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Assessment of Groundwater Potential and Prediction of the Potential Trend up to 2042 Using GIS-Based Model and Remote Sensing Techniques for Kiambu County

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Abstract

Groundwater is one of the important necessary renewable resources of the world. It forms part of the natural water cycle that is present in the underground strata with the principal sources being precipitation and streamflow. Traditionally, information on the potential occurrence of groundwater was obtained using techniques such as drilling, geophysical, geological, hydrogeological and geo-electrical which are time-consuming, costly and lacked full coverage. This study shows that remote sensing and GIS techniques can be utilized to map groundwater potential using a GIS-based model, the Modified DRASTIC Model, which incorporates factors that influence groundwater occurrence. These factors are the surface attributes that infer groundwater potentials and they include geology, soil texture, land use, lithology, landforms, slope steepness, lineaments and drainage systems. A prediction of the groundwater prediction was done by utilizing the MOLUSCE tool, a plugin in Qgis that utilizes ANN, multicriteria evaluation, weights of evidence and LRs algorithms in predicting land changes. The kappa value for prediction was 0.83. The results showed areas in the Southwest region had low to very low potential and the central region had high to very high potential for all the years and there were little changes between the years. The prediction showed that by 2042, the eastern region of Kiambu County will have a decline in groundwater potential.

Keywords

Groundwater, DRASTIC, MOLUSCE, Remote Sensing, ANN, LR

1. Introduction

Groundwater is one of the important necessary renewable resources of the world. It forms part of the natural water cycle that is present in the underground strata with the principal sources being precipitation and streamflow. Groundwater becomes usable when the water-bearing formations are permeable enough to allow water to infiltrate through them, to yield an adequate amount of water for use through boreholes, hand dug-well and springs, which can be replenished from recharge sources to permit continued exploitation [1].

Groundwater is a valuable resource that serves as a significant source of water for communities, agricultural and industrial purposes. It plays a critical role in ecosystem sustainability and human resiliency in the face of catastrophic and unpredictable global climate change [2]. Compared to other sources of water, groundwater is less vulnerable to climate fluctuations in an undisturbed aquifer system and can therefore, act as a critical buffer against drought and variations in rainfall [3]. This brings out the need to identify groundwater potential zones for groundwater development and effective water resource management. The potential of groundwater in a region depends on different facts and varies from place to place. Since groundwater cannot be seen directly from the earth's surface, its occurrence, distribution and movement depend upon the geological and hydro-geomorphological features of the area [4].

A variety of techniques have been put forward to give information on the potential occurrence of groundwater for easy exploration of the resource. Some of the techniques comprise: drilling, geophysical, geological, hydro-geological and geo-electrical but are deemed expensive and time-consuming. For that reason, the exploration calls for the putting into practice of actual approaches of precision and that saves both time and money [5]. Such approaches include Remote Sensing (RS) and Geographical Information System (GIS) technologies that have been applied extensively in ground studies. RS and GIS techniques provide access to large coverage including inaccessible areas. GIS offers spatial data management and analysis tools that assist in organizing, storing, editing, analyzing and displaying positional and attribute information about geographical data [3]. In the recent past, several researchers have utilized these techniques in the identification of groundwater potential zones around the world. [6] explored groundwater potentials by integrating GIS and remote sensing technologies. [2] stacked a few algorithms to create a hybrid model and used the model to perform groundwater mapping. On the other hand, [5] integrated remote sensing and vertical electrical sounding in mapping groundwater potential in Asals areas. [7] and [8] were keen to employ a resistivity survey technique in combination with GIS and remote sensing in prospecting groundwater potential zones.

In this study, an endeavour was made towards delineating and classifying underground water potential areas by using an overlay GIS model, the modified DRASTIC model which is a substitute of the initial D—depth to groundwater, R—recharge rate, A—aquifer, S—soil, T—topography, I—vadose zone's impact, and C—aquifer's hydraulic conductivity (DRASTIC) model that was used to map groundwater vulnerability zones [9]. This model is one of the better-known and extensively used in various studies to assess the intrinsic vulnerability of groundwater by considering known properties of the aquifers [10]. For this research, the factors used in the initial model are replaced with the factors that influence groundwater occurrence. These factors are the surface attributes that infer to groundwater potentials and they include: geology, soil texture, land use, lithology, landforms, slope steepness, lineaments and drainage systems. In addition, the climate conditions especially rainfalls also control movement and storage of groundwater.

Kiambu County is one of the 47 counties in Kenya. The county experiences high population projections due to the influx of people from other counties in search of better livelihood. Kiambu is situated next to the capital city, Nairobi and it is perceived that people who work in the city prefer to live in Kiambu County and surrounding areas where there are less congestion and well-developed infrastructure [11]. Furthermore, there has been a general shift in land use from agriculture to residential and commercial buildings in the area due to the increase in population. For that reason, there is need to diversify water sources to meet the high demand for water in Kiambu County. Some of these sources include groundwater resource, which is highly ignored in Kiambu and Kenya in general [3]. Therefore, this resource can be developed to supplement the water from other sources which is not enough for the growing populations in Kiambu county. Additionally, mapping groundwater potential zones will provide information on the water potential of Kiambu County and prevent the effect of sudden drying of boreholes or minimal yields from the boreholes during the dry seasons.

This paper, therefore, aims to provide information about groundwater potential zones and predict the future of groundwater potential in Kiambu County using the modified DRASTIC model together with Remote sensing techniques for further groundwater exploration, proper planning, sustainable utilization and management of groundwater resources.

2. Description of Study Area

Kiambu County lies between latitudes 10˚20' and 00˚25'S and longitudes 36˚31' and 37˚15'E. As per the 2019 census report, the county’s population is 2,417,735 with a population density of 952.4/km^2. The county covers an area of approximately 2538.6 km^2 (**Figure 1**).

3. Materials and Method

3.1. Data

To identify the groundwater potential zones in Kiambu County, different data were used to prepare various thematic layers of the study area. The used data incorporated satellite imagery in conjunction with auxiliary data such as geology, soil, lithology, geomorphology and rainfall as shown in **Table 1** below.

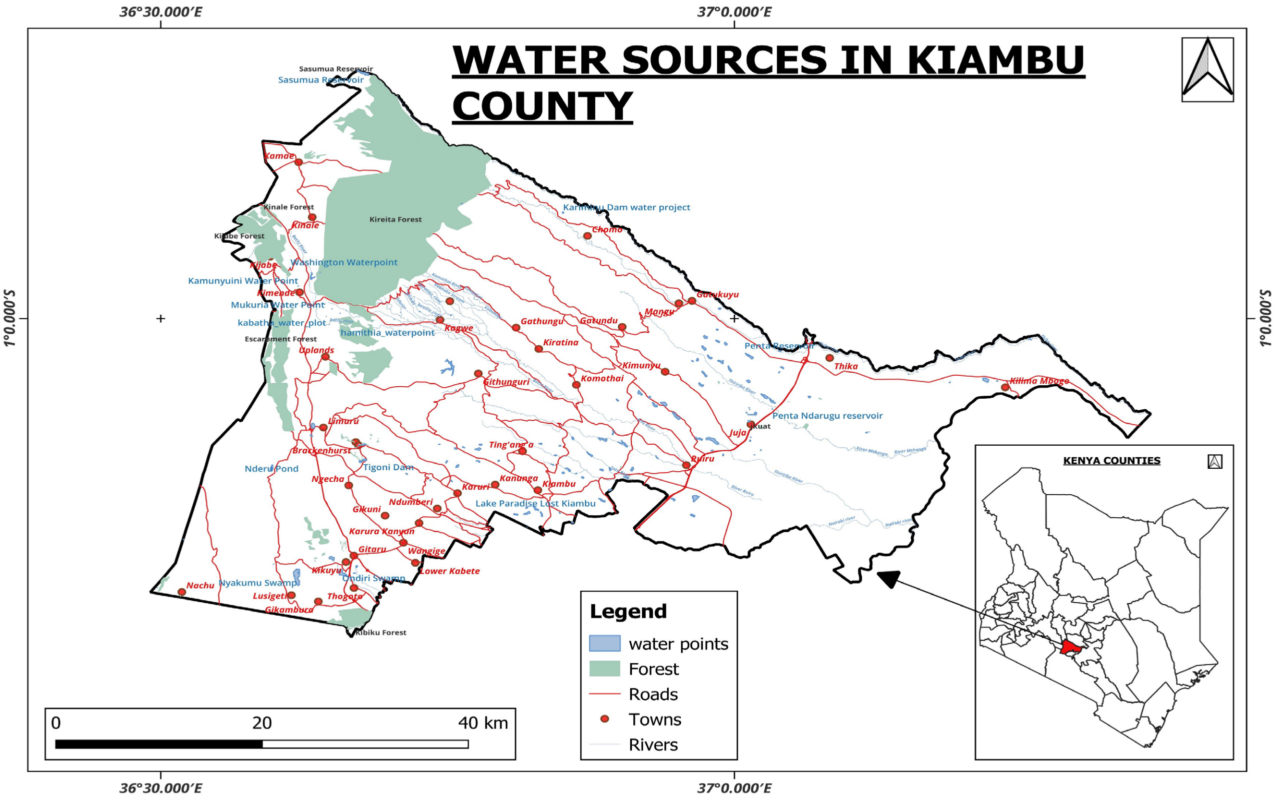


Figure 1. Kiambu county.

Table 1. Data sources.

Data	Source	Spatial Resolution (m)	Purpose
Landsat 4 (TM)/Landsat 7 (ETM+)/ Landsat 8 (OLI) (1992, 2002, 2012, 2022)	Earth Explorer	30 m	To extract lineament To perform LULC classifi-cation
SRTM DEM	Earth Explorer	30 m	Obtaining slope and drainage density
Soil	ISRIC		Obtaining soil types and texture
Lithology & Geomorphology	RCMRD		To produce lithology and geomorphology maps
Geology	USGS		To produce a geology map
Rainfall-CHIRPS (1992, 2002, 2012 & 2022)	USGS FEWS NET DATA Portal	5 Km	To give rainfall estimates

3.2. Methodology

The potentiality of groundwater in Kiambu County was evaluated using the modified DRASTIC approach. The approach considers the intrinsic characteristics of an aquifer, in hand with anthropogenic activities on the earth surface [10]. The factors that were employed in the model included: soil, land use land cover, lineaments density, drainage density, geology, geomorphology, lithology, slope and rainfall. The processing of these factors is given in detail in the subsections below.

3.2.1. Land Use Land Cover Classification

The three Landsat Imageries, Landsat 4 Thematic Mapper (TM)/Land-sat 7 Enhanced Thematic Mapper Plus (ETM+)/ Landsat 8 Operational Land Imager (OLI) acquired for the years 1992, 2002, 2012 & 2022 were pre-processed and later classified to obtain the land use land cover of the study area. The images were classified into six classes namely: Built-up, Cropland, Grassland, Bareland, Water and Forest land.

3.2.2. Lineaments Extraction

The Landsat images were used to extract lineaments. Principal Component Analysis (PCA) an image enhancement technique was performed where principal component statistics were computed in ENVI software. PCA was performed in order to minimize the dimensions of the data and to collect the most information in a band. The PCA image is used as an input image in PCI Geomatica for automatic lineament generation. The algorithm for lineament extraction in PCI Geomatica software consists of edge detection, thresholding and linear extraction steps which were carried out.

3.2.3. Soil

The KENSOTER database which contained the soil components was processed. This was done in ArcGIS environment. The downloaded soil texture data was processed to obtain the soil texture map.

3.2.4. Geology

A geology map was obtained from the downloaded Africa's geology data. The data was clipped to the area of interest and projected to be able to identify the various rocks in the study area. It was converted to raster for the model input.

3.2.5. Geomorphology & Lithology

Data downloaded on geomorphology and lithology was processed to identify the various geomorphic and lithological units in Kiambu County.

3.2.6. Rainfall

Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) is a quasi-global rainfall dataset that is obtained by combining data from real-time observing meteorological stations with infra-red data to estimate precipitation [12]. To obtain the annual rainfall estimates for each of the study years, the data was processed. The processes consisted of projections, resizing and spatial analysis. Spatial analysis entailed the computation of cell statistics and Inverse Distance Weighting (IDW) interpolation.

