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# Mapping of Feasible Artificial Groundwater Recharge Areas: Case of Nairobi City County, Kenya

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**Abstract**

The stress on ground water resources continues increase in most urban centers. Some wells in the upper aquifer within depths of 120m below ground level have dried up indicating depletion. The paper presents the research aimed at identifying the feasible areas for groundwater recharge using planned recharge techniques within Kenya's city. A systematic analysis of land cover, slope, geology and vadose zone thickness was undertaken generating feasible parameter layer maps using ArcGIS. Integration of the feasible parameter layers maps using Boolean logic function resulted in a feasible area map. 22.57% of the area was found feasible for planned recharge of the aquifer. The identified areas for groundwater recharge provides the guidelines for planned recharge in the city thus supplementing the water supply to the city which at one point is battling floods and another time facing severe drought. The research study showed a co-benefit of flood mitigation.

**Keywords:** Artificial recharge • Boolean function• GIS • Groundwater• Water supply sustainability

## 1.0 Introduction

Urbanization in Africa has proceeded at an unprecedented rate of between 6 - 9% per annum. Water quality, Water timing and water quantity are the current water problems faced by many African cities. Any slight alteration of one single problem affects the others significantly. In mitigating this demand water is pumped from far locations from the cities. This is attributed to the high rate of urbanization that the governments are unable to meet with the rate of infrastructure developments to meet the urbanization needs (Connor, 2015).

Water quality and quantity remain one of the challenges to many states. Ground water recharge, one form of rainwater harvesting, is contributory in determinations towards realizing long-standing water security. By taking water out of the overstressed storm drainage system then replenishing shallow aquifers, groundwater recharge well efficiently increases the water tables as well as decreasing flooding intensity. As evident there needs to save excess rain water for the dry time. Land development adds an impervious surface layer through pavements, rooftops that greatly increases storm water runoff (Miller, 2006). The drying up of wells within the Nairobi aquifer is a clear indication of reducing groundwater level, therefore, needs to store excess water instead of releasing it to the drains for use over the dry season. Sustainability of the aquifer can be improved by planned/artificial recharge.

With the resolutions of the UN member states and Kenya being a water-scarce state and the deficit being experienced (Guterres, 2018). The citizens are opting to rely on groundwater to meet the ever-increasing demand. Urban flood in Nairobi city has been as a result of storm drain being unable to cater for the needs of the flash floods whenever a medium to high precipitation event thereby becoming a nuisance. In this regard, it's critical to undertake groundwater recharge. The county government embarked on an action of drilling boreholes around the city in a bid to supplement the supply as Ndakaini dam the biggest storage for water is becoming unreliable.

Boreholes for initial settlers in the Karen area have had their boreholes dry up due to new settlers drilling deeper wells. In other counties within Kenya, there is immense pressure, especially on the groundwater as most people moved back to counties as a result of devolution. It's quite evident that we are overexploiting the groundwater without knowing the quantity available. It is common knowledge that financing groundwater is the best thing and is safer in comparison to surface water (City Council of Nairobi, 2007; Foster, 2005).

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Groundwater pumping began around early 1930. It progressively expanded to a projected 85,000 cubic meter per day by the year 2002 that amounts to about twenty-five percent of the total water supply for the larger Nairobi city residents, despite this quite a lot of private borehole owners remain as well connected to the Nairobi City mains water supply system that offers low-priced water on the other hand still use and rely on the borehole water as a back-up source clarifying as to why the installed bore hole capacity ranging between 300-350MLD is considerably higher compared to actual abstraction that's estimated at 85,000 cubic meter per day (Foster, 2005; Owour,2019).

