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MERTI AQUIFER RECHARGE ZONES DETERMINATION USING GEOSPATIAL TECHNOLOGIES

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Abstract

The Merti Aquifer is a fresh water aquifer in an arid area in the North Eastern part of the country straddling between Garissa and Wajir districts. In this study, the aquifer is defined by the 1,000 mg/l line of the Total Dissolved Solids (TDS). This starts West of Habaswein to Liboi on the East, along the Ewaso Ng'iro River drainage way (known as the Lagh Dera). It generally follows the Ewaso Ng'iro River with water flows encountered only during flooding events.

Development of the aquifer since the 1940's to date by governmental agencies and its development partners through drilling has resulted in generation of, over time, data and information on its water resources. This is arid region and it is essential to identify the potential recharge zones so that these can be protected from groundwater contaminants.

In this research, borehole data and water sample chemical analysis results were obtained from the Ministry of Water and Irrigation and reports by various researchers. A spatial database for the aquifer was developed. Remote sensing data was used to characterize the land covers in the area and to delineate lineaments in the study area.

The geophysical and geochemical characteristics with the derivative products from remote sensing were combined within a Geographic Information System. By applying spatial analysis techniques, potential recharge zones were found to be located between Habaswein and Liboi, providing a solid basis that confirms conclusions made by earlier researchers.

Keywords: aquifer, recharge zones, groundwater, lineament, GIS, remote sensing

1. INTRODUCTION

The Merti Aquifer is unique as it is a fresh water aquifer in an arid area, straddling Garissa and Wajir counties. It sits along the Ewaso Ng'iro River drainage way, on the ephemeral section generally known as the Lagh Dera with water flows encountered only during excessive flooding events like the El Nino Southern Oscillation (ENSO) (Wanyeki 1979). It starts from Habaswein in the west to Liboi in the east, on the Kenya–Somalia border and into Somalia. Its development started in the 1940's (GIBB Eastern Africa Ltd., 2004) through drilling. This has resulted in generation over time of data and information on its water resources. This data and information has been used in studies by various researchers like Swarzenski and Mundorff (1977); Wanyeki (1979); Gachanja and Tole, (2002); GIBB Eastern Africa Ltd. (2004) Heath et al. (2008).

Groundwater recharge in this area is of significance since this is an arid area that depends solely on groundwater for its water supply. Estimates have indicated an average annual recharge to the Merti Aquifer of 8.9 x 106 cubic meters (m^3) of water per year or 24,383.56 m^3/day. There are about 43 operational boreholes within the Merti Aquifer with an annual abstraction of 2.5x106 cubic meters (m^3) of water per year (6,849.32m^3/day) which represents 28% of the annual recharge (Ministry of Water and Irrigation 2005). Since the settlement of a large number of refugees from Somalia in the early 1990's in the Dadaab Axis which refers to the area within which Dadaab and the refugee camps lie. There has also been a significant increase in population due to the opportunities as a result of the refugee camps. Development of groundwater for their use has been significant and a number of boreholes have been drilled in the Axis. (GIBB Eastern Africa Ltd., 2004)

This research seeks to explore the utility of geospatial technologies in identifying the recharge zones of the Merti Aquifer by utilizing the already existing body of geochemical data coupled with remote sensing data and elevation data. This will be significant as it allows a quick and cost effective solution to pinpoint areas that can be considered for drilling of more boreholes with a high chance of yielding fresh water that can be consumed by man and animal in the arid areas such as this area.

2. MATERIALS AND METHODS

2.1.Study Area

The Merti Aquifer is a freshwater aquifer found within the Lorian Swamp - Lagh Dera drainage way beyond the ephemeral part of the Ewaso Ng'iro River. It is about 100km North of Garissa town. It starts from where the ephemeral section of the Ewaso Ng'iro River ends and is known from here as the Lagh Dera. This area extends from Habaswein (39^{0}25 'W) in the west to the Kenya Somali border (41^{0}E), a distance of about 200 km. Figure 1 shows the area occupied by the aquifer.