3.2.7. Slope and Drainage

The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) was processed in the ArcGIS Spatial Analyst environment. The slope tool was applied in acquiring the slope map of the area. The hydrology tools were used to obtain the watershed of the area. The drainage properties of the watershed were analyzed to determine the drainage density.

These contributing factors were weighted according to the weights in **Table 2** to obtain the final groundwater potential map

The above discussed processes are captured **Figure 2** below. To project the groundwater potential to 2042, Artificial Neural Network (ANN) technique inside the Modules for Land Use Change Evaluation (MOLUSCE) plugin was used to model transition potentials and simulate the future. ANN approach is more effective than Linear Regression (LR) [13]. MOLUSE, a plugin that is employed in Quantum GIS (Qgis) environment, is designed to analyze, model and simulate land use changes. The plugin incorporates well-known algorithms, which can be used in land change analysis, urban analysis as well as forestry applications and projects.

Based on the groundwater potential data for 2002, 2022, explanatory variables and transition matrices, we projected the groundwater potential for 2042. To validate the model and prediction accuracy, the plugin offered a kappa validation technique and comparison of actual and projected images, and a kappa value of 0.83 was obtained. In the ANN learning process, 100 iterations were chosen for the projection. **Figure 3** outlines the steps used in implementing the prediction in the MOLUSCE model.

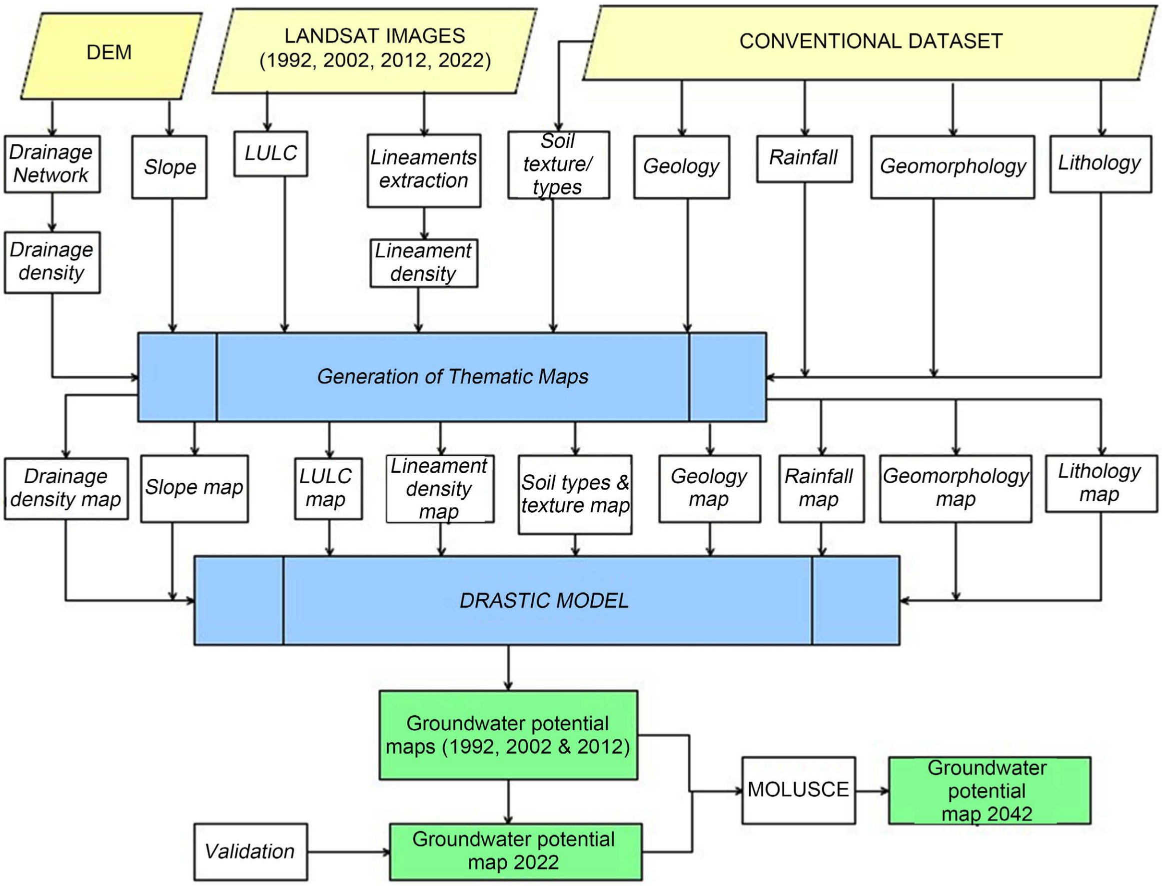


Figure 2. Methodology flowchart.

Table 2. Weights applied in the DRASTIC based overlay scheme.

Factors	Weights (%)
LULC	12
Slope	12
Lineament density	15
Drainage density	15
Geology	10
Rainfall	8
Geomorphology	10
Lithology	10
Soil types	4
Soil texture	4
Total	100

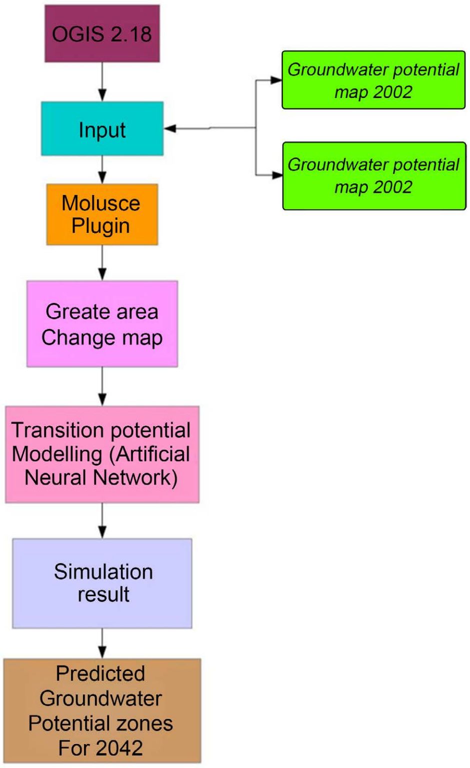
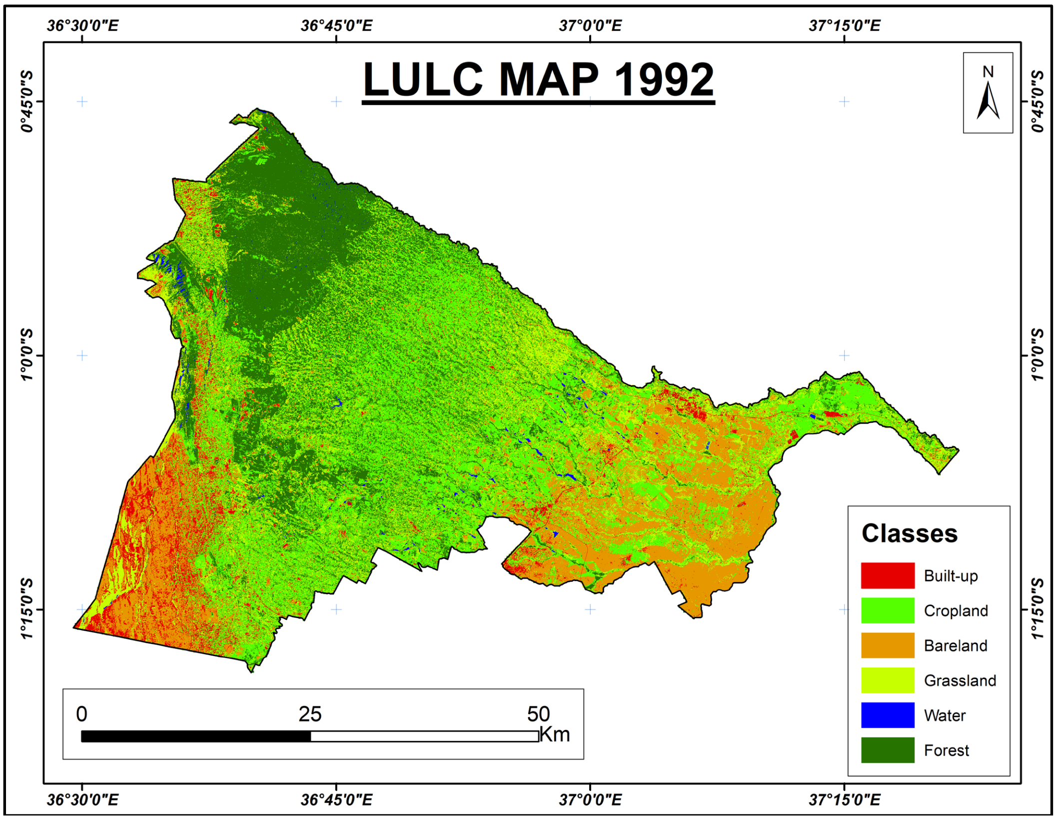


Figure 3. Preparation of predicted groundwater map.

