having been recorded at one time and 84 water bird species, including 34 Palearctic migrants, known from the lake according to Nature Kenya.

Other aquatic animals in the ecoregion include *Hippopotamus amphibius*, *Crocodylus* spp., and an endemic freshwater turtle, the recently discovered and imperiled Turkana mud turtle (*Pelusios broadleyi*).

Wildlife in Turkana county is managed under the Western conservation area with head offices are in Kitale. Role of KWS is to carryout Problem animal control (PAC) and Human wildlife Conflict resolution (HWC). The South Turkana National Reserve is under the county Government but currently managed by the KWS. Plans are underway to hand it over to the county government in Kainuk. However, the region is plagued with banditry and Cattle rustling hence no meaningful investment can be done to enhance socioeconomic development of this area unless security is addressed by the national government.

There is potential for crocodile farming but this has not been exploited in Turkana county. Other opportunities that can be exploited include raring of Guinea fowl, Ostrich farming and rearing of Quails for their meat eggs and medicinal value. Poultry farming is a good investment in hot climate and since there is plenty of land this can be a good opportunity to diversify income generating activities to better their livelihoods. DikDiks have been severely hunted down for food and their population is dwindling down. Arrangements
should be made to relocate DikDiks from areas where they are abundant to restock numbers here. It was reported that some animal species like elephants and buffaloes migrated to South Sudan due to human activities like clearing their habitats and hunting them down. Sand harvesting destroys breeding grounds for aquatic life like fish and crocodiles besides destroying their eggs and young ones affecting future generations. Hence the county government should stop harvesting of sand in rivers that have high aquatic life. Migratory birds like the Flamingo frequent the shores of the Lake Turkana.

Leopards and Hyenas can be found on the Muruiris Hills, whereas Lions, Ostriches, gazelles elephants are found in Kibish Subcounty. Tortoises are found in Todonyang area. Survey done in Loima identified 87 species of avifauna, 48 in Aminit forest above 2,050 m and the rest in Acacia wetland at 800 – 2,050 m. The only herbivores identified are bushbucks, troops of Olive baboons and bush pigs. Elephants and buffaloes were absent but are known to have existed here in the past.

6.5 Forests

The Forest tree cover in Turkana County is estimated 4.06%. There exist forests in high altitude ranges or mountain (montane forests) and along river courses (riverine forests) (figure 6.1a). Forests known to exist can be found on Loima hills, Mogila hills, Songot hills, Pelekech Hills, Lorionotum, and Lokanamur.

Figure 23: A view of Mogila Hills
6.5.1 Loima Forest

The Ministry of Energy, Environment and Natural resources is in the process of surveying and gazetting Loima Forest and loitikipi game reserve to protect and conserve the natural montane ecosystem for intergenerational equity. Loima forest also known as “Moru apolon” is situated 03° 30’N 35° East, and covers an area of approximately 3,300 Km². The forest width at its widest point is east to west approximately 9 Km long and length, north to south approximately 15.8 Km long. The mountains are made up of tertiary and metamorphic volcanic rocks. Rainfall ranges between 610 – 890 mm per year.

There are a lot of Epiphytes, Mosses and Lichens due to high moisture content which has a lot of impact on the ecology of the forest. Forested plateau is flat with an altitude range of 200 m surrounded by steep cliffs. The west side forms water catchments for Tarach, east – Kawalathe and south/south east – Kospir. This is valuable to pastoralists in plains and residents and migratory fauna. Vegetation in the Loima hills is due to elevation not terrain.

The dominant species at the lower slopes include Aristida mutabilis, Acacia mellifera, Acacia tortilis. The dominant species at the dry mountain is Juniperas procera (Aminit), Olea europea, Olea capeusi, Teclea nobilis, and Podocapus falcatus. Survey done in 2001 identified 87 species of avifauna, 48 in Aminit forest above 2,050 m and the rest in Acacia wetland at 800 – 2,050 m. The only herbivores identified are bushbucks, troops of Olive baboons and bush pigs. Elephants, the spotted hyena and buffaloes were absent but are known to have existed here in the past. The study identified 120 flora species in the plains along the Tirikwel (Turkwel River) in Aminit forest, 15 of which have medicinal value, one has never been known before and one is endemic.

There is need to advocate for participatory forest management by the communities and other relevant stakeholders. There is need to sensitize the community and local leaders on the need to gazette Loima Forest, to get the consent from the community on the gazettement of Loima forest, to establish the user groups of Loima hills, to establish social economic impacts of gazetting Loima forest and to establish environmental impact of gazetting Loima forest.
6.5.2 Threats To Afforestation

Threats to forest are unsustainable cutting of forest produce, overgrazing and charcoal burning. Factors causing threats include increased human population & activities, poverty, unregulated uses, insufficient local & national institutional capacities, lack of alternative means of livelihood. This results in clearing forest edges for settlement agriculture livestock farming and creation of small market centres.

Figure 24: MEENR inspect a traditional charcoal kiln

Around Lake Turkana and Kalokol there many doum palms found growing naturally. The seed is used by fishermen to cure or smoke the fish from Lake Turkana. The danger is that they use the female species more than the male species. The fruits are preferred since they burn for a long time. This is affecting regeneration and subsequent survival of doum palms in Kalokol hence the Ministry should advice the fishermen of the impending risks of using the fruits for curing fish.

In general several tree species found are growing in this ASAL environment and these include *Acacia drepanolobium*, *Acacia tortilis*, *Cordia sinensis* (*Edome*), *Cyathulia coriacea*, *Grewia tenax* (*engomo*), *Indigoera ambelacansis*, *Lantana camara*, *Lewsonia inermis*, *Prosopis juliflora* (*Etirae*), *Salvadora persica* (*Esokoni*), *Terminalia orbicularis*.