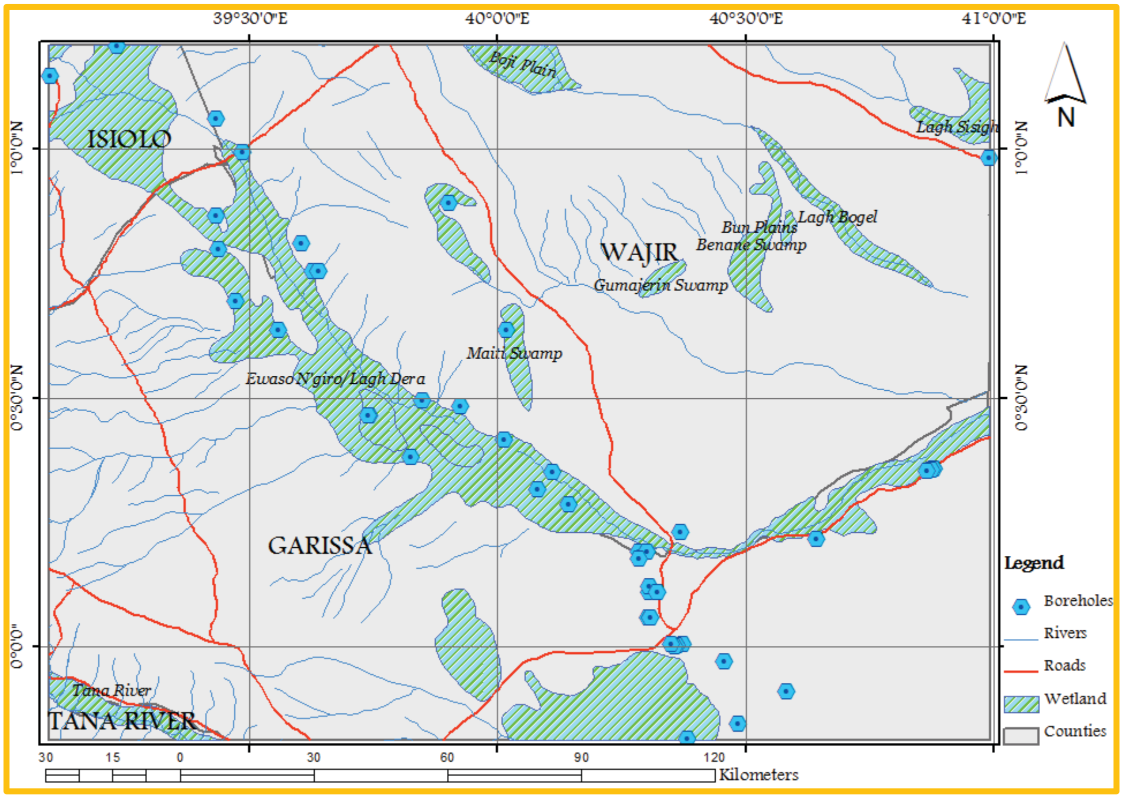


Figure 1. The Merti Aquifer Study Area

It has varying width and is narrowest to the west, widening to the east and generally follows the course of the Ewaso Ng'iro River (Wanyeki, 1979). The study area forms the generally flat flood plain of the Ewaso Ng'iro River with elevations ranging from 100 - 200 meters above mean sea level. The annual precipitation is between 200 - 300mm. This low rainfall falls in an area where annual evapotranspiration varies from 2,200mm to 2,600mm. The mean annual temperature ranges from between 24^0 to 30^0 C (Wanyeki, 1979).

The Ewaso Ng'iro becomes the ephemeral Lagh Dera between Merti and Habaswein. There is no clear cutoff, except that the transition from perennial to ephemeral is retreating westwards (the Lagh Dera is lengthening and the Ewaso Ng'iro shrinking). East of Habaswein it flows into the Lorian Swamp. The Lorian Swamp has, however, shrunk over historical time but the name has stuck for this area although currently no swampy vegetation exists to describe it (Heath, et al., 2008)

2.2.Data and Methodology

The data used for this research were obtained from a variety of sources. Table 1 outlines the various data used and their corresponding sources.

The project work was broken into two main portions: namely the geochemistry component and the geomatics component. The geochemistry component comprised the steps conducted to convert the borehole data into spatial distributions of the various chemical characteristics of the entire study area.

The geomatics component comprised of the steps undertaken to extract land cover classes from remote sensing datasets and calculation of slope from the Digital Elevation Model (DEM).