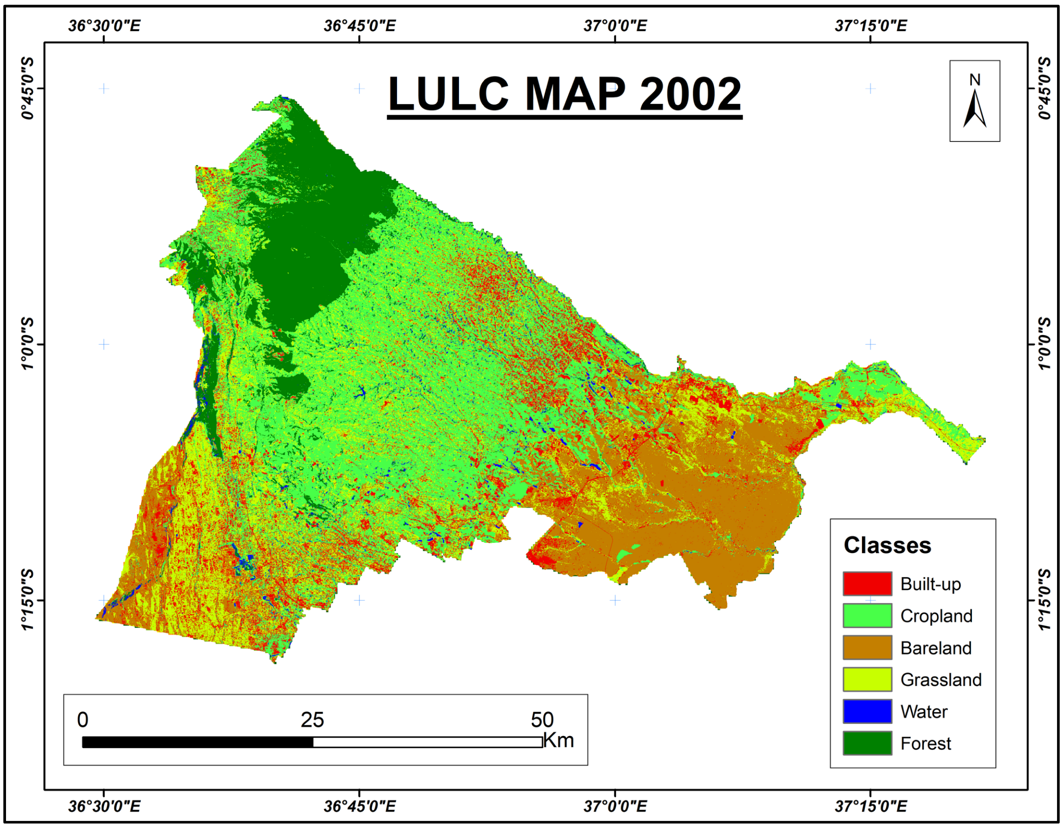
4. Result and Discussion

4.1. Land Use Land Cover

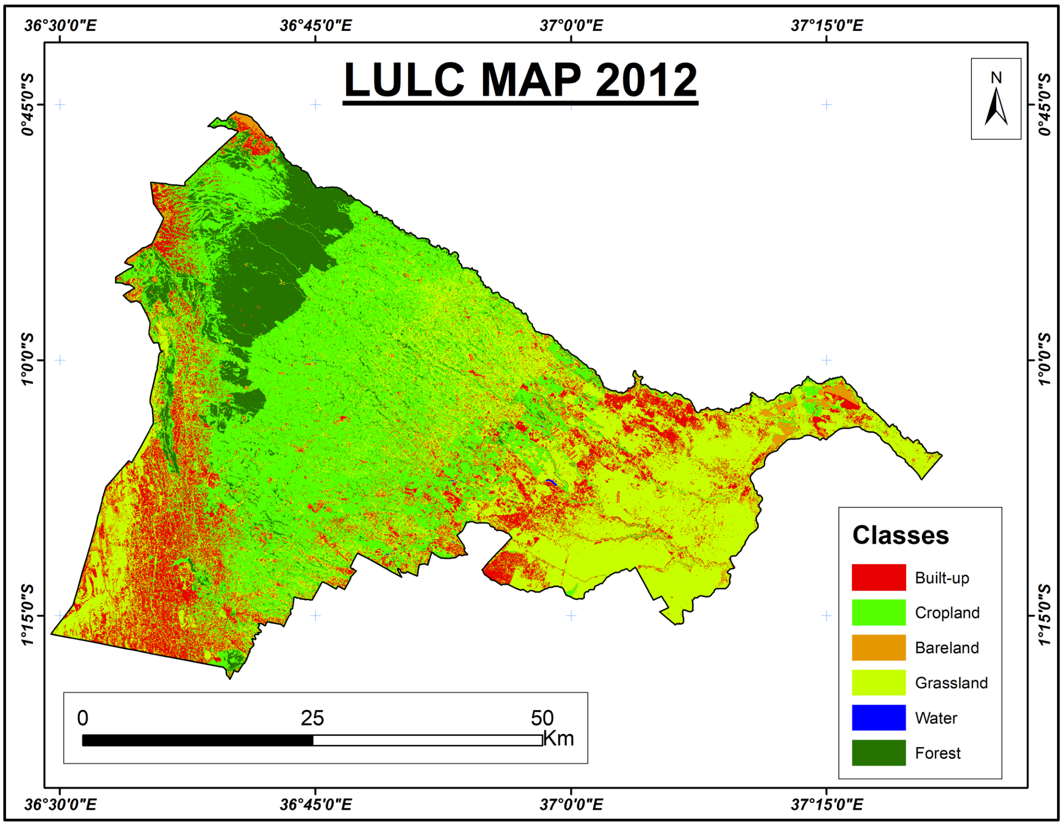
Land use land cover distribution within the area was obtained for 1992, 2002, 2012 and 2022 as shown in Figure 4. From the analysis, it was realized that built -up areas increased gradually from 1992 to 2022. In 1992, built up areas covered an area of approx. 164.96 km^2 to 347.28 km^2 in 2022. This effect was attributed to the increase of population in the area that led to the development of towns and growth of settlements. Contrary to built-up areas, forest areas reduced from 688.48 km^2 in 1992 to 370.94 km^2 in 2022. The reduction was assigned to deforestation to create more land for settlement and agricultural use. Croplands increased immensely from 799.65 km^2 in 1992 to 990.11 km^2 in 2022 owing to the high demand of food to feed the growing populations in the area. Water followed the same trajectory. It increased from 11.49 km^2 in 1992 to 65.34 km^2 in 2022 as a result of increased rainfall and run off water from upstream. Grasslands increased slightly from 469.71 km^2 in 1992 to 488.70 km^2 in 2022. The increase was as a consequence of bareland being converted to grassland and other land. This resulted in reduction of bareland from 410.40 km^2 in 1992 to 282.32 km^2 in 2022. The effect of land use land cover is manifested either by reduced runoff or by trapped water. Water droplets trapped go down to recharge groundwater hence vegetal cover reduces evaporation and runoff, increasing infiltration and chances of groundwater recharge as compared to barren soil. Furthermore, the root system makes the soil pervious. In settlements and built-up areas, infiltration is low due to roads, pavements and buildings covering the soil surface hence low groundwater potentials. Due to the presence of built-up structures in these areas, they are largely avoided in locating suitable sites for groundwater potential.



(a)


LULC MAP 2002
36°30'0"E
36°45'0"E
37°0'0"E
37°15'0"E
0°45'0"S
1°0'0"S
1°15'0"S
N
Classes
Built-up
Cropland
Bareland
Grassland
Water
Forest
0
25
50
Km

(b)


LULC MAP 2012
36°30'0"E
36°45'0"E
37°0'0"E
37°15'0"E
0°45'0"S
1°0'0"S
1°15'0"S
N
Classes
Built-up
Cropland
Bareland
Grassland
Water
Forest
0
25
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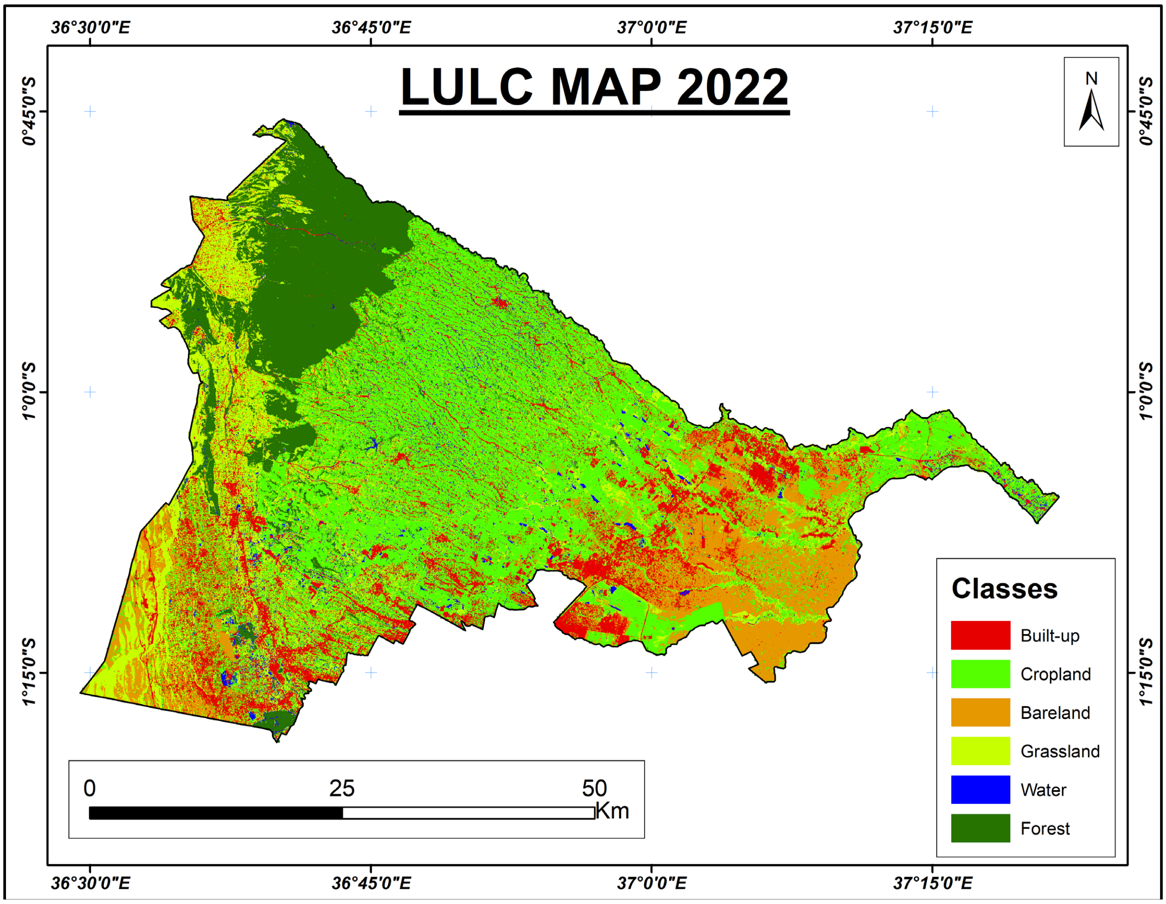
Km

(c)

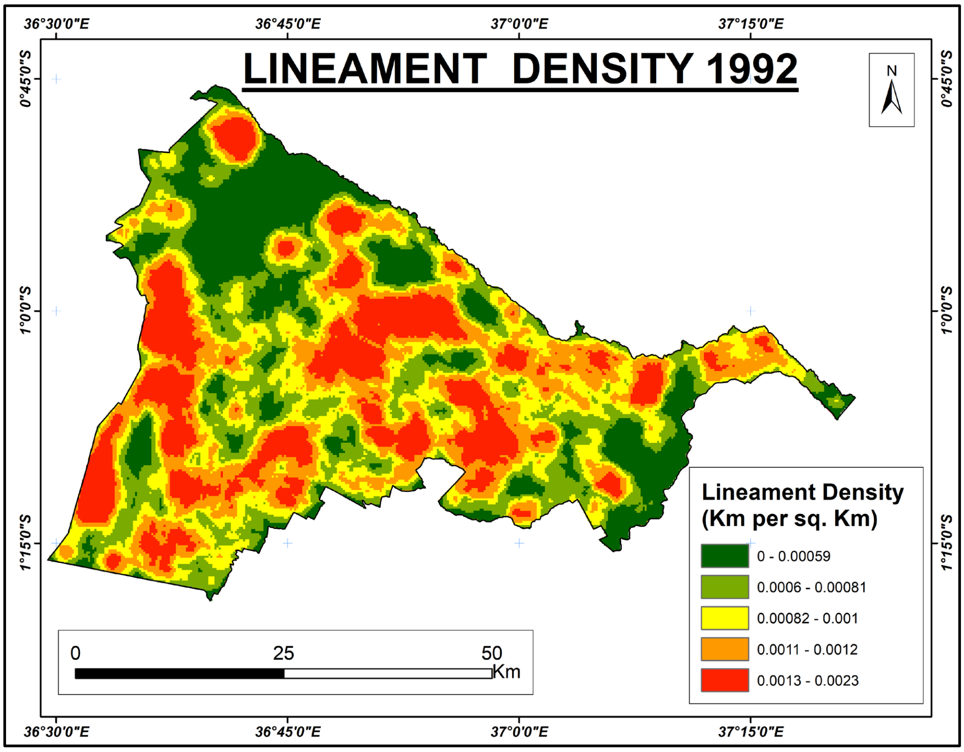


(d)

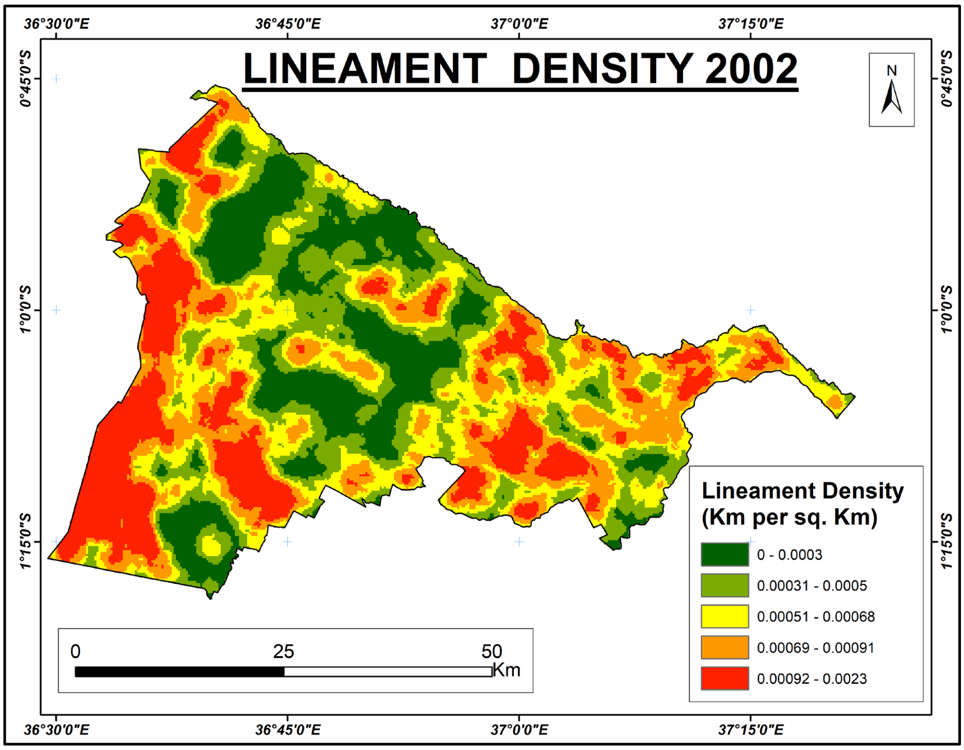
Figure 4. (a) 1992 LULC map, (b) 2002 LULC map, (c) 2012 LULC map, (d) 2022 LULC map.