**1.1 Study area**

The study area was Nairobi County, in the Republic of Kenya. It lies between latitude 1°17'S 36°49'E and 1°16'S 36°49'E occupying an area of about 696km² as shown in

Figure *1*. It experiences temperatures ranges between 18˚C-28˚C. The yearly precipitation varies in amount and ranges from 800mm to 1,200mm. The larger the amount and intensity of rain storms, the higher runoff hence flooding. Nairobi's altitude varies between 1,600m and 1,850m. The county's western region is located on high ground ranging approximately 1,700 - 1,850m above sea level having a craggy landscape. On the contrary, the eastern region stands predominately low at approximately 1600m above sea level and flat (City Council of Nairobi, 2007; WRMA, 2015). The primary aqua source for the Nairobi city is from Tana Basin with the greatest contributor being the surface water (UNEP, 2009; WRMA, 2005; WRMA, 2015). Following the 2009 census, which focused on households, the major access mode to water in the city was piped water (75.7%). This was mainly from Ndakaini, Ruiru and Sasumua dams thus the city imports its piped water primarily from Tana Basin (City Council of Nairobi, 2007, WRMA, 2005; WRMA, 2015). A significant proportion of the population and industries of Nairobi depend on or supplement their water budget with ground water (Jacobsen, 2012).

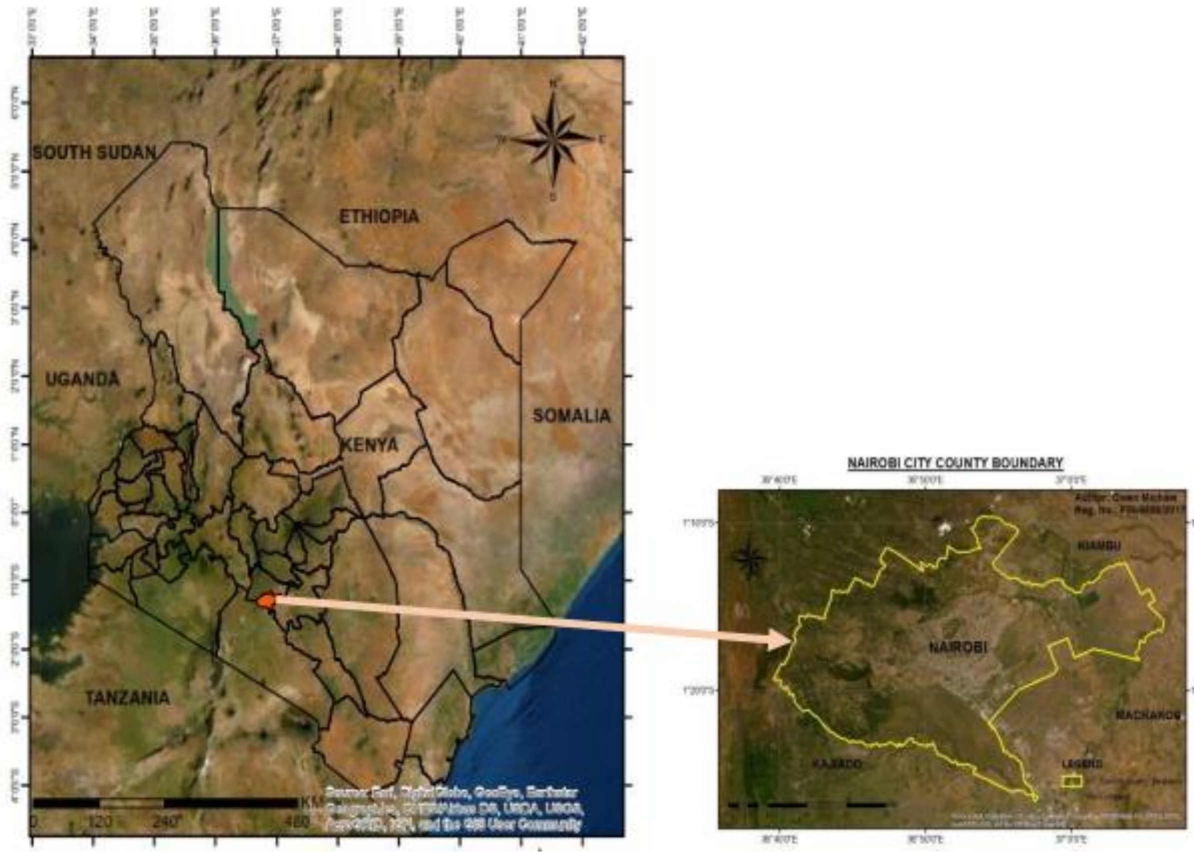



Figure 1: Map of Kenya showing study area of Nairobi City County.