Table 1. Data sources used

	Data	**Source**
1.	Remote sensing data Landsat Thematic Mapper (2001)	United States Geological Services' Earth Explorer
2.	Shuttle Radar Topographic Mission Digital Elevation Model (90 m resolution)	Data Exchange Platform for the Horn of Africa
3.	Borehole data (Chemical data)	Ministry of Water and Irrigation

Figure 2 shows the workflow adopted in this research.

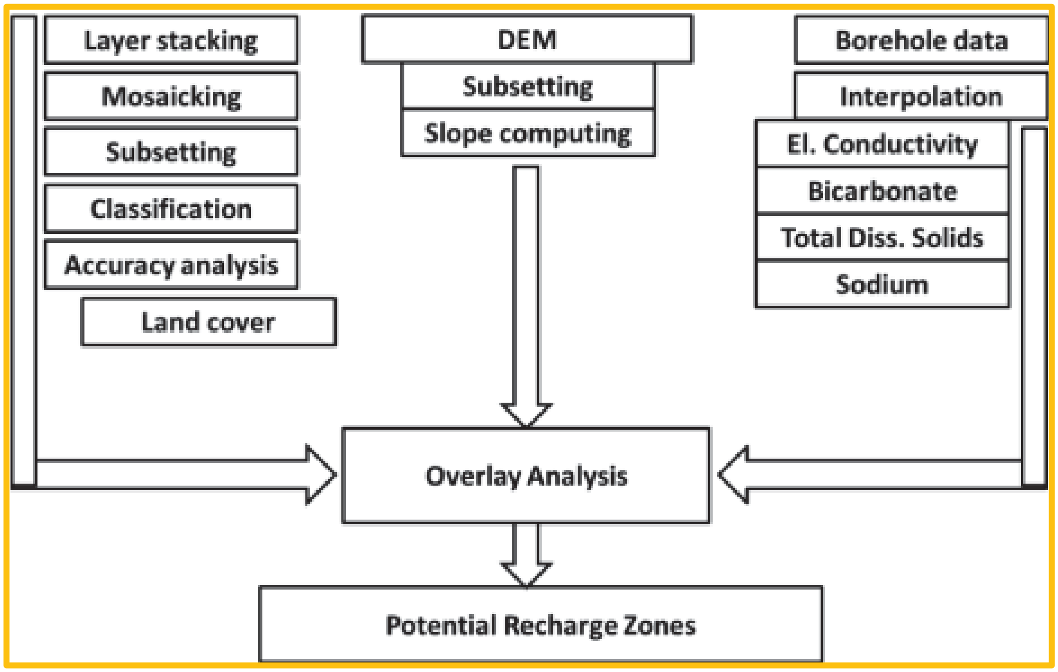


Figure 2. Methodology flowchart

The remote sensing data was obtained in individual bands per scene. For meaningful analysis, the bands for each scene had to be stacked together. Four scenes covered the entire area and these were mosaicked while ensuring that the histograms for each image agreed to a large extent with the other histograms (Lillesand et al., 2008). This is especially useful since the images were obtained under differing illumination conditions. To reduce the computation cost, the mosaic was subset using the parameters of the study area. Supervised classification was then carried out on the subset image. In this work, we used the maximum likelihood classifier and identified four main classes, namely: wetland, rivers, clayey and bare surface. To verify the authenticity of the classification exercise, a number of ground truth samples were collected and compared with the classification samples.

The DEM data was obtained for the whole country. This was subset to obtain a clipped area for the study area. Due to the significance of terrain on potential discharge, slope was considered as playing a role on the likelihood of slowing the flow of surface water thereby enhancing recharge. Thus, a slope parameter was computed for each 90 x 90 m pixel for the entire DEM.

From the borehole data collected, corresponding geochemical surfaces were interpolated using the kriging method for each of the geochemical parameter considered. All the layers were subsequently overlaid in the Geographical Information System (GIS) to produce a recharge zone potential map of the study area.

3. RESULTS AND ANALYSIS

The images obtained from the Earth Explorer interface were processed yielding a subset of the mosaic covering the area of interest. These images comprised a set of four scenes collected by the Landsat TM sensor in 2000 and 2001 during the months of February and March. Much of the imagery from the platform for most of the periods had cloud cover hence the large temporal consideration. The choice to take both years was also informed by the minimal land cover changes that were anticipated in the study area being a largely arid area other than in the wetlands. To mitigate for differential land cover changes, the period taken is that just before the onset of the rainy spells in both years.