4.2. Lineaments Density

Lineaments are structurally controlled linear and curvilinear features identified from the satellite imagery by their relatively linear alignments. They express the surface topography showing the zones of faulting and fracturing that increase the porosity and permeability. Lineaments were obtained for the years 1992, 2002, 2012 and 2022, and from their analysis, it was revealed that there was variability in lineament structures for each of these years. [14] found out that the number and orientation of the lineaments can change significantly and gradually return to its initial state after sometime. Lineaments densities were obtained for each of the years as shown in **Figure 5** below. Generally, the lineaments density was very high on the western region which was an indication of many faults and sharp change in linear alignment. Water drains through the faults to the permeable rock hence they are suitable sites of groundwater potential. The eastern part of the county comprised of a mixture of high, moderate to low lineaments density in 1992, 2002 and 2022. In 2012, the central area consisted of low lineaments density thus hinders the percolation of water into the earth surface. The information obtained from the lineaments show the movement and storage of groundwater. Potential sites for productive water are usually located around these features because, they are responsible for infiltration of surface runoff into subsurface and also for movement and storage of groundwater. Therefore, areas with high lineament density are good for ground water potential zones.



(a)



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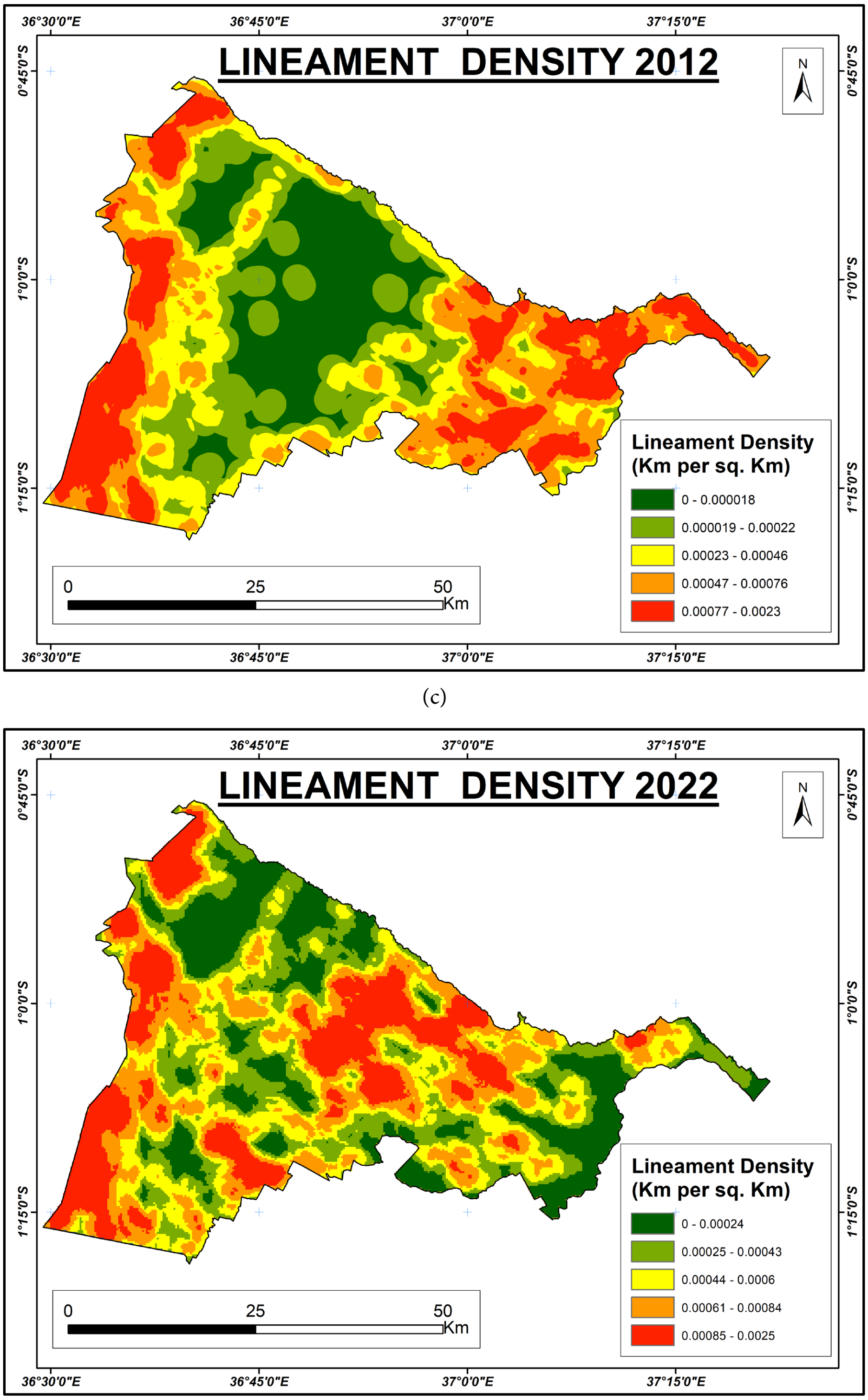


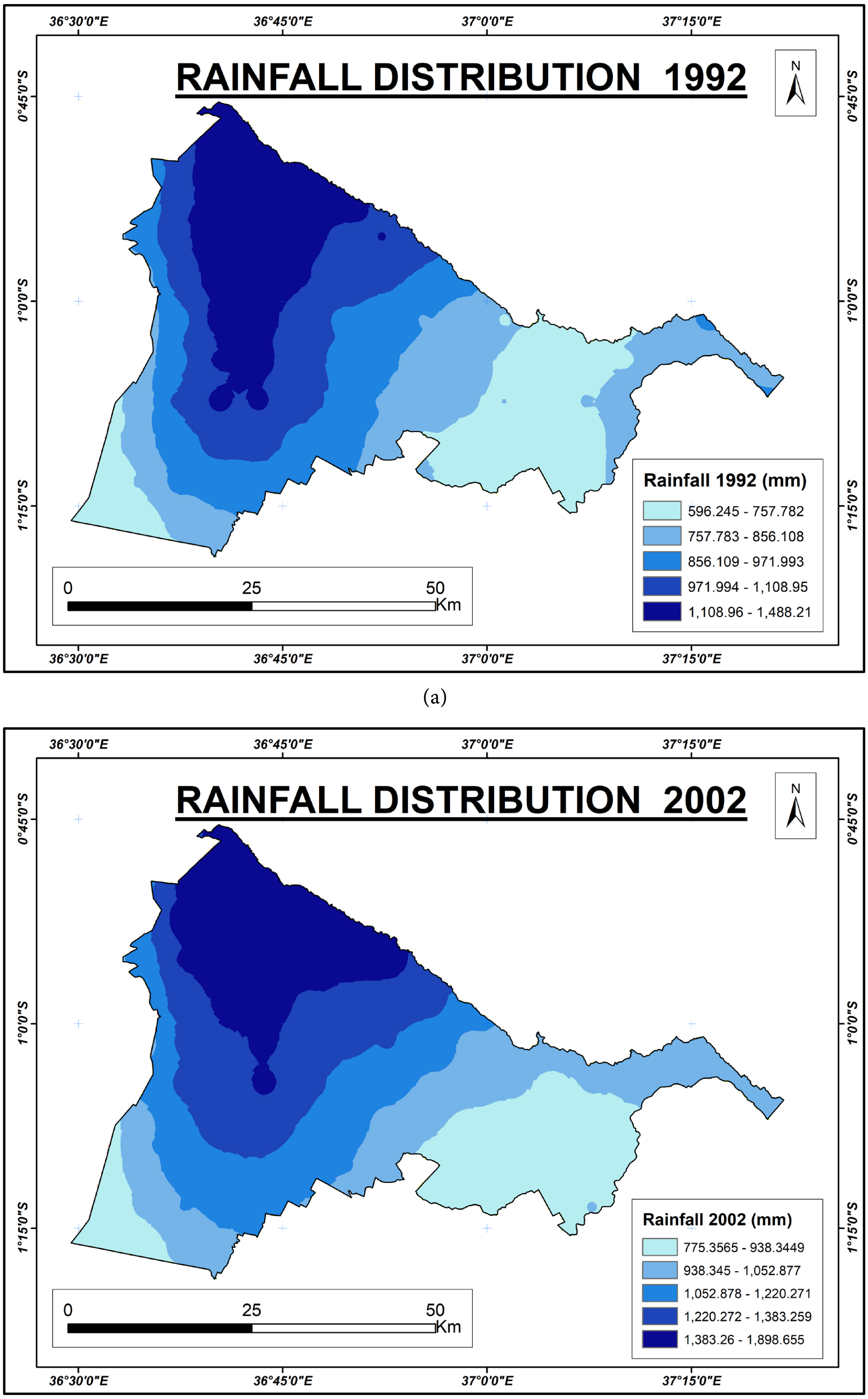
(c)

(d)

Figure 5. (a) 1992 Lineaments density map, (b) 2002 Lineaments density map, (c) 2012 Lineaments density map, (d) 2022 Lineaments density map.

4.3. Rainfall

CHIRPS data was processed to give the annual rainfall values for 1992, 2002, 2012 and 2022 in Kiambu county as shown in **Figure 6**. The annual rainfall ranged from 596 mm to 1488 mm in 1992, 775 mm to 1899 mm in 2002, 860 mm to 2266 mm in 2012 and 428 mm to 1396 in 2022. The highland region of



(a)

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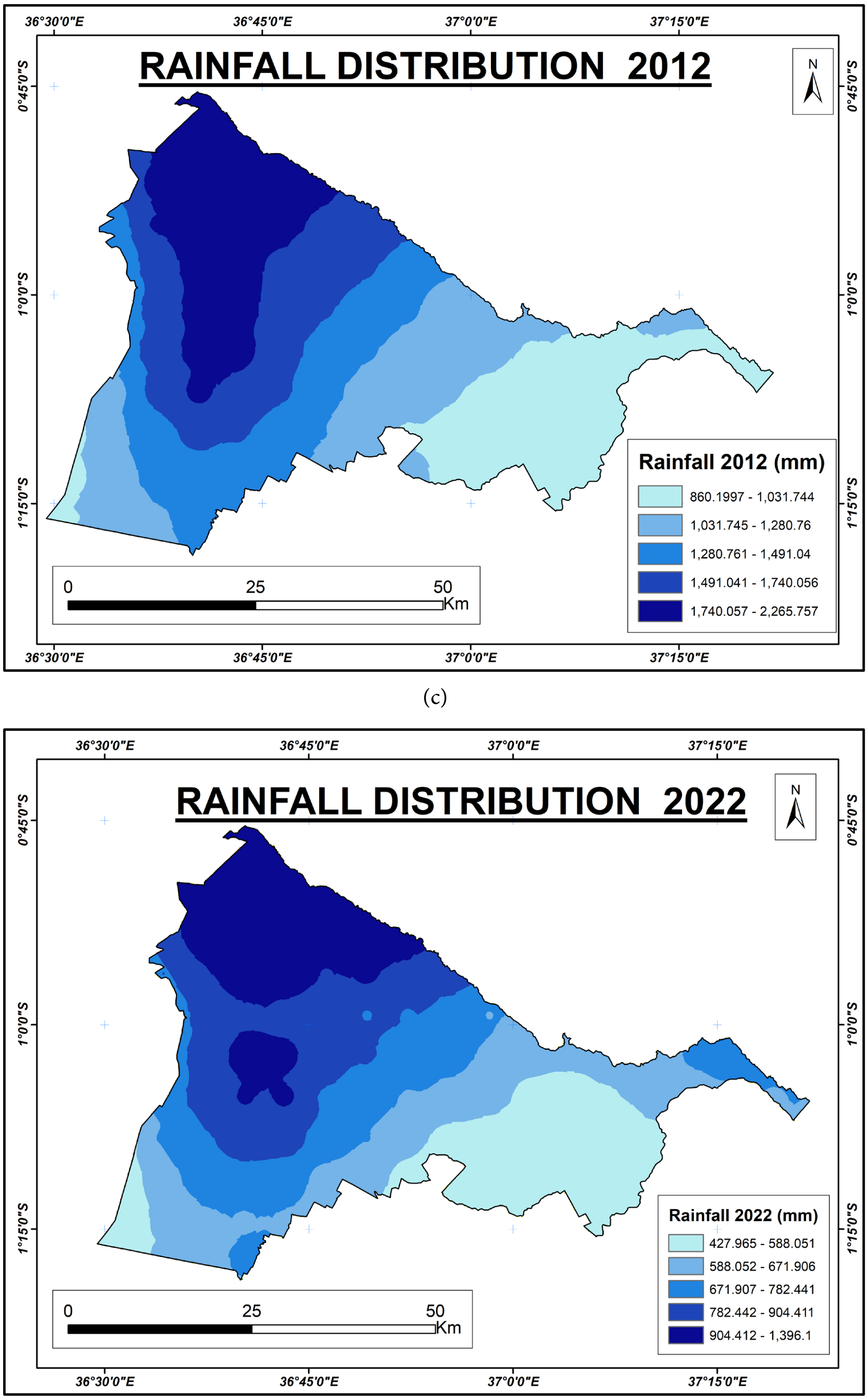