Presently, the core and wide usage of groundwater remain domestic water supply, a complementary or substitute source to Nairobi city Council mains water supply systems. The availability of groundwater as a 'back-up resource' for emergency conditions will contribute significantly towards the constituency of the overall water supply. Rapid development has led to over-exploitation of groundwater. The negative impacts of groundwater level declines bring about high boring and siphoning costs; diminishing water quality since the high mineral and salts centralization, owing to the groundwater over-abstraction.

These two simultaneously occurring situations need to be mitigated unfortunately lack of adequate guidelines for artificial recharge of the aquifers in the country as well as the city remains an uphill task. Poor planning guidelines application and enforcements have affected the overall quality of life in the city in relation to water supply plus storm water management systems.

### 3.0 Methodology

To identify the feasible areas, key factors influencing planned recharge for groundwater that is land use, slope, the thickness of the vadose zone and geology. The key factors data was used to develop the applicability maps of each factor using ArcGIS 10.3. The maps were developed using Boolean logic functions with each layer of each factor created and reclassified in binary coding system with "1" being a feasible area whereas "0"being the not applicable feasible areas as demonstrated in Figure 2.

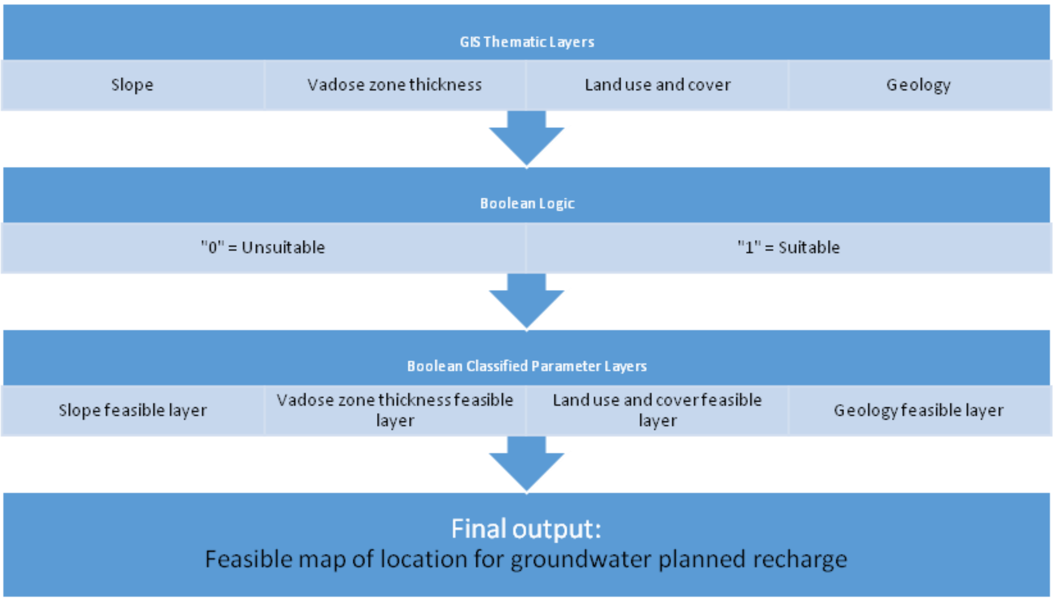



Figure 2: Flow process of the GIS input and output expectation

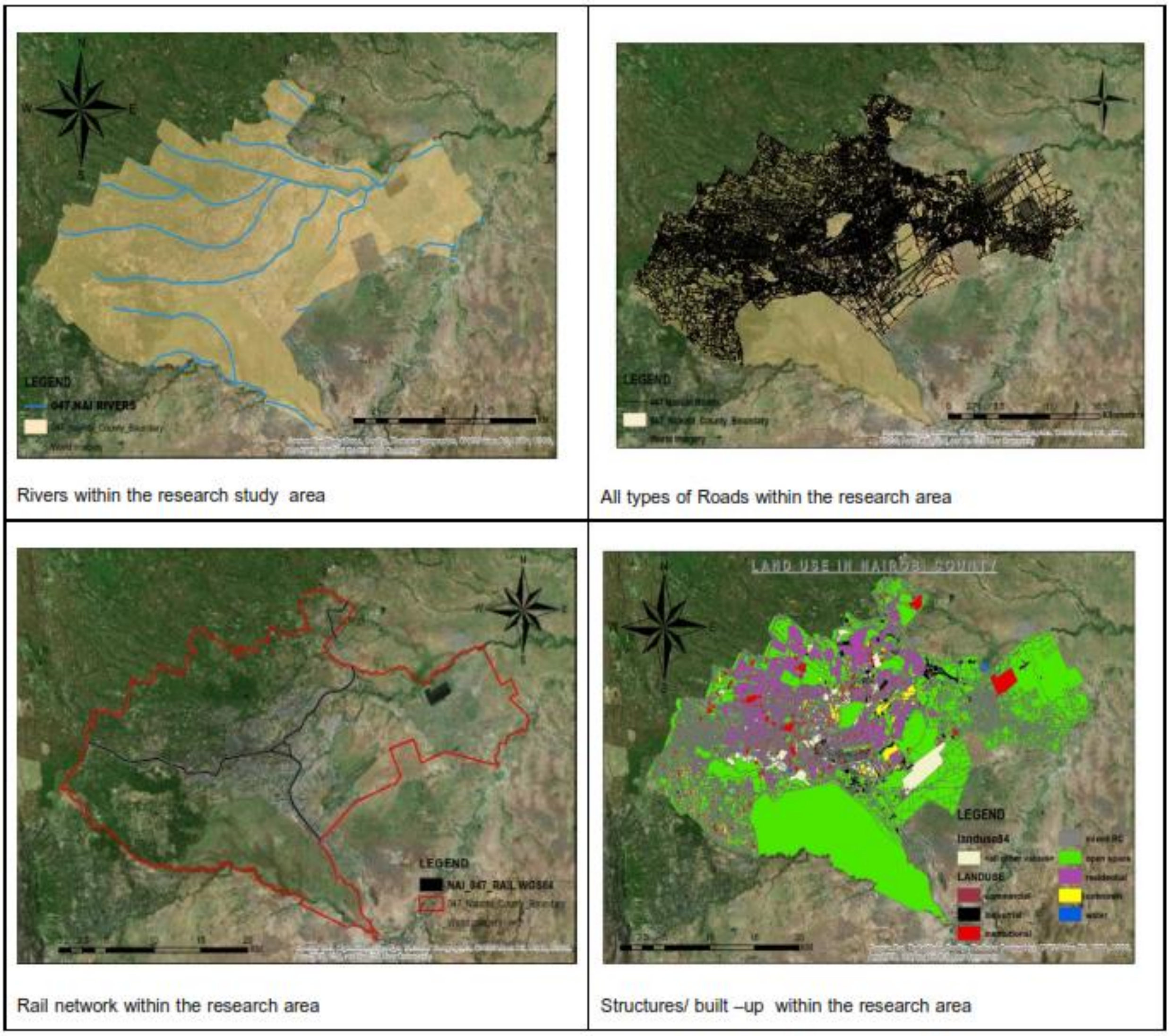
Boolean operators intersect (AND), negation (NOT), exclusive union (XOR), and union (OR) can be used to combine binary logic maps obtaining the integrated results. Each other factor map was combined using the Boolean logic function and a final map of the feasible area for applicability of recharge generated.

### 3.1 Land use and cover

Inputs used in the preparation of the shape file used in the development of feasible map in regard to this factor are:-

- Spatial identification and demarcation of roads within the research area
- Spatial identification and demarcation of the river within the research area with a buffer zone of 500m (Owuor, 2019; WRMA, 2005; WRMA, 2015).
- Spatial identification and demarcation of the railway network within the research area.
- Spatial identification and demarcation of structures within the research area.