Species utilized for fodder include *Cordia quercifolia*, *Lecanodiscus flavinflorius*, *Plucheadis choridis*, *Securine gavirosa*, *Terminalia brevipes*. 
Herbaceous Species Aristide adscensionis, Blephanis linafolia, Cenchrus ciliaris, Cyperus rotundus, Cynodon plectostachyus, Echnochloa haploclada, Evolulus alsinoides, Launea cornuta

Edible fruit tree species: Acacia nubica (Epelet), Acacia senegal (Ekunoit), Balanites pedicellaris (Elamash), Balanites orbicularis (Ebei), Borscia coriacea (Edung), Cordia sinensis (Edome), Dobera glabra (Edapal), Ficus sp. (Echoke), Grewia bicolor (Epat), Grewia tenax (eng'omo), Hyphaene compressa (eengol), Maerua subcordata (eerut), Salvadoria persica (esokon), Tamarindus indica (Epederu), Zizyphus mauritiana (Ekalale).

Species that produce fruits that can be cooked and used for food: Acacia tortilis (Ewoi), Balanites pedicellaris (Elamash), Balanites aegyptiaca (Ebeyi), Borscia coriacea (Edung), Cordia sinensis (Edome), Dobera glabra (Edapal), Maerua subcordata (eerut), Zizyphus mauritiana (Ekalale).

Species important during drought: Balanites pedicellaris (Elamash), Borscia coriacea (Edung), Cordia sinensis (Edome), Dobera glabra (Edapal), Ficus sp. (Echoke), Grewia bicolor (Epat), Hyphaene compressa (eengol), Maerua subcordata (eerut), Zizyphus mauritiana (Ekalale).

6.6 Wetlands

According to the Ramsar convention (1971) wetlands are areas occasionally flooded by water up to 10 metres either permanently like lakes or temporarily like swampland that are habitat to waterfowl fauna. Wetlands are important ecosystems as they help in purification of water, are an important recharge aquifer for rivers, conserve biodiversity, source of building material like reeds and clay and are an important habitat for waterfowl species. Key wetlands in Turkana are Lake Turkana which is home to about 50 species of fish, 11 of which are endemic (Hopson 1982). The lake is saline hence water not suitable for human consumption. Lake Turkana like all Rift Valley Lakes is saline because it has no outlets hence high salt concentrations. Doum palms growing around the lake and in Kalokol have been overexploited for curing fish hence serious rehabilitation is recommended.

Turkana County has no permanent rivers except Rivers Turkwel and Kerio which flow most parts of the year courtesy of Turkwel hydropower project which regulates stream flow. This river feeds Lake Turkana although River Omo from Ethiopia is the main source of water for Lake Turkana (over 90%).
Damming of River Omo in Ethiopia will affect water levels of Lake Turkana spelling doom to this important wetland ecosystem and its fishery resources.

It is reported that Lotikipi plains has 3 key water aquifers that hold up to 26 Billion cubic meters of water sufficient to serve this nation for the next 70 years. Water pans found in Kibish are used by pastoralists to water their animals. Nadapal wetlands used between Toposa and Turkana people. All efforts need to be made to conserve wetlands by not compromising their functions and existence. This includes alleviating poverty. Riparian reserves/zones need to be respected and where demarcations lack this need to be enforced. One common problem affecting wetlands is Prosopis juliflora which invades the wetlands replacing the indigenous species hence affecting the ecology of wetlands.

It is recommended that the ministry should capacity build the local community to be able to conserve the environment manage invasive Prosopis, plant suitable species to protect wetlands like bamboo. Similarly focus should be on best agricultural practices to support functions and existence of wetland ecosystems.

### 6.7 Fisheries

Lake Turkana is unique among the larger lakes of the eastern Rift Valley in that its aquatic fauna is dominated by Nilotic riverine species, rather than by species of the cichlid family (Lowe-McConnell 1993). Compared to other large African lakes, Turkana has relatively low fish species richness, providing habitat for about 50 species, 11 of which are endemic. According to Hopson (1982), four fish communities live in the main lake: a littoral assemblage, an inshore assemblage, an offshore demersal assemblage, and a pelagic assemblage.

Fishing in Kalokol is a major activity. Limited fish storing facilities means fishmongers may have to sell at compromised prices to make gain. Activity is carried out by women, men and children. Local fishing population would benefit from ready market storage facilities and good road. There is provision for sundried fish but this is affected by rainy season. Refrigerated trucks help to transport the fish but these take up to 2 weeks to fill 5 tonnes.

Declining water levels of Lake Turkana due to perennial drought, evaporation, siltation and damming activities of River Omo in Ethiopia threaten to affect this source of livelihood for the local community.
According to Godfrey Monor, director of fisheries in the Fisheries Ministry, poor infrastructure and insecurity have hampered efforts to provide market access to fishermen. There are initiatives to introduce solar [fish] driers, and fishermen are also being sensitized on how to produce sun-dried salted fish. This will go a long way in conserving the environment since the doum palms they used for smoking fish are fast disappearing since they used the female doum palm and the fruit husks as a source of fuelwood. Solar energy is green energy which is the best alternative to using doom palms though the test of fish will not be the same.

A private partnership between Kenya and the Democratic Republic of Congo is expected to provide a ready market for the sun-dried salted fish. "There is also a private developer who is putting up a cold storage facility in Lodwar [main town in the region]," said Monor, adding that the government is also helping to initiate irrigation schemes around the lake to help fishermen to diversify their income streams. (IRIN)

**6.8 Kibish Sub - County**

Todonyang plains lie west of the northern tip of Lake Turkana close to the Ethiopian border. Prolonged droughts have made the local community vulnerable as pasture becomes scarce and wells dry up. The Daasanach of Ethiopia move into Turkana territory in search of pasture since their government handed most of their traditional land to large-scale farming developers. Competing for the fishing grounds of Lake Turkana and the pastures around it, these rival communities are trapped in a vicious cycle of conflict as they struggle to survive. The Turkana and the Daasanach lived side-by-side for centuries and learned to adapt to the harsh conditions of their arid environment.