(c)

(d)

Figure 6. Annual average rainfall for (a) 1992, (b) 2002, (c) 2012 & (d) 2022.

the county receives the highest rainfall through the study period. The areas towards the south, south east and south west, received the lowest annual rainfall throughout the study period. The central regions receive moderate to low rainfall as per the annual average scale. The regions towards the east and west of the county are characterized by moderate rainfall. Rainfalls are the primary sources of groundwater and dominantly recharge the groundwater. Rainfall determines the amount of water that would be available to percolate into the groundwater. High rainfall is favourable for high groundwater potentials hence it is assigned higher priority during weightings.

4.4. Slope

The slope map of the area is shown in **Figure 7**. The area is relatively flat with the majority of the region having slope of less than 5%. The slope on the North East part of the area ranges between 5% - 25% while the slightly steep areas of >25%, covers the least area. Slope influences groundwater infiltration and recharge, in sense that, areas with steep slopes cause more runoff, less infiltration and have low groundwater prospects compared to areas with gentle slope. Gentle slopes cause less runoff, high infiltration rate and have good ground water prospects hence slope is a proxy for groundwater potential analyses.

4.5. Drainage

Stream classification is very important because it gives an understanding of a stream ecosystem [15]. Ordering the streams in the area showed that the region is largely endowed with the third order streams draining into the region as shown in **Figure 8** below. The fifth to sixth order streams were few same as the first and second order streams. The capacity of the fourth and third order streams were higher hence suitable for storage capacity in the area.

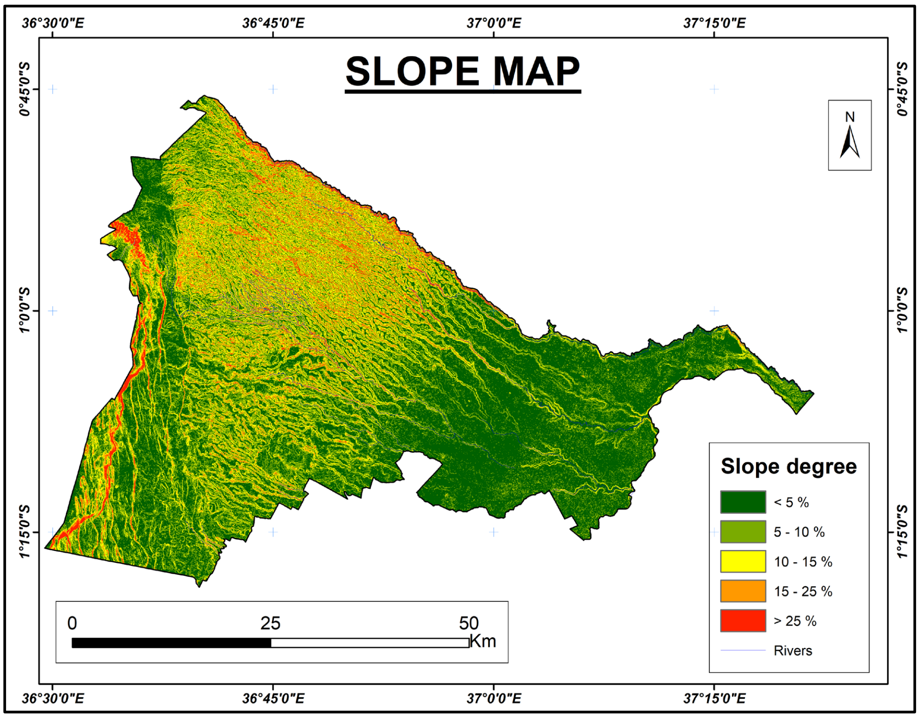


Figure 7. Slope map of the study area.

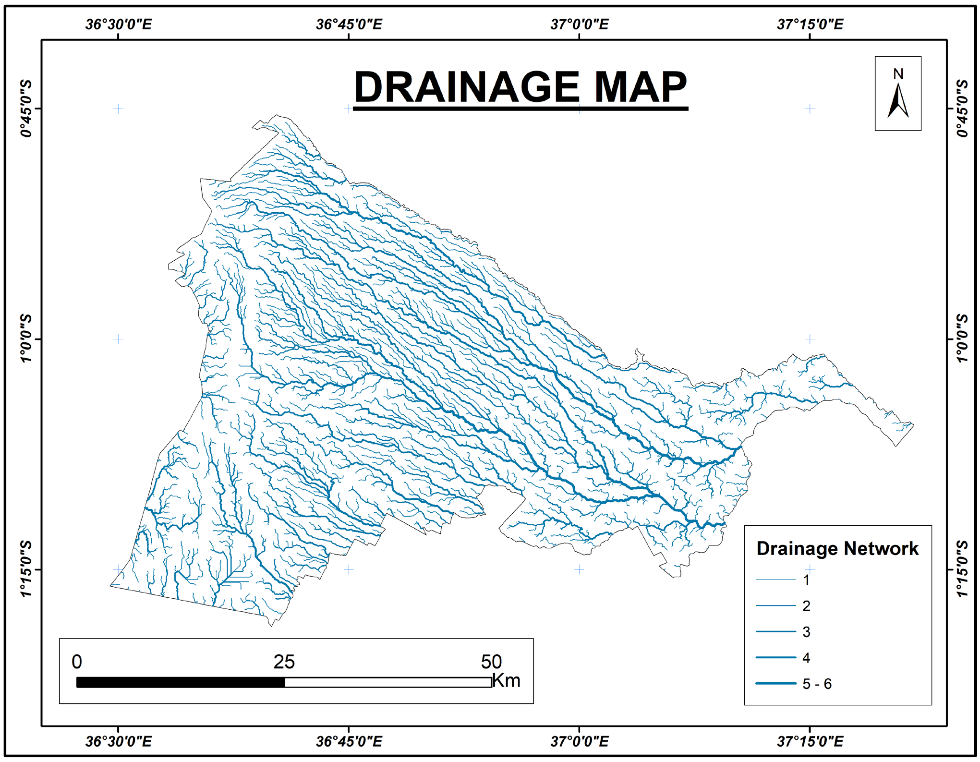


Figure 8. Stream ordering.

The stream network below was used to generate the drainage density as shown in **Figure 9**. Low drainage density areas were observed on the exterior periphery of the area since these areas are characterized with first order stream. High drainage density areas were seen on the North Eastern part towards the central part of the area. This was so because these areas have a high concentration of third and fourth order streams. When the drainage density is high is an indication of high runoff and consequently low infiltration rate. Low drainage density implies low runoff and high infiltration hence the areas have high groundwater potential.

4.6. Soil

Infiltration of water is highly dependent on the type of soil and soil texture. The distribution of soil classes within the county were obtained as shown in **Figure 10** below. Nitisols had the highest coverage while the Fluvisols, Gleysols and Phaeozems had the lowest coverage. Andosols have excellent internal drainage because of their high porosity. Planosols are of alluvial horizon having loamy or coarser textures. Ferralsols are deeply weathered and mostly clayey whereas Regosols are deep, well drained, medium textured and sensitive to erosion. They have low water holding capacity and highly permeable.

The soil texture was represented as given in **Figure 11**. Very clayey soil texture had the highest coverage, followed by clayey and loamy while sandy soil texture had the least coverage. Soils with sandy texture have large particle constituents, which makes it to have high transmissivity and high infiltration values.

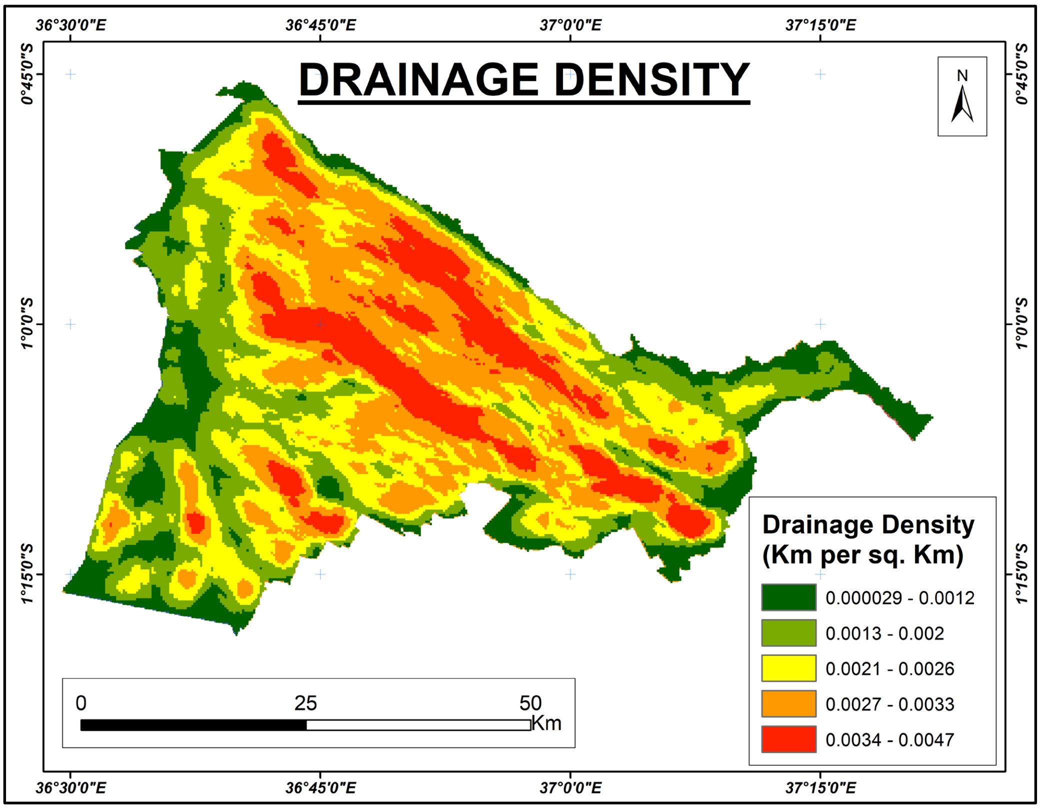


Figure 9. Drainage density.