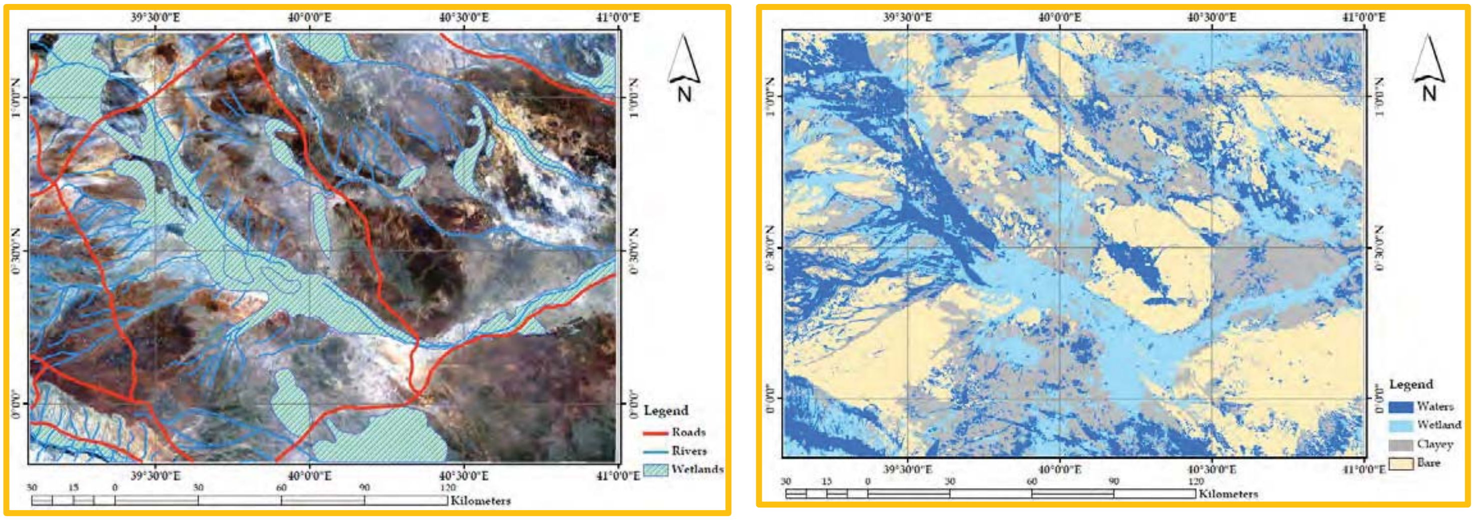


Figure 3. Remote sensing processing results; a) subset of image mosaic and b) classification results

Table 2. Image classification accuracy assessment

		Reference				Row Total	User accuracy
		Wetland	River	Clayey	Bare		
Classification	Wetland	832	57	29	121	1039	80.08%
	River	34	568	32	65	699	81.26%
	Clayey	21	43	754	76	894	84.34%
	Bare	53	86	97	3542	3778	93.75%
Total		940	754	912	3804	6410	
Producer's accuracy		88.51%	75.33%	82.68%	93.11%		
Overall Accuracy			88.86%		**Kappa**		0.8124

Figure 3 shows the remote sensing outputs, a) shows the subset image while b) shows the classification results. Comparing these results it can be seen that visually there is a good correspondence between the classification and the mapped features, especially the wetland regions.

Ground truth information was collected from high resolution images (Quickbird) from which a set of 6410 samples were collected. These samples were compared with the corresponding classification samples. The results of this analysis are given in table 2, which shows that the accuracy of the classification while not perfect is acceptable for the work being undertaken.