However with the changing climate and unpredictable anymore and the size of the pasture is rapidly shrinking creating fierce competition for survival between the rival ethnic groups. Although a part of their culture fishing is considered a lowly occupation practiced only by the poorest. Left with no alternatives to secure food for their families more and more Turkana are turning to the lake for survival.
The Maritime Police Unit was recently deployed to the village of Lowarengak to protect the Turkana community from the increasing attacks from the rival Daasanach tribe by patrolling the Omo River delta along the Ethiopian border. Although the fish tolerate the highly saline lake waters they migrate north to breed in the estuary of the Omo River that brings nutritious sediments and fresh water supply to Lake Turkana. As the fish population has decreased drastically in the past decade due to overfishing the starving people often hunt for food in the Omo delta where disturbing the breeding grounds further contributes to their dwindling numbers.

In recent years the attacks by the rival Daasanach tribesmen are more frequent and aim to scare off the Turkana from their land in order to gain access to their fisheries. As Lake Turkana suffers from overfishing the actual size of the fish and its overall population numbers have reduced drastically over the last several decades making it increasingly difficult for the Turkana to make ends meet during times of prolonged drought. The shallower waters are critical for breeding fish. "If the government could scale up support for fishermen to make the deeper waters accessible, that would help." Beach management unit provides nets to assist fishermen.

The findings of a Kenyan nutrition survey, published this month by the health ministry in consultation with the UN and NGOs, have alarmed experts. In the most vulnerable arid and semi-arid regions, which span about 80% of the country, one in four children is acutely malnourished and requires medical attention.

In summary the current nutrition situation has slightly deteriorated, this is evidenced by NDMA MUAC surveillance data and routine health facility nutrition data. However the deterioration seems to be within normal season trends. There is a high likelihood of the situation worsening if the food security situation deteriorates further and if the current long rains season (March to May 2014) performance is below average, late or poorly distributed. There is need for increased nutrition surveillance to monitor the impact of the current food security as appropriate response mechanisms are put in place.

The HIV/AIDS pandemic competes for attention with many other pressing issues. The problem with Turkana is that it has many neglected issues that are more important to people than HIV... like food insecurity, water, education and
poverty. If people have no water and are hungry, it therefore becomes difficult to talk to them about HIV/AIDS"

Sustainable water sources to feed animals sustain crops and raise fodder. The water level is very low once again, and the group, from the Napak irrigation scheme, is digging an emergency channel to ensure that they have water for their maize crops.

The scheme, and another, larger one in neighbouring Napeika, are co-ordinated by a local community-based organization, Apad, which, with USADF support, has successfully formed former pastoralists into co-operatives to manage water resources and build capacity in farming techniques. This has included taking groups of Turkana out of the county to see successful irrigation projects elsewhere in the country – places, Lomari says, they had never thought they would see. In the south, he says, people are so healthy. That is what he wants for his community.

To enhance sustainable exploitation of natural resources communities are encouraged to form marketing cooperatives for their resources to get value of their products. These include sand and ballast harvesting cooperatives, charcoal producers association small scale miners association, fishing cooperatives and so on. There is need to revive the defunct fisheries cooperatives in Kalokol invest in boats to enable deep lake fishing and reinforce the beach management unit. Similarly women can form community groups that produce food and cash crops like Aloe turkaniensis.

In such organized groups there is potential for support, motivation, training and funding so as to improve business skills and enhance income generation through sell of seedlings produce fodder for livestock, raise fruit trees, search for markets for their charcoal learn how to efficiently produce charcoal without harming the environment carry out reafforestation programmes and learn entrepreneurial skills. Farmers can learn modern livestock husbandry carrying capacity disease control to avoid loss during severe droughts which includes getting insurance.
6.8 Alternative livelihoods like beekeeping

Recommendations on how to build the capacity of the local people to be more involved in the utilization of the identified natural resources.

With fears that climate change increases the frequency of droughts, the priority is to find ways of helping the Turkana use their livestock and land to build economically sustainable activities that will enable them to move away from aid dependency.

A roadmap that shall guide Turkana County government on the best approaches for engagement with the private sector / potential investors in order to leverage on the established natural resource base includes.

Pursue private partnership between to provide a ready market for the sun-dried salted fish.
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Chapter 7: Renewable Energy Resources

Renewable energy is the type that is obtained from resources that are naturally occurring and that can be naturally replenished over time.

Three emerging renewable energy sources are:

  i. Solar Energy
  ii. Wind Energy
  iii. Biomass

Unlike conventional fuels that contribute to the greenhouse effect, renewable energy reduces the carbon footprint and has therefore earned the title ‘Green Energy’. It has also been referred to as the ‘Energy of the Future’ due to its constant replenishment and resultant sustainability.

Renewables, being readily available, can be exploited and channeled towards attending to the immediate energy needs of Turkana County.

In conducting the natural resource mapping exercise for Turkana County, we focused on the three emerging renewables: Solar, Wind and Biomass as sources of energy; and examined their potential and viability in the county.

1 Solar Energy

Turkana County enjoys sunlight for an average of 10 hours daily. This is an opportunity that is already being tapped into, albeit on a relatively small scale. The radiant heat and light has been harnessed from the sun as both electrical and thermal form.

Solar thermal energy is heat generated from solar and is mostly used to heat water for domestic or industrial use. Solar electrical energy on the other hand is electricity generated from the sun through the principle of photovoltaics (PV). Electricity produced is in the form of DC power and can be converted to AC power through inversion. This has been tapped into in Turkana County only for lighting a few houses, schools, health facilities and missionary facilities.

Electricity generated can be used directly or can be stored in batteries for future use. In the case of storing the power, a charge controller is necessary to protect the battery from damage as a result of overcharging or undercharging.
1.1 Solar Assessment

It is imperative that before projects involving thermal or electrical generation are pursued, viability of solar as a resource is carried out. It is important to note that no solar assessment has been conducted in Turkana County.