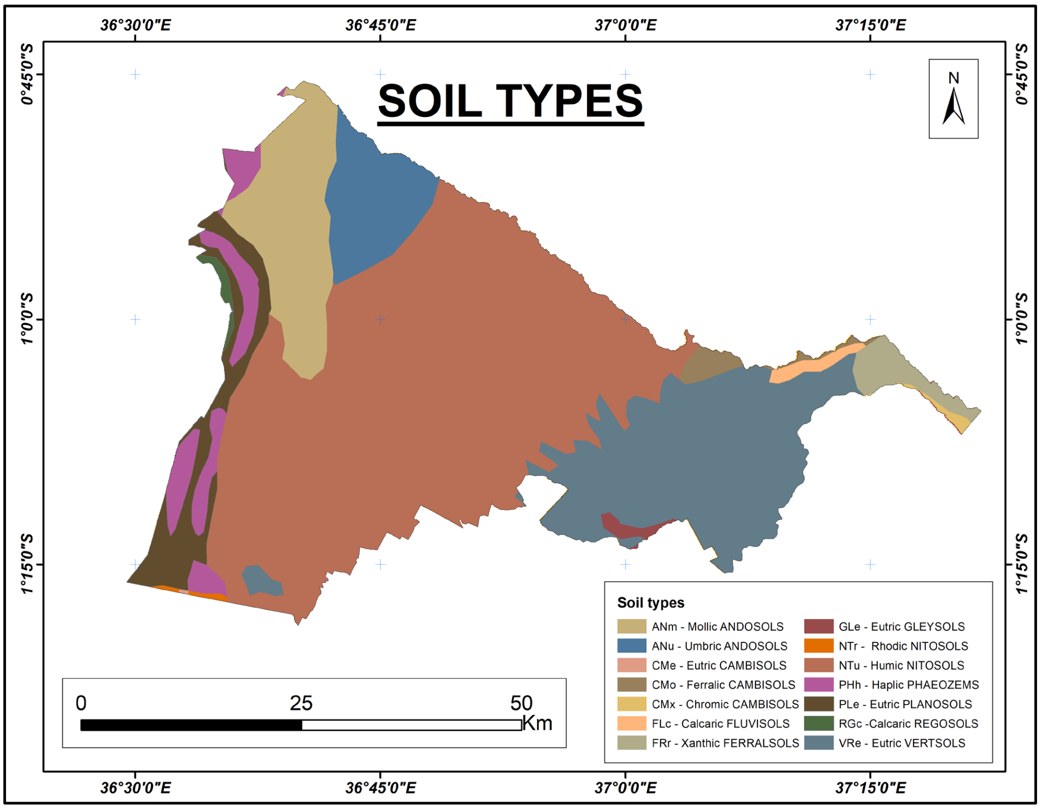


Figure 10. Soil types.

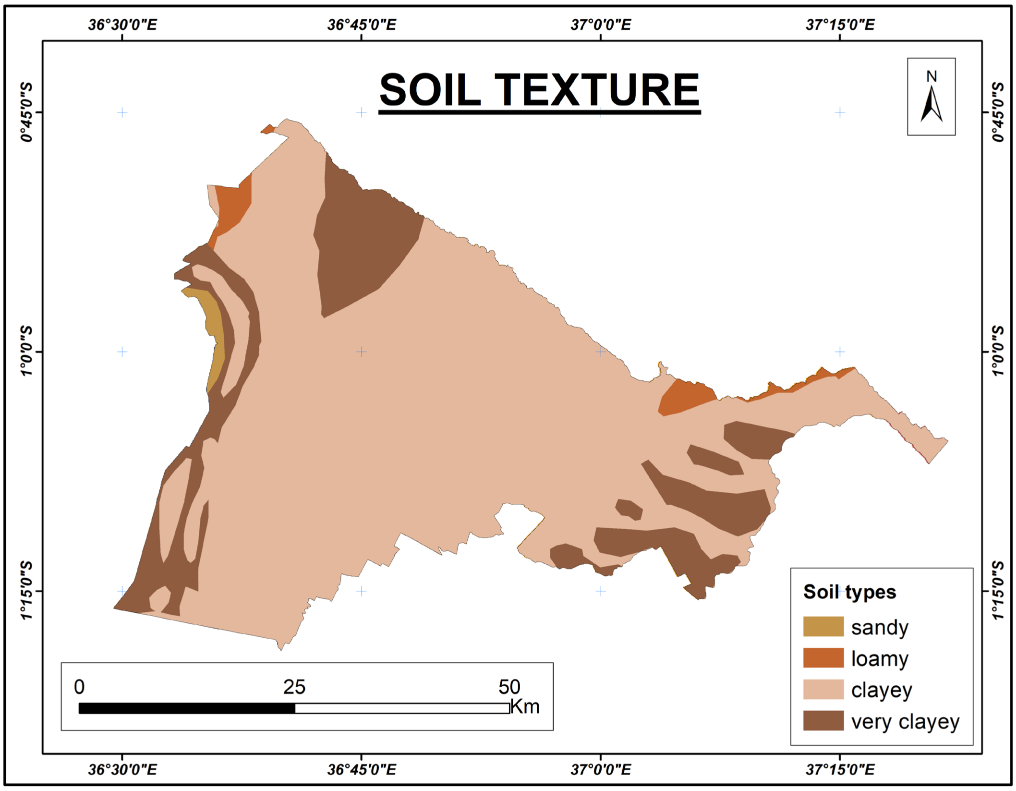


Figure 11. Soil texture.

On that account, areas with this kind of texture have high groundwater recharge and potential as opposed to areas with clayey texture soils. Very clayey and clayey texture have soils with small particle constituents, resulting in low infiltration rates. Soils with loamy texture have a medium weight because they neither have a low infiltration

4.7. Geomorphology

Geomorphology plays an essential role in the groundwater conditions of an area. Geomorphological features of a given area controls not only the occurrence but the surficial distribution of a surface water as well as the groundwater conditions. Geomorphological units of Kiambu county are captured in Figure 12 and they include: Escarpments, footslope, hills and mountain footridges, mountains, plain and plateau. Majority of the area is covered by the plain and hills and mountains.

4.8. Geology

Geology also plays an important role in the occurrence of groundwater in a given area. Geologically, the study area is underlined by formations of quaternary, tertiary and Precambrian rocks as shown in Figure 13. Tertiary rocks are the dominantly rock in the area while Precambrian rocks had the least coverage in the area.

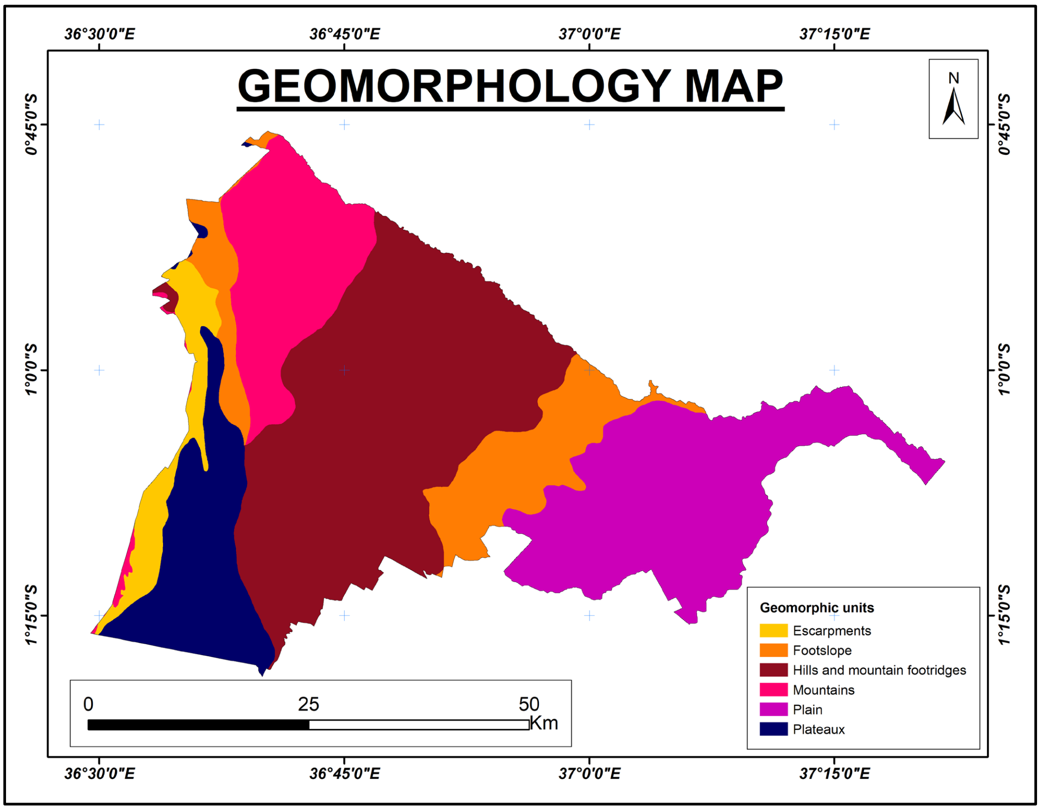


Figure 12. Geomorphology.

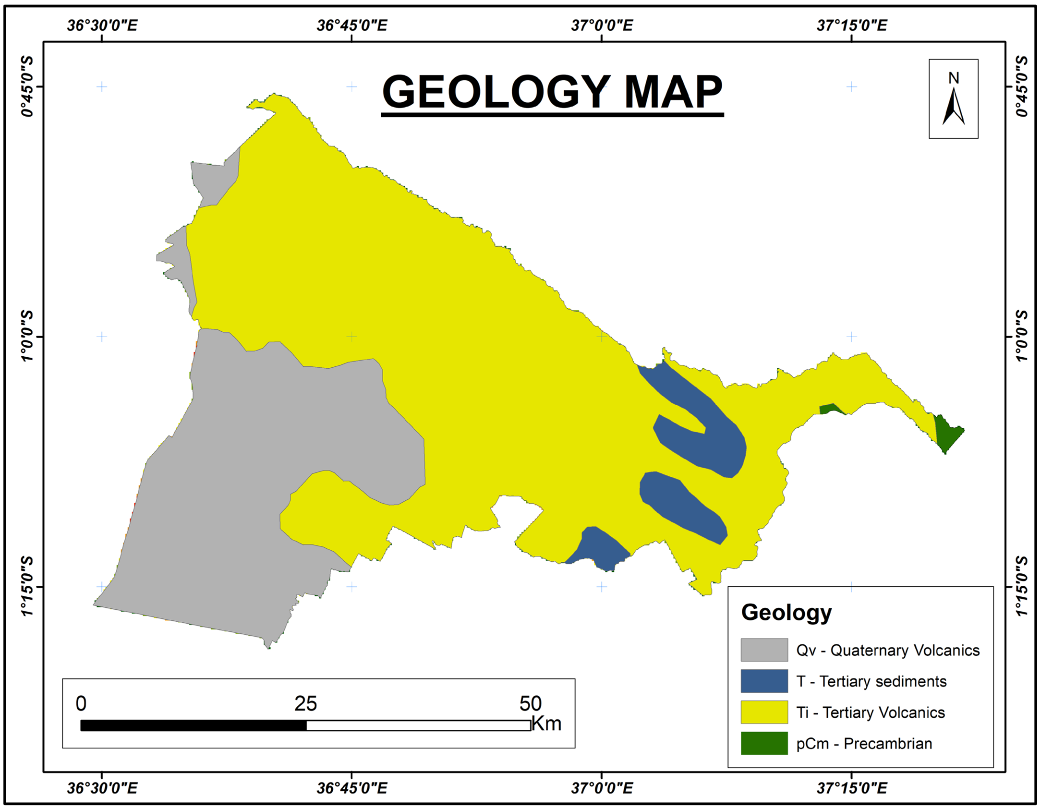


Figure 13. Geology.

4.9. Lithology

Lithology is the rock composition and texture. The serial arrangement of different rocks and their interaction determines the total infiltration capacity of an area. Various landform and drainage characteristics that have a direct control on the occurrence and flow of groundwater were mapped and delineated. **Figure 14** shows the lithological units in the area and they comprise of volcanic, colluvium, extrusive volcanic and metaigneous. Volcanic rocks covered the largest part of Kiambu contrary to metaigneous rocks that covered the least area. The volcanic aquifer stored in the fractured and weathered parts of volcanic rocks are sources of groundwater [16]. Porous and permeability of lithology units translate to the storage and transmitting capacity which supports the groundwater occurrence and distribution in an area.