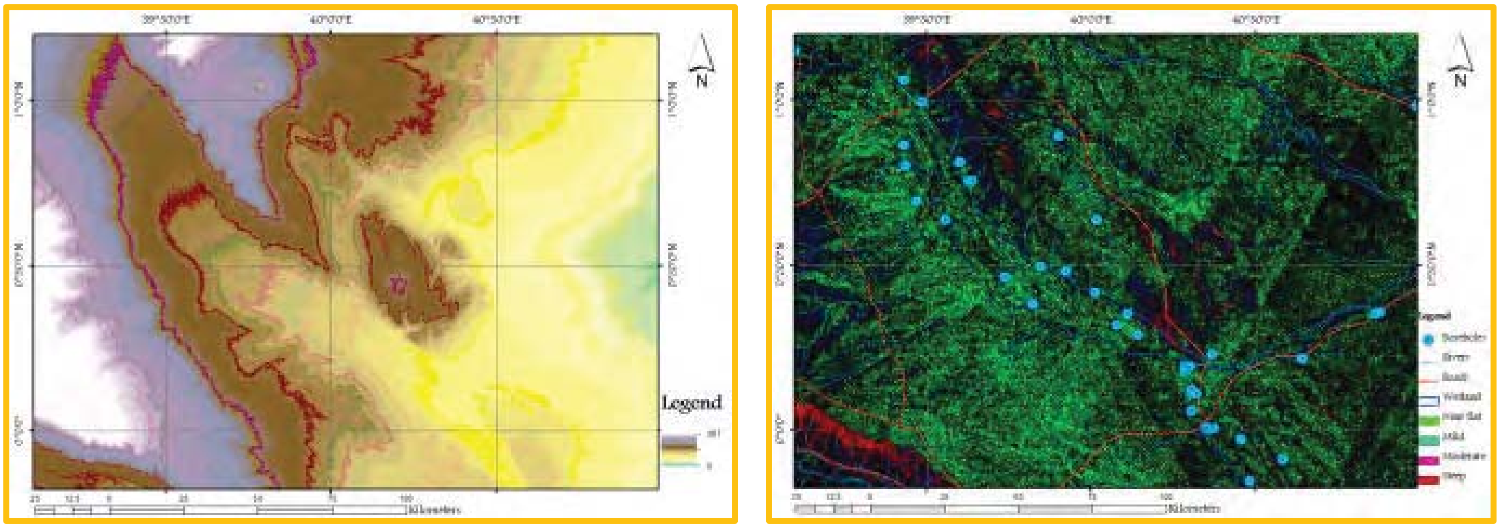


Figure 4. Topographic analysis; a) subset DEM and b) computed slope classified into four classes

Shuttle Radar Topographical Mission (SRTM) DEM was subset to cover the region and subsequently used to compute the corresponding slopes. Slope was computed as a percentage. Figure 4 shows these two results of elevation analysis. To aid in the visualization of the effect desired, the slope parameter was reclassified into four classes spanning near flat, mild, moderate and high slopes.

The geochemical layers after interpolation were also reclassified in order for them to be amenable to the subsequent steps of spatial overlaying. Table 3 shows the various ranges adopted in defining the rules of likelihood as potential recharge contribution.

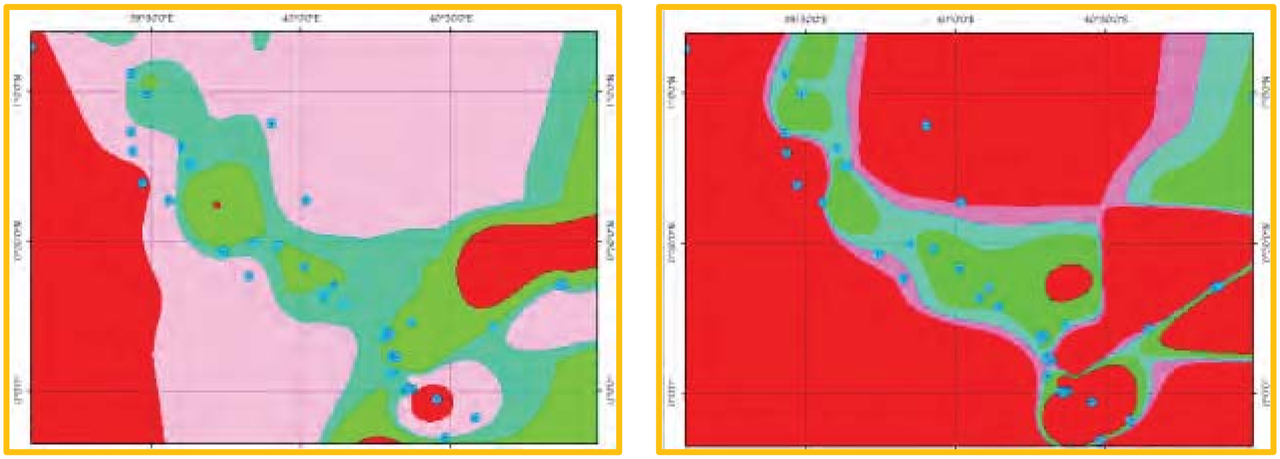
Table 3. Reclassification rules for the various input layers