Solar radiation assessment should be done to establish the average daily solar irradiance that a given area receives, over a specified period. Data is collected through satellites, ground metrological stations or in some cases, a combination of both.

In a nationwide assessment done by SWERA from the year 2000 to 2002, data collected by a Meteosat satellite was used. The M-7 satellite used is located at 0° latitude and 0° longitude and performs a scan every 30 minutes at a spatial resolution of 5x5 km².

Global Horizontal Irradiance (GHI) and Daily Normal Irradiance (DNI) data acquired from 34 metrological stations over a period of 3 years was used to develop a solar atlas for the country. GHI is more relevant when assessing PV potential and an average value that exceeds 5kWh/m² indicates good solar potential.

It is evident from the national atlas that Turkana County receives between 4 - 6kwh/m² of daily solar radiation and therefore has a vast potential for solar energy production.
Figure 25: Daily Solar Irradiance in Turkana County
2 Wind Energy

This is a form of energy extracted from air flow and can either be mechanical or electrical. Windmills are used for their mechanical power that is mostly used in water pumps, while wind turbines convert kinetic energy from the wind into electrical power.

Wind turbines are essentially AC induction generators, having 2 or 3 blades mounted on a shaft to form a rotor. A combination of lift and drag causes the blades to spin like a propeller, in turn spinning the shaft to generate electricity.

2.1 Wind Assessment

In order to quantify the wind energy available at any given area, wind power density has to be calculated. This by definition is the mean annual power available per square meter of swept area of a turbine and is a factor of the wind density and wind velocity.

A wind atlas was also developed alongside the solar atlas by SWERA in May 2008. Wind speed data was collected between 2000 and 2002 from about 34 synoptic ground stations spread across the country at heights of 10m and 50m. Data collected was later analyzed and used to develop the country’s wind atlas.

During our mapping exercise, efforts to access current wind speed data from the Ministry of Energy and Petroleum in Nairobi were not successful. As at the point of production of the final report, necessary effort shall be made to access the data.

Research shows that wind speeds between 2.8m/s and 3.5m/s are sufficient for power lifting applications. Speeds above 3.5m/s are enough to spin wind turbines, with speeds above 6m/s being the most ideal for firm electricity generation. Most parts of Turkana County can be categorized as moderate wind energy zones since wind speeds are between 3-5m/s. Northern parts of the county and some parts bordering the lake to the south, are good energy zones since wind speeds experienced are in excess of 5m/s.
Figure 26: Mean Annual Wind Speeds in Turkana County
3 Biomass

Many a time when talking about renewable energy, we forget to mention biomass, which by all means is a vital renewable resource if obtained sustainably.

Biomass is organic matter; material derived from living or recently living organisms and mostly refers to plants or plant based materials. Biomass finds it use in the following 3 forms:

- As biopower – When burnt directly
- As biofuel – When converted to liquid fuels
- As bioproducts – When converted into chemicals for making plastics et cetera.

It is a flexible form of energy and can be exploited at a localized scale for heat generation or at a large scale for power generation. Since it can also be stored and used on demand, it is deemed controllable and thus a very possible solution to the ever increasing energy demands.

3.1 Biomass Potential

Assessing for biomass potential essentially involves evaluating a probable source and examining whether or not the source can be obtained in a sustainable manner, without leading to environmental degradation and the resultant imbalance in the ecosystem.

In Turkana, the largest potential lies in *Prosopis juliflora*. Initially introduced to the arid and semi-arid regions of Kenya in the 1980s, it has slowly become a nuisance to the population. It has become a noxious invader, spreading rapidly and posing threats to the herders’ livestock and to the environment in general. Currently it covers a vast area of the county and efforts are underway to deal with this pandemic.
In a research paper submitted by Oduor and Githiomi from KEFRI, *Prosopis juliflora* was discovered to have a calorific value of 4.952 Kcal/gram at a moisture content level of 5.25%. With 4.64% moisture, calorific value rose to a level of 7.854 Kcal/gram. (Note: Calorific value is the amount of heat released per unit mass). This implies that it is a very high quality fuel wood that is usable either as wood or charcoal.

As a mitigation strategy, this plant can be used as a primary source of biomass in the county. On small scale, it can be used for heating in homes and on a larger scale be used to generate electricity. Biomass (in our case, *Prosopis juliflora*), is converted into electricity, heat and residual char by a process known as cogeneration. Electricity generated would be fed into the grid and sold to Kenya Power through a Power Purchase Agreement (PPA). The residual produced heat will be fed into industries and the residual char used in water purification or as a fertilizer.
4 Greenfield Sites

These are potential sites where development of mini-grid hybrid stations could greatly influence the productivity of adjacent nascent and small growth town centers.

Most of these hotspots were identified in the REMP of 2009, with additional ones being identified later by SREP. From a survey done by Economic Consulting Associates for the kfW project in 2014, the sites are shortlisted to 22 viable sites. Of these 22 sites, the following 7 are located within Turkana County:

- Naduat
- Kokuro
- Kalokol
- Oropoi
- Kataboi
- Longtech island
- Lowarangak

Short listing was based on criteria such as absence of the national grid in the area, sufficient electricity demand, economic activities, potential for expansion and synergy with existing projects.

5 Existing Projects

Current developments within Turkana County in regard to renewable energy include the burning of charcoal from Prospis juliflora. This is a primary source of fuel for homes, hotels and institutions being used for heating and cooking. Otherwise it has not been exploited on a large scale, yet the potential exists.

Wind and solar resources are the most commonly exploited with most companies involved have been driven by the need to reduce costs of operation, through alternative sources of energy.
Solar has been welcomed into the county by a number of institutions, though still not fully exploited and it is being used in both micro and small scale projects. Wind energy, being the oldest form of energy, has been harnessed since the early 1990s using wind mills to pump water.