The output was overlaid on world Imagery referenced to WGS84. And assigned binary values using Boolean function values "0"in areas where roads, buffed river, railway network and structures are available thus unsuitable. The value "1" assigned to areas where the infrastructures are absent thus suitable as in Figure 3.




Rivers within the research study area

All types of Roads within the research area

Rail network within the research area

Structures/ built –up within the research area

Figure 3: Spatial identification of various structures and utilities

### 3.2 Slope

An Input used in the preparation of the shape file used in the development of feasible map in regard to this factor is:-

- Elevation/ Contours of terrain within the research area.

The output was overlaid on world Imagery referenced to WGS84. The maximum slope applicable is less 5% thus assigned the Boolean value of "1" as suitable and for slopes greater than 5% assigned Boolean value of "0"thus unsuitable as in Figure 4.

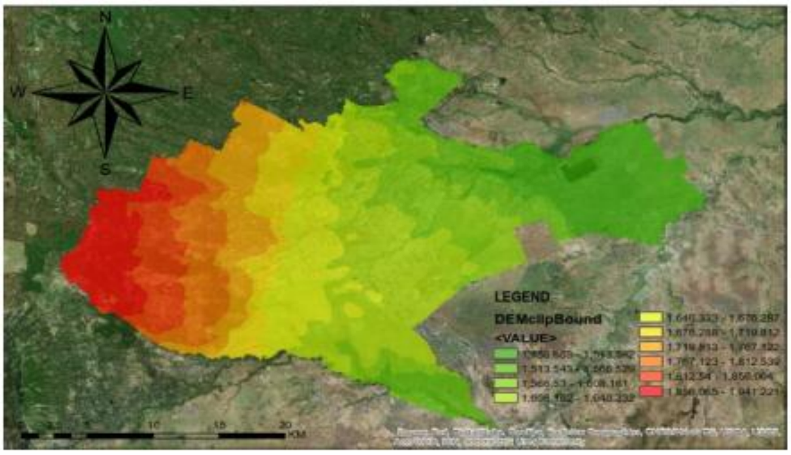



Figure 4: Slope Map area

3.3 Vadose zone thickness

In obtaining the thickness of the vadose, a map of the groundwater elevations and the surface elevation were obtained and the resultant difference became the vadose thickness. The vadose thickness of minimum of 15m is assigned the Boolean value “0” thus unsuitable whereas with more than 15m is assigned the Boolean value “1” as suitable as shown in Figure 5.

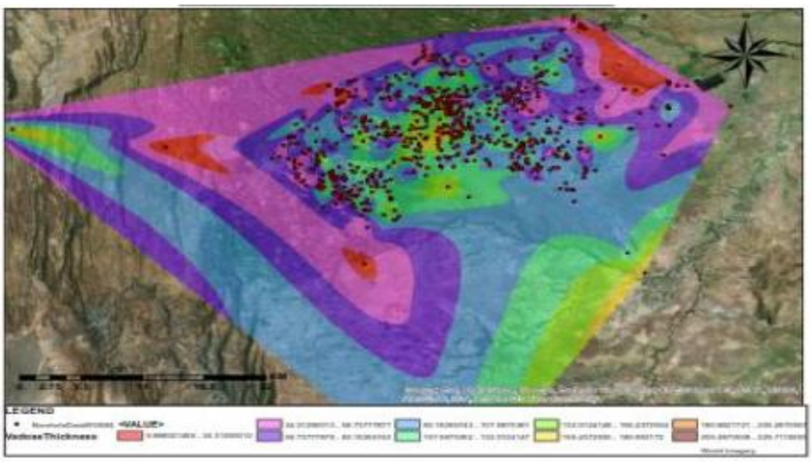



Figure 5: Vadose zone thickness

### 3.4 Geology

Inputs used in the preparation of the shape file used in the development of feasible map in regard slope layer:-

- Type of geological deposits within the research area (Saggerson, 1991).

The output was overlaid on world Imagery referenced to WGS84. The colluvial deposits assigned the Boolean value of “1”and Hydrography/ deposits swamps assigned value “0” unsuitable as in Figure 6.