Reclassified classes	**Land covers**	**Slope (%)**	**Sodium (mg/l)**	**TDS (mg/l)**	**Bicarbonate (mg/l)**	**Elec. Cond. (µS/cm)**
1	Wetland	0 – 5	0 - 200	0 - 1000	0 - 200	0 - 1000
2	River	5 - 12	200 - 500	1000 - 1500	200 - 400	1000 - 1500
3	Clayey	12 - 20	500 - 2000	1500 - 2000	400 - 600	1500 - 2000
4	Bare	> 20	> 2000	> 2000	> 600	> 2000

Figure 5 shows the four geochemical parameters considered in this study. These results are the reclassified variables giving an indication of the respective contribution to the recharge potential of each of these parameters. The likelihood indicator follows the color scheme showing green (1) as most likely, cyan (2) as likely, magenta (3) as less likely and (4) as least likely.

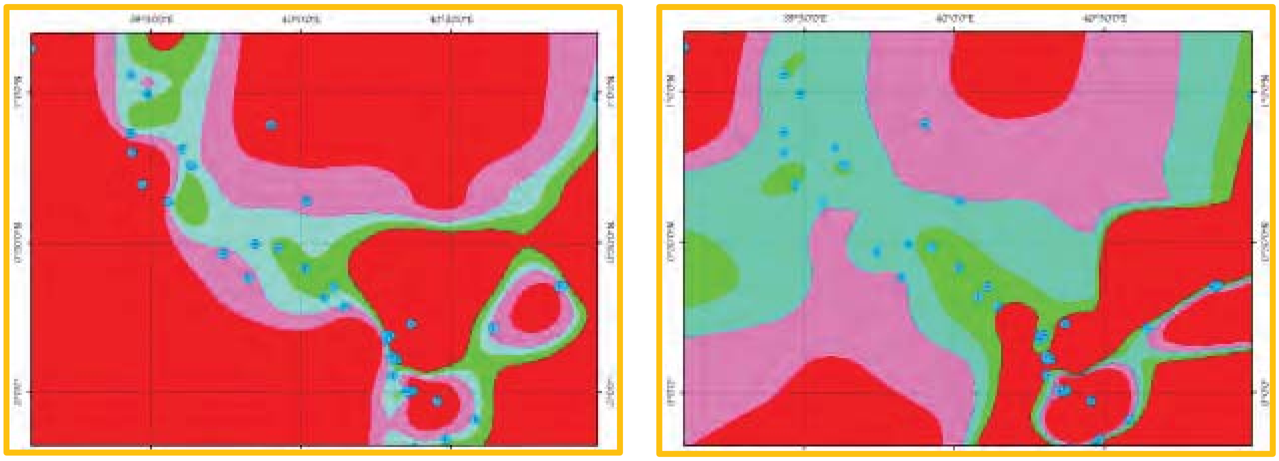
Table 4. Weighting regime for the various layers

Layer	**TDS**	**Elec. Con.**	**Bicarb.**	**Sodium**	**Slope**	**L. Cover**	**Total**
Weight (%)	28	14	14	14	15	15	100



Bicarbonate

Electric conductivity



Total Dissolved Solids

Sodium

Key

🟩 1 🟦 2 🟪 3 🟥 4

Figure 5. Reclassified geochemical parameters

To obtain the final overlay scenario, the various layers after reclassification had to be weighted. Table 4 shows the various weights adopted in this study. This was based on the fact that, the geochemistry part plays a key part in determining the likelihood (combined effect is 70%) while the geomatics part also has a significant but subdued part (30%).

Mathematically, the overlay operation can be described as follows:

$$\text{likelihood} = \frac{\sum_i^k weight_i \sum_j^l layer_{ij}}{\sum weight} \qquad (1)$$

where $weight_i$ represents the weight of a layer, while $layer_{ij}$ is the j^{th} class for a layer within the $layer_i$.