Wind as a source of electricity is however a relatively new concept in the county with only a few projects running on electricity generated from wind. It is not as widespread as solar, but is slowly catching on, albeit on a micro scale.

Some of the institutions that have pioneered renewable energy in Turkana County include:

**Kenya Power**

Lodwar is 200km from the nearest grid and has a peak demand of 1011kW. It is powered by an off-grid station commissioned in 2007. The station was initially developed by the Rural Electrification Authority. After completion, operations were handed over to Kenya Power.

The Mini-Grid was being operated as a stand-alone diesel powered station up until 2012, when a PV system was introduced. It is as a result now a diesel-PV hybrid system; with the PV complementing the power generated by the gen-sets.

As of 2014, the PV solar system had an installed capacity of 60kW, which is still very low, compared to that of the 4 gen-sets at the station. The 4 diesel powered gen sets have a combined capacity of 1440kW. Power generated by both systems is fed directly into the Lodwar power grid.

This move has resulted in major savings in terms of fuel costs. Fuel costs have been reduced by up to 1.4 million shillings every month. Plans are still underway to increase the capacity at the station. This clearly demonstrates that solar energy is the energy of choice for Turkana County in the near future.
**Lodwar Water and Sewerage Company (LOWASCO)**

Lodwar Water and Sanitation Company in partnership with JICA (Japanese Aid Agency) have embarked on a project to provide a solution to the water needs of Turkana County, especially for the residents of Lodwar town. The joint venture has resulted in installation of hybrid systems that combine solar power and gen-sets. The borehole water pumps are powered by an array of PV panels during day and at night, the power source automatically switches to gen-sets. This accounts for 24 hour water supply in Lodwar town.

**Figure 28: PV Array - LOWASCO**

The employment of solar has also reduced maintenance and running costs, while also ensuring access to clean water. This is a model that should be scaled up and indeed help pump water to the communities in the various rural areas.
**Safaricom**

Being the leading service provider in telecommunications in Kenya and indeed the region, it is in the company’s best interest to keep its subscribers connected to the service. As a measure, Safaricom is using solar energy and wind energy to power most of their Base Transmission Stations (BTS) spread across the county.

![Figure 29: Safaricom Hybrid BTS](image)

Since most BTSs are erected on hills and in very remote areas, access to the grid is actually absent or very limited. Where Safaricom has set up such stations, it has moved from relying on diesel powered gen-sets, to incorporating solar and wind to hybridize their systems.

In some areas, solar and wind alone is sufficient to run the base stations but in more than 8 of these stations across the county, the systems are diesel-solar-wind hybrids.
Lomidat Meat Factory

A visit to the abattoir revealed that the facility uses solar power as a backup. Proximity to the grids means that the property is directly connected to electricity from the supply station at Lokichogio.

The slaughter house is yet to move to 100% green energy but the PV systems in place provide a buffer to inconsistencies in power supply. This in essence means they are able to light the facility and power a few computers within the premises.

Apart from the aforementioned establishments, we still have a number of ongoing projects by both the public and private sectors that have tapped into the wind and solar resource. Some of the projects include:

Solar Street Lighting
This year, in an initiative led by the county government, more than 70 solar street lights were erected around Lodwar town. These lights, standing at 7m meters above the surface have beautified the streets, improved security and are one step towards realizing a 24 hour economy.

Figure 30: Solar LED Street Light, Lodwar
The PV panels are exposed to sunlight for more than 6 hours during the day and this is sufficient to power the LED lights after dark.

**Rural Electrification Programme**
This is an initiative undertaken by the national government to provide electricity to public institutions and bring access to the rural populace. Rural electrification has been implemented either by grid extension or off-grid supply by Rural Electrification Authority (REA).

So far, 45 public facilities in the county have benefitted from this programme.

**Borehole Pumps**
Most of Turkana County is semi-arid and thus access to clean water is a major challenge. Communities living in Turkana are predominantly pastoralists and have to traverse the county in search of pasture and drinking water for themselves, as well as their cattle, sheep, goats and camels.

As a counter measure, boreholes have been drilled across the county either by the national government, Diocese of Lodwar, county government or even international organizations to give the resident communities access to clean water.

*Figure 31: Hybrid Borehole Set-up*
Water occurs at a depth and therefore means of bringing it up to the ground has to be devised. For the existing boreholes, their power sources are as indicated in the table below.

**Table 5: Boreholes and their power sources**

<table>
<thead>
<tr>
<th>Power Source</th>
<th>Number of Boreholes</th>
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</thead>
<tbody>
<tr>
<td>Manual</td>
<td>147</td>
</tr>
<tr>
<td>Mains Supply</td>
<td>4</td>
</tr>
<tr>
<td>Diesel</td>
<td>75</td>
</tr>
<tr>
<td>Solar</td>
<td>23</td>
</tr>
<tr>
<td>Wind</td>
<td>20</td>
</tr>
<tr>
<td>Hybrids</td>
<td>2</td>
</tr>
</tbody>
</table>

It is evident that 54% of existing boreholes are manually operated, by use of hand pumps. Less than 0.2% use alternative energy, an indication that more has to be done to promote these alternative sources of energy.

**Napuu Irrigation Project**
Following the discovery of the Napuu aquifer, 6km from Lodwar town, the national government through the Ministry of Environment, Water & Natural Resources initiated an irrigation project with a vision of irrigating 180 hectares of land.

![Figure 32: PV Panels - Napuu](image)
Five boreholes have since been drilled in the area and each equipped with a solar water pump, capable of pumping 1000 litres/min. Each of these pumps is powered by an array of PV panels. More than 600 panels have been installed, and the estimated installed capacity on site is 90kW.

6 Challenges Facing Renewable Energy Development

Policy
At the moment, the policy framework in the country breeds confusion and hence hampering the uptake of renewable energy. Roles of the national government and the county government are not clearly cut out. They seem to be overlapping, leading to uncertainty amongst the public and even potential investors.