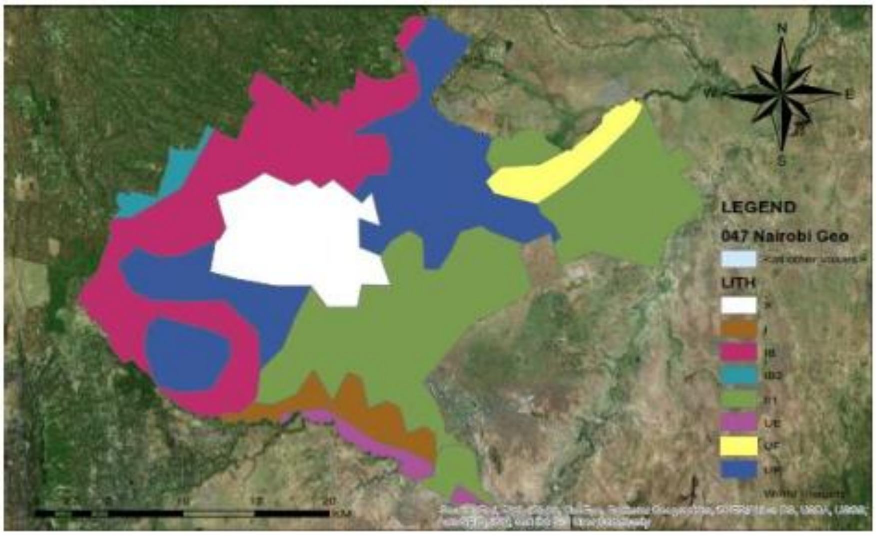



Figure 6: Geology of the research area

### 4.0 Results and Discussion

Assessment of the feasible recharge area was observed as follows based on each parameter:-

### 4.1 Land use and cover

Feasible area mapped in terms of buffered 500m river network is 73.42% of the research area. In terms of the road network, only 35.39% was observed feasible. In terms of the rail network, only 98.34% was observed feasible. In terms of built up/ structures, only 64.78% was observed feasible. Overlaying the four Boolean logic maps resulted in only 64.68% being feasible as shown in Figure 7.

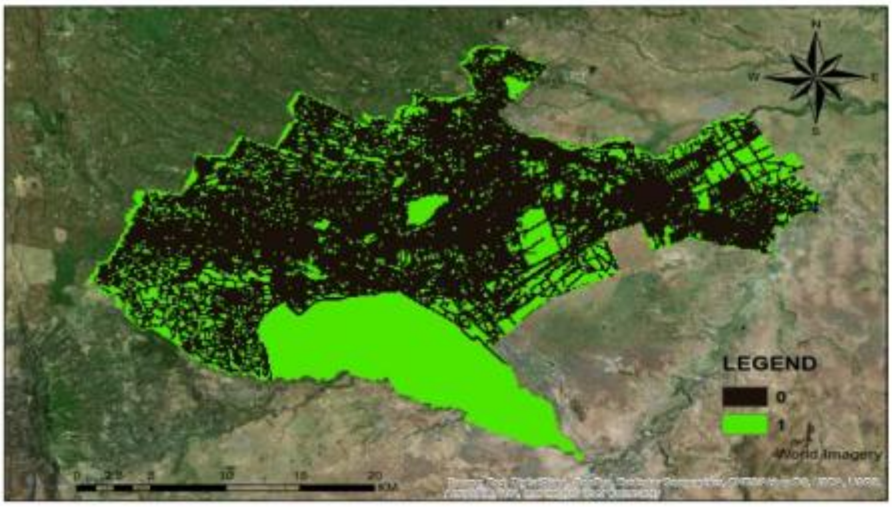



Figure 7: Feasible area map in terms of land cover and use.

4.2 Slope

Feasible area mapped in terms of the slope is 98.59% of the research area. That means there is generally not a steeply sloping area as shown in Figure 8.