4.10. Groundwater Potential Zonation

From **Figure 15**, we observed that the suitable sites kept on changing form one year to another. In 1992, the central towards the eastern region had high potential of groundwater. The south west region had potential ranging from medium to very low, and a few areas had high potential. In 2002, the northern region began to have high potential as a result of increased rainfall and conversion of the forest land to croplands. On the other hand, potential on the eastern region reduced and this was attributed to the emergence of settlements and low rainfall. The potential on the south west region continued to reduce as people began to build settlements in those areas. In 2012, the northern region maintained high potential since the rainfalls continued to increase on those sides. The south west continued to have low potentials as settlements continued to grow in the areas. In 2022, there was a tremendous decrease in the groundwater potential for most of the regions. The potential on the northern region began to reduce to medium potential and the same applied to the eastern region. However, the central region had high potentials and the south west maintained the low potentials.

4.11. Prediction of Groundwater Potential

This section is an important part of the study where groundwater potential of 2042 was predicted with the help of artificial neural model in QGIS. The predicted groundwater potential reveals that majority of the north side will have medium to very high potential unlike the west and some parts of the south side which will have low to very low potentials. The potential on the eastern region will reduce greatly as compared to the potential in 2022. Very high potential areas will be in regions around Ndumberi, Kijabe, Kagwe, Gathungu, Komothai and Gatundu.The ground water potential in Thika, Wangige, Kamae, Gatukuyu, Kimunyu and Ruiru will be medium. Juja, Ngenya and Chomo will have high to medium potential whereas areas around Limuru, Nachu, Kilima mbogo, Karuri, Uplands and Ngecha will have potential ranging from low to very low. The discussed above information is captured in **Figure 16** which shows how the groundwater potential zones will be in 2042.

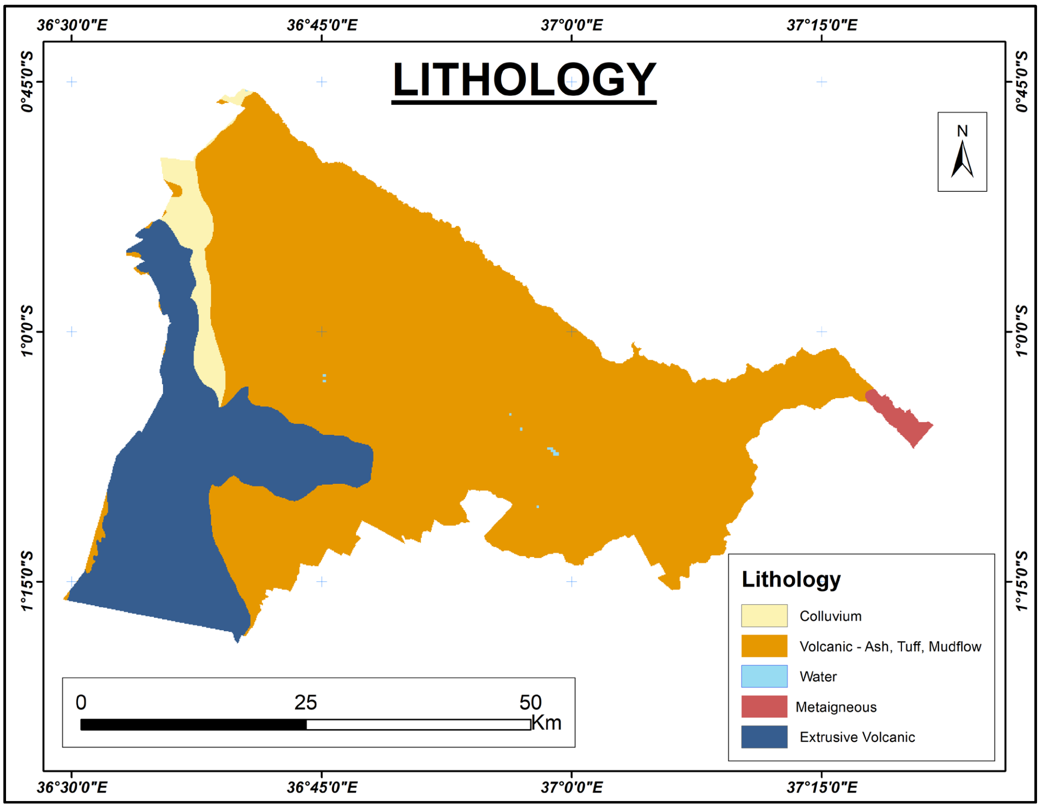
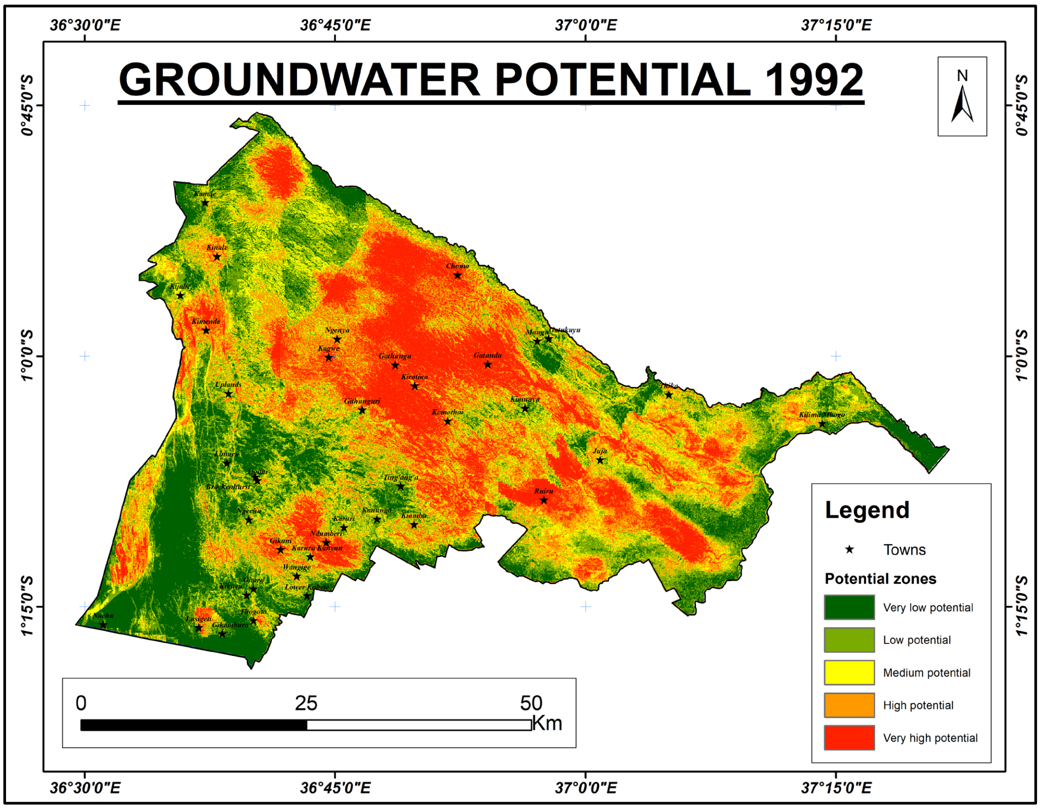
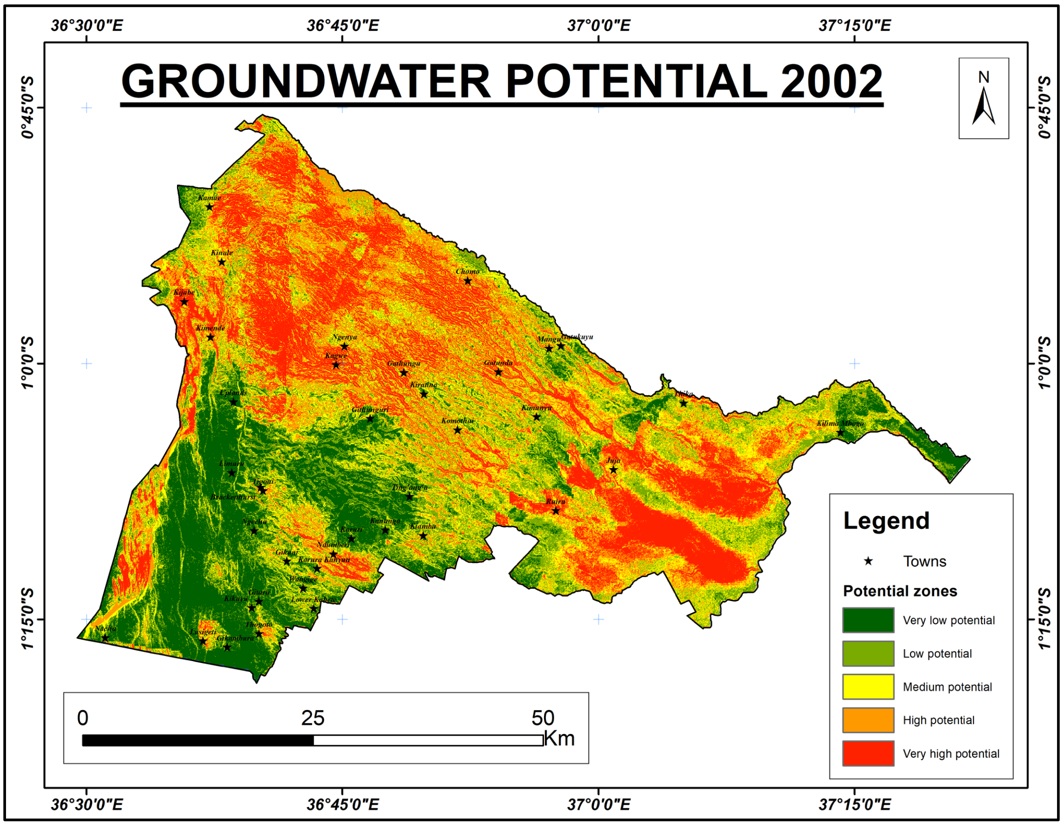


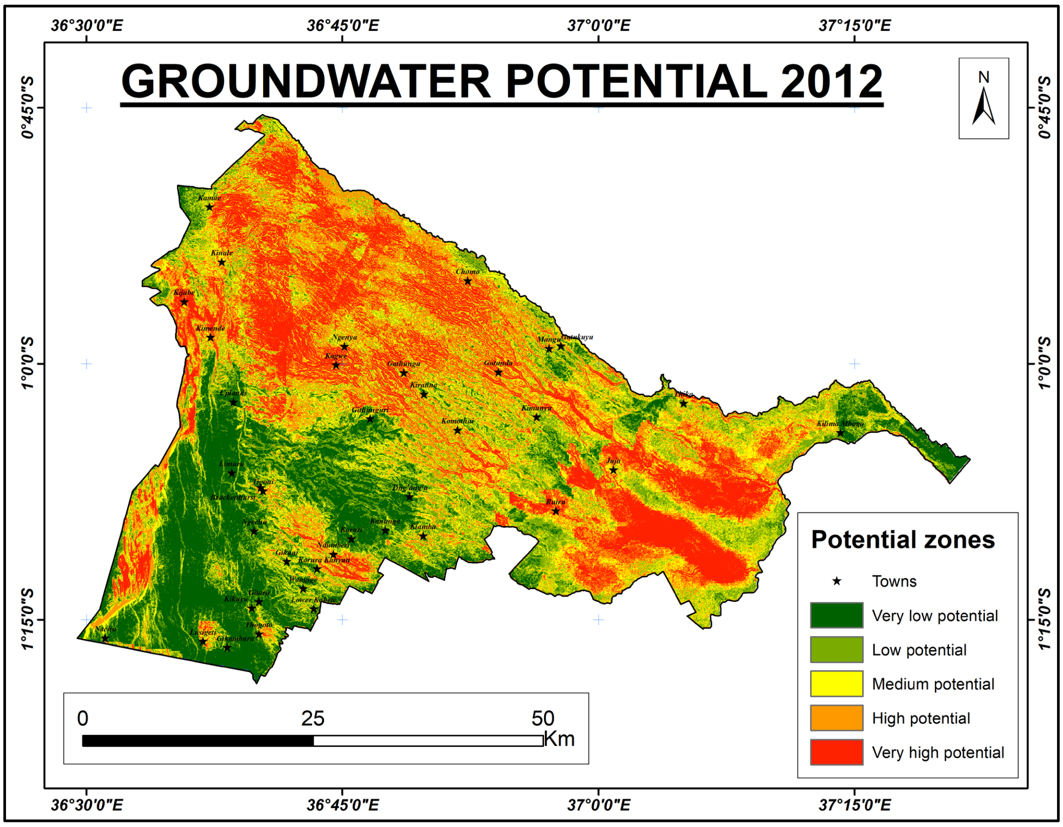
Figure 14. Lithology.