Uninformed Public
The population is green on this topic and is yet to understand the benefits of seeking alternative sources of energy. Without access to information on solar and wind energy, a bigger chunk of the population is still over reliant on fossil fuels that are expensive, prone to price fluctuations and are not environmental friendly.

Lack of Resource Data
Lack of accurate and well organized data on wind and solar creates a technical barrier to potential investors. Currently, data available is scanty and most of the data collected by metrological stations is for agro-metrology and civil aviation.

Most decisions to install PV systems are made based on human observations and practice rather than reliable and scientific data. No reliable data is readily available on energy demand, solar radiation and wind speeds.

Inadequate Technical Skills
Even with the current developments in solar and wind energies within the county, there is still a gap in expertise. There is lack of adequate skilled personnel to undertake monitoring and evaluation of resource data. Moreover, inadequate domestic technical skills have led to poor installation, maintenance of equipment and after sales services.
Energy Storage
This problem largely affects existing projects. It is manifested in battery failures and is not much so a problem with the type of batteries used but rather lackluster connections and poor maintenance. This again points to lack of technical know-how.

7 Recommendations

Turkana County has huge potential for solar farms, wind farms and even cogeneration plants, but in order to fast-track the deployment of renewables, a number of steps have to be taken.

Policy Framework
It should be made clear what role the county government is supposed to play in terms of energy and particularly renewable energy. With clearly outlined mandates, then the county should be able to fast-track the uptake of renewables and create an enabling environment for investments in this lucrative and beneficial sector.

As part of the policy, the county government should also enforce mandatory PV and wind installations in all upcoming county ministry offices in a bid to encourage renewables in the county.

Sensitizing the Public
The public should be sensitized on emergent alternative sources of energy that are safer and more cost effective compared to the conventional fuels still being used across the county.

People should be educated on the benefits of adopting renewables in a bid to encourage them to embrace renewables. This will also bring renewables into the mainstream energy agenda, shifting it from the periphery where it has been for the longest time.

Incentive Schemes
The county should come up with sufficiently strong and durable incentives that are specific to the renewable energy sector. This will motivate more investors to support the renewables and ensure cleaner and safer energy for the current and future generations.
Robust Data Collection

Information gathered from satellite sources though indicative is insufficient to warrant heavy investment to exploit these renewable resources. It forms part of the baseline survey and thus further ground work has to be done before feasibility of renewables in a particular area is confirmed.

Data needs to be collected in an organized manner and made available to the public and potential investors. Some of the vital equipment that facilitates data logging includes:

i. Solarimeter

![Solarimeter](image)

Figure 33: Solarimeter

Also known as a pyranometer, it is a portable autonomous instrument that measures solar irradiation for control of PV and thermal installations on site.

The device is used to analyze sunshine on short term or long term periods and gives critical information useful in determining the appropriate thermal or PV generator and even optimum orientation of the solar panels.

Solarimeters should be installed in different parts of county to assess in detail the solar energy potentials in these areas. These instruments should be placed on open sites free from shadowing, and at 10cm above the ground.
ii. Anemometer

![Figure 34: Anemometer](image)

This wind meter is a device used to measure wind speeds. For effective wind assessment, they should be spread across the county and erected at 50m above the ground. Most commercial wind turbines are 50m tall; hence data at 50m should be conclusive.

**Capacity Building**

Trained manpower capable of managing and servicing RETs is a prerequisite to embracing renewable energy. Technical personnel play a huge role in implementing renewable energy projects and therefore their capacity and skills have to be sharpened.

Technical training should focus on the following key areas:

i. Technical feasibility assessment
ii. Remote monitoring
iii. Energy storage
iv. Control equipment
v. Load management
Research and Development

Seeing as to how much potential the county possesses, Turkana County Government should invest to specifically steer research on these sources of alternative energy. Research needs to be done on how best to tap into these resources to provide energy security to the people of Turkana County.

8 Future Plans and Opportunities

Having created an enabling environment for the dissemination of renewables within the county, some of the possibilities include:

i. Development of solar farms
ii. Development of wind farms
iii. Development of cogeneration plants

The rewards will be immense for the county government and the people of Turkana when such projects are pursued. Wind and solar exploitation will change the face of the county; bringing in more investors that could potentially add to employment opportunities, infrastructure development and improved the economic activities for the people of Turkana county.

For starters, Turkana County Government should put in place a policy that ensure all county government buildings are equipped with solar panels to ensure productivity given the frequent power outages. The policy should gradually extend to new commercial buildings to ensure that developers and investors tap into the abundant solar energy available in the area.
Chapter 8: Challenges that Hinder Exploitation of Natural Resources in Turkana County

During the process of conducting the mapping exercise, it was imperative to establish the challenges that obscure the people of Turkana county from sustainable exploitation of the vast resources bequeathed unto them by Mother Nature. The most common challenges enlisted included:

i. Extreme difficult in accessing water, both for the people and livestock.

ii. Insecurity and conflict on trans-boundary resources.

iii. Over reliance on livestock and the attendant exposure to the vagaries of drought and livestock diseases.

iv. Low levels of education and access to information.

v. Low penetration of mobile telephony and (Information and Communication Technology) ICT.

vi. Cultural practices that do not embrace capitalism.

vii. Poor and inadequate infrastructure.

viii. Land tenure system – community ownership of land.

ix. Inadequate access to markets and market information.

x. Poor energy supply and therefore failure to attract and support manufacturing / processing and therefore limited employment and wealth creation opportunities at the community level.

xi. Low uptake of opportunities provided by state agencies, e.g. KWS commercialization of conservation efforts.

xii. Low levels of entrepreneurial culture among the people.

xiii. Lack of appropriate tools and equipment as well as storage facilities, especially for fishing. Most of the people conducting artisanal mining in gold, gemstones, gypsum and dimension stone do not have appropriate tools, protective clothing or any safety gear.
Chapter 9: Recommendations and the Way Forward

It is imperative that guidelines and operational strategies for a county specific approach in harnessing the benefits of existing results be established. Fifty years since independence, the people of Turkana people have not indeed savoured the fruits of independence. This therefore means that the leadership at the county government level must devise innovative approaches in ensuring that water and food security are guaranteed to the people of Turkana. There is need for transformation in the mindset so Turkana County stops being viewed as a county of “lack” but one of plenty, for indeed the county’s natural resource endowment has the capacity to change not only the local economy but the national as well as regional economy. This is a necessary intervention by the leadership so as to offer hope to the people and indeed attract the right mix of investors and investments.