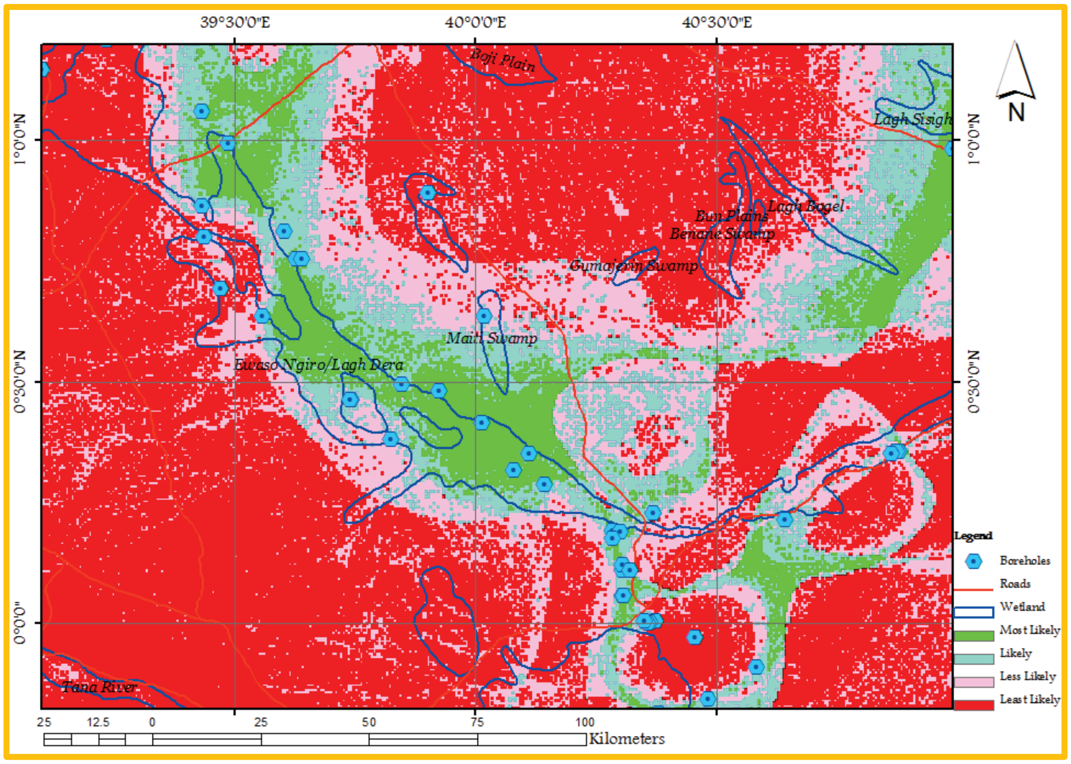


Figure 6. Recharge likelihood map

Figure 6 shows the results of the overlay operation. In this figure, it can be seen that the potential zones of recharge occur in mainly the marshy and wetland areas. This confirms the earlier conclusions that did not utilize geospatial technologies. The advantages of using geospatial technologies is the ease and cost effectiveness of the approach. While it does not replace the requirement for geochemical and other analysis, it can be used to complement these methods in a practical way.

4. CONCLUSION

The results of the analysis shows there are potential recharge zones corresponding to regions of low levels of Totally Dissolved Solids, Electric Conductivity, Sodium and Bicarbonate, within the fresh water Merti Aquifer. From remote sensing, areas that can be considered wetlands, river channels, clayey and bare ground were identified. From SRTM DEM, slope values were computed and reclassified to yield regions of near flat terrain, mild, moderate and high slopes. The geochemical characterization of the aquifer gives an indication of coincidence of the low values. The zones of low concentration are at Liboi, Dadab, Hagdera, Sabule, Meri and Habaswein.

As had been postulated by earlier researchers such as Swarzenski et al (1977); W anyeki (1979); Gachanja and Tole, (2002); GIBB Eastern Africa Ltd. (2004); Heath et al (2008), zones of recharge occur between Habaswein and Liboi during the excessive flooding events. Using geospatial technologies it has been demonstrated that zones of recharge for the Merti Aquifer occur along the Ewaso Ng'iro drainage based on the available data.

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