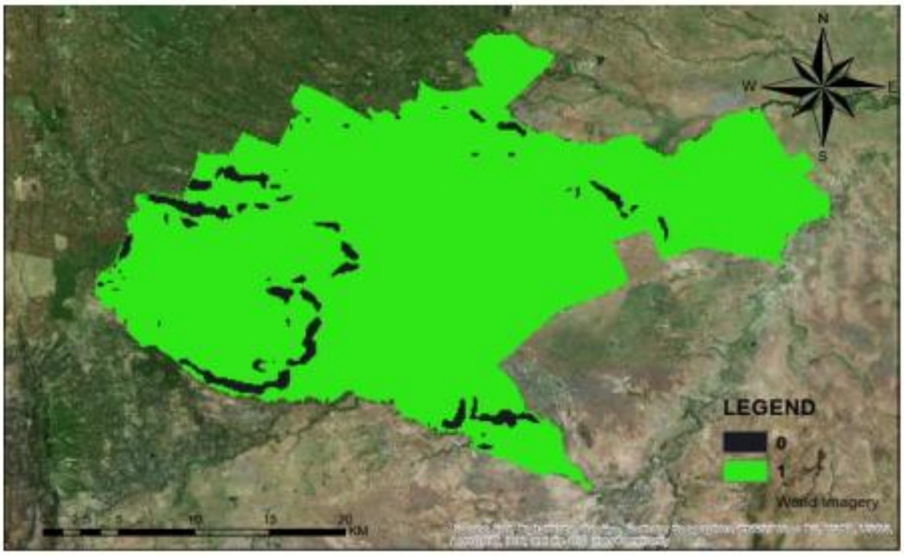



Figure 8: Feasible area regarding slope

4.3 Vadose zone thickness

Feasible area mapped in terms of vadose zone thickness is 98.91% of the research area. Most areas have a vadose zone of more than 15m thickness as shown in Figure 9.

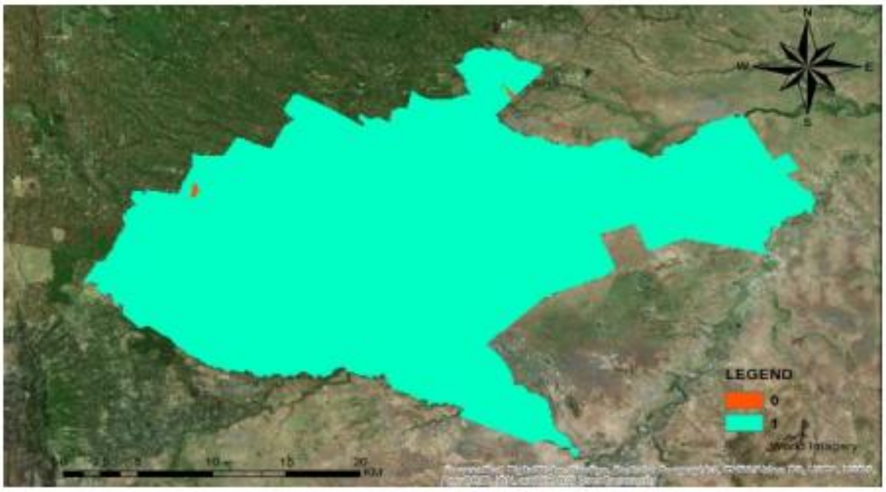



Figure 9: Feasible area map in terms of vadose thickness

**4.4 Geology**

Feasible area mapped in terms of geology is 47.92% of the research area. There is substantial area covered by colluvial deposits as shown in Figure 10.