Turkana county has many lessons to learn from economies that have become beacons of hope despite their past tragedies and indeed hostile climate conditions. Such countries have leveraged on the resilience, motivation and education of their people to become recognized as pacesetters in their own right. Such economies include Botswana, Namibia, Rwanda and Israel. In order to position herself as a progressive economy, Turkana needs to devise an attractive and predictable investment climate and this has the potential to leapfrog the county from the poorest to one of the leading counties in Kenya in the next two decades. The lessons learned from the extensive exploration work conducted by Tullow oil and the subsequent social and economic benefits to the people of Turkana County exhibits a perfect model for the emerging mineral exploration potential in Turkana County.

In order to ensure that there is sustainable use of natural resources, there is need to consider the following fundamentals:

- Environmental and social costs fall on those who impose them. (Polluter Pays – those individuals or organizations who pollute the environment are made to pay a fine for that action), and efficient resource use is incentivized (individuals or organizations who act to protect or conserve the environment are rewarded through incentives).

- Using sound science responsibly: ensuring that policy is developed and implemented on the basis of strong scientific evidence, whilst taking into account scientific uncertainty as well as public attitudes and values.
✓ Promoting good governance: promoting effective, participative systems of governance in all levels of society – engaging people's creativity, energy, and diversity.

Having taken inventory of the natural resources in Turkana County and their potential to transform the quality of the lives of the people, the following recommendations will shape the future of sustainable management of the exploration and exploitation of the identified natural resources:

i. An aggressive and sustained effort to supply clean drinking water. While this effort shall ensure that the population is able to access portable water, the same shall ensure that fruits and vegetables can be produced and hence the nutrition of the Turkana community greatly enhanced. The cost of providing water is quite high and the county government needs to explore opportunities of engaging in mutually beneficial partnerships with investors who may be interested in mining, agriculture, manufacturing, or any other sector. The county government further needs to closely work with Diocese of Lodwar in order to harness the experience and expertise in especially management of the mobile borehole maintenance/recovery units. Turkana County government should discourage development of any social facilities in areas without access to water, whether such developments are public or private.

ii. The other key priority in facilitating the people of Turkana county enjoy the natural resources mapped is by the county government investing in exploring possibilities of harnessing the identified potential for solar, wind and geothermal energy. Energy is the second most important driver after water for optimal and sustainable exploitation of natural resources. In order to achieve this target, Turkana county government needs to loop in potential investors and indeed carry out feasibility studies that will inform requisite future actions, targeted at increased energy production.

iii. Turkana County has vast and beautiful land that would be very useful for community owned and managed conservancies, with the attendant benefits of conserving wildlife and indeed supporting tourism. The conservancies shall go a long way in transforming the landscape and indeed ensure that future generations shall have the opportunity to share in what nature has endowed upon the current generation.
iv. The county government ought to play a proactive role, especially in creating incentives around provision of land for setting up of both solar and wind farms, parks or fields. Research findings indicate that one of the things that discourage investors from having elaborate wind and solar farms is the cost of land. The land required varies from one acre to hundreds of square kilometers, depending on the nature of the project.

v. It is important that Turkana County government considers the issue of model villages. This is a development where housing is developed in an identified area and amenities such as water, schools, electricity, health, security, etc are provided to the population. Given that the Turkana community is basically pastoralist, this will ensure that there is some level of access to basic services for most of the population. Indeed, with this kind of a development, it is possible to initiate and maintain suitable pastures for the cattle, goats, sheep and camels. This model has been tried in Rwanda and it has worked with remarkable results.

vi. The County government should initiate and roll out programs to strengthen the capacity of the local communities through offering basic business management skills either through cooperatives and/or community based organizations in order to ensure the development of an entrepreneurial culture as well as sustainable approaches in the exploitation of the identified and mapped natural resources.

vii. While Aloe Turkaneisis and Neem tree do very well in Turkana, there has not been adequate deliberate attempt for them to be grown on a commercial scale. This is an opportunity that needs to be exploited and indeed create a brand of an assortment of organic health products (oil, gel, soap, etc.) that should be placed on the local, national, regional and international market.

viii. Despite the large levels of livestock in the county, there is not a corresponding scale of leather processing establishments in the county. This is an opportunity that needs to be further explored as value addition in hides and skins will contribute towards wealth and employment creation.

ix. There is need to invest in setting up commercial apiaries in the county and produce branded honey products. The fact that the county boasts of huge trucks of land and fairly reasonable vegetation cover is an opportunity that honey production is a potential game changer in the local economy.
x. Turkana County government should engage the Ministry of Mining at the national level, Kenya Chamber of Mines and the various exploration companies already working in the county so as to have a coordinated approach in mineral exploration and exploitation. It is important to note that there is need to create a well thought balance between artisanal and commercial mining activities. For the County to become an attractive mining investment destination, a blend of the two is most ideal and the community must be educated on the benefits of commercial mining. For example, petrified wood abounds in the county. It is excellent material for furniture, tiles and landscaping. It can be done both at artisanal and commercial levels on a pilot basis.