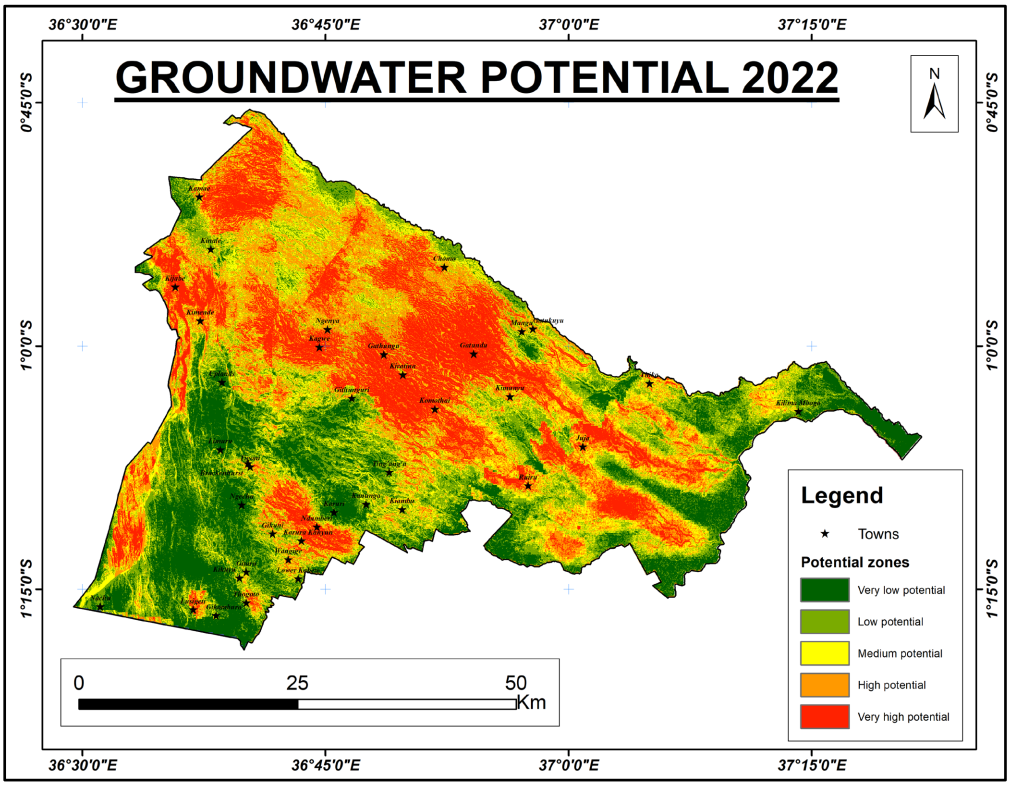
(a)


GROUNDWATER POTENTIAL 2002
36°30'0"E
36°45'0"E
37°0'0"E
37°15'0"E
0°45'0"S
1°0'0"S
1°15'0"S
N
Legend
Towns
Potential zones
Very low potential
Low potential
Medium potential
High potential
Very high potential
0
25
50
Km

(b)


GROUNDWATER POTENTIAL 2012
36°30'0"E
36°45'0"E
37°0'0"E
37°15'0"E
0°45'0"S
1°0'0"S
1°15'0"S
N
Potential zones
Towns
Very low potential
Low potential
Medium potential
High potential
Very high potential
0
25
50
Km

(c)



(d)

Figure 15. Groundwater potential maps for (a) 1992, (b) 2002, (c) 2012 & (d) 2022.

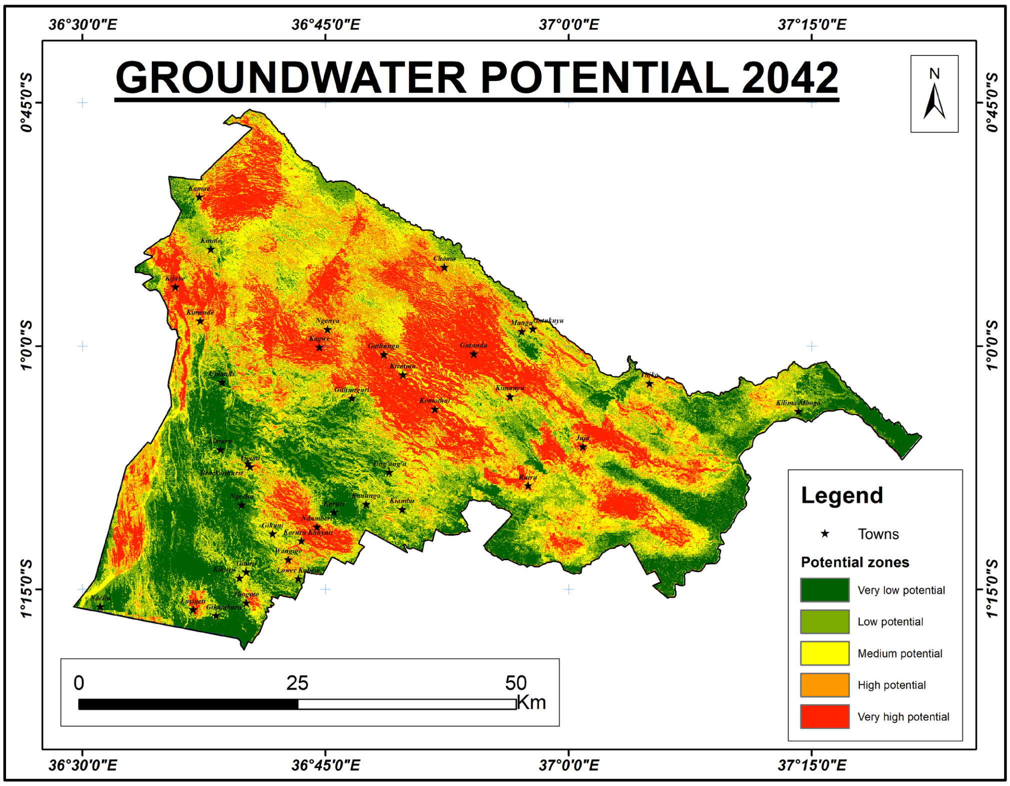


Figure 16. Groundwater potential for 2042.

4.12. Change Analysis

To obtain the change for each groundwater potential class, the areas for each year were obtained as shown in **Table 3**, from which the difference between the years were computed, which represents magnitude of change between corresponding years.

Changes in groundwater potential are inextricably tied to geography, climate change, physical and socioeconomic factors. During the study period, we observed an uneven shift in land use due to rapid urban expansion and deforestation. Urban areas are given low weights in determining groundwater potentials hence the change in ground water potential between the years. Furthermore, the effect of climate change has been adverse resulting to reduced rainfalls *i.e.*, low rainfall declines water level thus the change in groundwater potential. The changes over the years were derived as indicated in **Table 4** below.

The changes were little among the groundwater potential more so, for the low and very low ground water potential class. However, the changes are expected to become greater in the future if the factors affecting the occurrence of ground water continue with the same trend.

4.13. Trend Analysis

Trend analysis of the ground water potential zones was done where, we saw the very low potential zones increase at a very low rate. The low potential zones kept on varying but it was expected to reduce by 2042. The same applied to medium potential zones which are expected to increase immensely by 2042. The high potential zones will reduce significantly while the very high potential zones increased consistently. This information is illustrated in **Figure 17** below.

Table 3. Areas for each ground water potential class in sq·km.

Areas of Groundwater potential zones (sq·km)					
Years	Very low	Low	Medium	High	Very High
1992	511.519	502.237	504.837	515.558	485.647
2002	504.208	505.508	532.652	487.615	489.815
2012	505.762	503.552	514.447	505.781	490.256
2022	506.804	508.767	498.699	509.473	496.055
2042	507.910	427.911	731.893	318.925	533.159

Table 4. Change detection in sq·km.

Change Areas of Groundwater potential zones (sq·km)					
Years	Very low	Low	Medium	High	Very High
2002-1992	−7.311	3.271	27.815	−27.943	4.168
2012-2002	1.554	−1.956	−15.059	18.166	0.441
2022-2012	1.043	5.215	−15.748	3.692	5.799
2042-2022	1.106	−80.857	233.194	−190.548	37.104

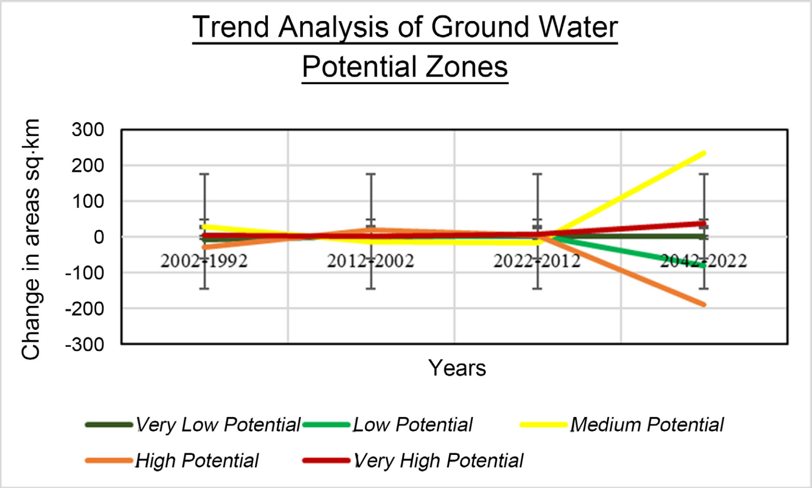


Figure 17. Trend analysis of the groundwater potential zones.

4.14. Water Quality

Not all the types of water are safe for human being. With every kind of development happening in this age, it is difficult to get naturally purified water because of industrialization that pollutes groundwater. Groundwater pollution often results from improper disposal of wastes on land. The sources of these pollutions include: industrial and household garbage, landfills, leaking underground oil storage tanks and pipelines, sewage sludge and septic systems for liquid waste [17]. To check the quality of water, a few parameters are investigated to determine their concentration in the water [18]. These parameters include manganese, fluoride, cadmium, iron, turbidity, total coliforms and *Escherichia coli* (*E. coli*) bacteria [19]. The contamination majorly affects the shallow well/boreholes, making the water unsuitable for use in drinking and food processing due to the presence of *E. coli* bacteria. [20] observed that shallows wells in Ruiru had faecal coliform contamination which is harmful to human health.

4.15. Validation

Field survey was carried out to confirm the image processing results. A questionnaire was generated to help conduct the verification. The major factors that were considered in the questionnaire were: water quality, reliability and sustainability of the underground water. Data was collected from 32 boreholes/wells and the following observations were made:

1) Out of the samples collected, water was sustainable in 19 boreholes/wells since it was available throughout even during the dry seasons.

2) Water provided by 24 boreholes/wells was sufficient for the residents in the area in which the borehole/well serves.

3) The quality of water was observed to be good for 25 boreholes/wells and the water in the boreholes/wells is regularly tested to ensure it is fit for human use.

The areas that were classified to have low to very low groundwater potential on the maps, were observed to have boreholes/wells that run dry occasionally especially in times of low to no rainfalls.

5. Conclusion

The aim of the paper was to provide information about groundwater potential zones and predict the future of groundwater potential in Kiambu county using the modified DRASTIC model together with Remote sensing techniques for further groundwater exploration, proper planning, sustainable utilization and management of groundwater resources. The study affirms the potential of groundwater in Kiambu county mostly for the central and some parts of the eastern region. There was a consistent trend in South west region where the potential continued to decline. Additionally, we observed little changes in the groundwater potential between the years. It was noted that most the changes arose from geography, climate change, physical and socioeconomic factors. The prediction showed that by 2042, the eastern region of Kiambu county will have a decline in ground water potential and areas that initially had high potential will shift to medium.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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