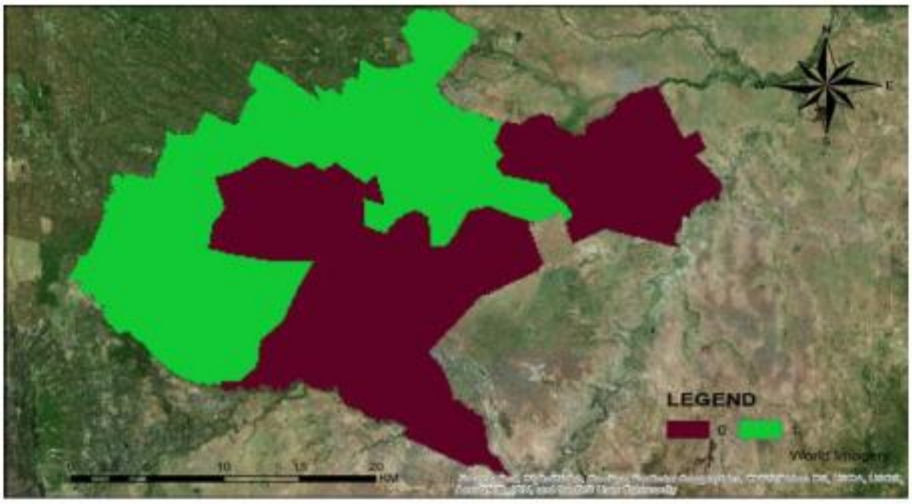



*Figure 10*: Feasible area map in terms of geology

**4.5 Feasible area**

Combination by overlaying of the four Boolean logic maps resulted in a feasible area mapped in terms of applicability of planned recharge technique is 22.57% of the research area. There is a substantial area that can be utilized for planned recharge as shown in Figure 11.

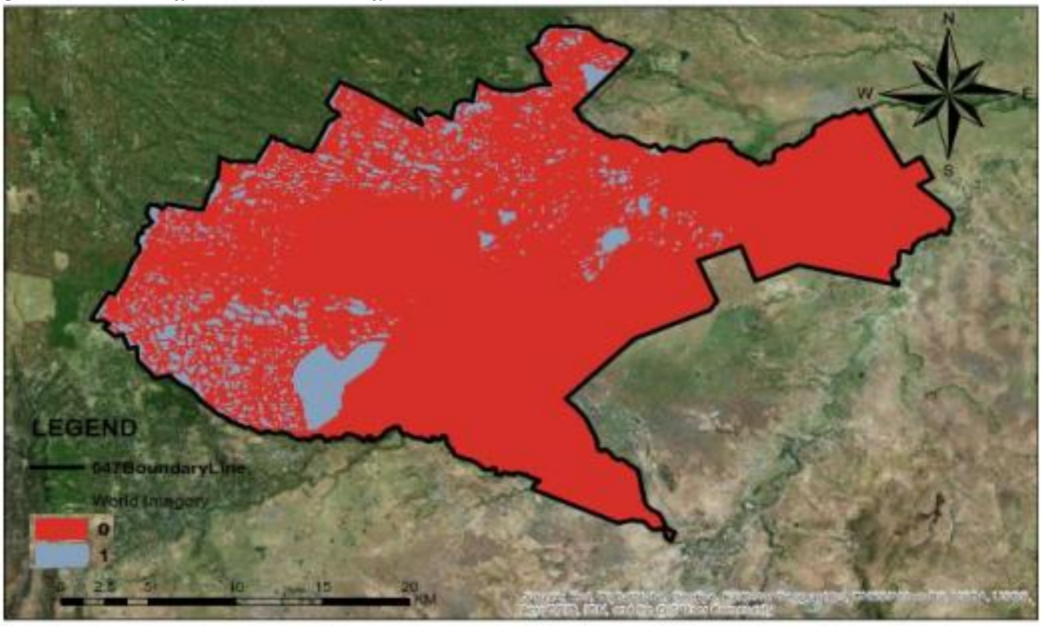



Figure 11: Feasible are map within the research area

**5.0 Conclusions**

The study concludes that:

- Availability of feasible areas that planned recharge can be undertaken within the City of Nairobi this can be used in flood mitigation as the city do experience floods during the rainy seasons which results to destruction of properties and loss of lives.
- Methodologies play real support and contribute significantly in obtaining feasible aquifer planned recharge points.

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## Author Contributions

M.O.O. conceived the idea and researched the project. S.O.D and C.O.T supervised and co-wrote the manuscript M.O.O carried out field data collection and analysed all the related data and wrote the original draft. S.O.D and C.O.T reviewed, edited and were research supervisors. All authors discussed the results and contributed to manuscript preparation.

## Conflicts of Interest

The authors declare no conflict of interest.