xi. The county has an unmatched endowment of minerals especially limestone and good quality gypsum. There should be a deliberate attempt to ensure that markets are accessed for the same, with a long term view of setting up a cement factory in the county to serve the County as well as parts of Southern Sudan. The gemstone industry has huge potential and the County should invest in adequate training on both extraction and cutting to ensure maximum benefits for the people of Turkana County.
## Appendices

### Appendix 1: Implementation Matrix – Natural Resource Mapping – Turkana County

<table>
<thead>
<tr>
<th>No.</th>
<th>Activity</th>
<th>Week 1 &amp; 2</th>
<th>Week 3 &amp; 4</th>
<th>Week 5 &amp; 6</th>
<th>Week 7</th>
<th>Week 8</th>
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The implementation matrix covers a period of eight (8) weeks between 1st April and 30th May 2015. The assignment was executed on schedule and the validation workshop was scheduled for Thursday, 21st May 2015, with the final report due by 30th May 2015. There were 3 days for preparations and logistics, 42 days for conducting interviews, field visits, gathering data, collecting and analyzing samples. Preparation and production of the draft report took 7 days, 2 days for the validation workshop and 6 days for the integration of the input of the stakeholders, preparation and submission of the final report.
Appendix 2: Mineral Resources Mapping Template

A. Where Mineral Is Identified

1. Identified mineral (sample taken and labeled properly)

2. Mode of occurrence-continuous or disseminated

3. GPS location

4. Rock type i.e. specific e.g. Ignimbrite (rock containing the mineral and country rock where mined)

5. Dip and strike of host and surrounding rocks

5. Geological Structures where mined i.e. -bedding, fault, shear zone

6. Associated minerals

7. Name of miner or company mining

8. Economic impact to community

9. Any fossils

B. Where Mineral Not Identified

1. GPS location

2. Rock type i.e. specific e.g. gneiss (sample collected and labeled properly)

3. Dip and strike of the rocks

4. Geological Structures-Veins, shear zones, Joints (occurrence and direction), lineation (occurrence and direction), folds, faults (occurrence and direction), Thrusts, unconformities, foliations,

5. Lithological changes, and geological contacts (GPS)

6. Any mineral indicators e.g. coloration, weathering products

7. Any economic activity associated with the rock

8. Vegetation type where the rock is not exposed

9. Any fossils
Appendix 3: Water Resources Mapping Template

**A. Surface Water**

1. Type e.g. spring, river, lake, pond
2. Status i.e. with or without flowing water
3. GPS i.e. source for spring, point of lake, or point at river channel
4. Surrounding environment e.g. swampy or not
5. Any economic activity associated with the water body

**B. Groundwater**

1. Type e.g. borehole, shallow well
2. Status i.e. with or without flowing water or dry
3. GPS
4. Surface geology
5. Structural characteristics of the investigated area (area of borehole, well); i.e. Geological Structures-Veins, Joints (occurrence and direction), faults (occurrence and direction).
6. Any economic activity associated with the borehole or well
Appendix 4: Distribution of Groundwater Abstraction Points (Boreholes and Shallow Wells) Per Ward in Turkana County

Figure 35: Shallow Wells - Lokichogio
Figure 36: Boreholes - Lokichogio
Figure 37: Shallow Wells - Kachodin
Figure 38: Boreholes - Kachodin
Figure 39: Shallow Wells - Kaikor
Figure 40: Boreholes - Kaikor
Figure 41: Shallow Wells - Kakuma
Figure 42: Boreholes - Kakuma
Figure 43: Shallow Wells - Kalobeyei
Figure 44: Boreholes - Kalobeyei
Figure 45: Shallow Wells - Kalokol
Figure 46: Boreholes - Kalokol
Figure 47: shallow Wells – Kang’atotta
Figure 48: Boreholes - Kang'atotoha
Figure 49: Shallow Wells - Kaptir
Figure 50: Boreholes - Kaptir
Figure 51: Shallow Wells - Katilia
Figure 52: Boreholes - Katilia
Figure 53: Shallow Wells - Katilu
Figure 54: Boreholes - Katitu
Figure 55: Shallow Wells - Kerio
Figure 56: Boreholes - Kerio
Figure 57: Shallow Wells - Kibish
Figure 58: Boreholes - Kibish
Figure 59: Shallow Wells - Letea
Figure 60: Boreholes - Letea
Figure 61: Shallow Wells - Kainuk
Figure 62: Boreholes - Kainuk
Figure 63: Shallow Wells -
Figure 64: Boreholes -
Figure 65: Shallow Wells - Lodwar Township
Figure 66: Boreholes - Lodwar Township
Figure 67: shallow Wells - Loima
Figure 68: Boreholes - Loima
Figure 69: Shallow Wells - Lokichar
Figure 70: Boreholes in Lokichar
Figure 71: Shallow Wells - Lomelo
Figure 72: Boreholes - Lomelo
Figure 73: Shallow Wells - Lorengipi
Figure 74: Boreholes - Lorengipi
Figure 75: Shallow Wells - Lorugum
Figure 76: Boreholes - Lorugum
Figure 77: Shallow Wells - Nadapal
Figure 78: Boreholes - Nadapal
Figure 79: Shallow Wells - Napeitom
Figure 80: Shallow Wells - Ngibilae
Figure 81: Boreholes - Ngibilae
Figure 82: Shallow wells - Ngissiger
Figure 83: Boreholes - Ngissiger
Figure 84: Shallow Wells - Pelekech
Figure 85: Boreholes - Pelekech
Figure 86: Shallow Wells - Yapakuno
## Appendix 5: Table Indicating the Calculated Boreholes Specific Capacities (S), Transmissivities (T) and Specific Yields/Storage Coefficients and Hydraulic Conductivity

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Figure 87: A limestone deposit in Kaeris Ward
Figure 88: Shade Net at Kaptir Dispensary
Figure 89: Heap of Petrified Wood at Makutano Gold – Nakalale
Figure 90: Gold bearing marble at Kaptir
References


