Groundwater potential mapping using GIS and remote sensing with multi-criteria decision-making in Shinile sub-basin, eastern Ethiopia

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Abstract

The main challenge for water resources development as well as food security in arid and semi-arid regions of Ethiopia is hydroclimatic variability. Groundwater resources are largely the main sources of water supply in such regions in order to alleviate the pressure of hydroclimatic variability on water resources. The present study delineated the potential groundwater zones in the Shinile sub-basin by using the geospatial technique. The criteria: geology, geomorphology, slope, soil, lineament density, drainage density, land use land cover, topographic wetness index, topographic roughness index, and rainfall were used. The relative weights were given by the analytic hierarchy process technique. The validation result was checked using the area under the curve (AUC=0.941) of the receiver operating curve (ROC) from borehole data. The study region classified as low, moderate, and high potential groundwater zones having; 1.5%, 43%, and 55%, respectively, of the total area. High potential areas are concentrated in the central part where alluvial and lacustrine sediment is a dominant geologic unit. The validation results suggest that the geospatial application of groundwater potential zone identification effectively performed well for the study area. This study is very important for water management experts as well as stakeholders and policymakers in the study region.

Keywords: Geographic Information System; Satellite imagery; Groundwater potential site; Multi-Criteria Decision-Making; Shinile sub-basin.

1. Introduction

Groundwater is water found in the sub-surface that fills the pore space of soils which is one of the main sources of worldwide water supply. It is a precious resource and population growth, intensive agriculture, rapid industrialization, and climate change are the coming challenges(Manap, Sulaiman, Ramli, Pradhan, & Surip, 2013). Ground-based hydro-meteorological observations are often limited in developing nations like Ethiopia due to a lack of resources. Ethiopia has a lot of surface water potential, however, developing its water resources is difficult due to its uneven distribution and topographic complexity. Most of the surface water resources are unevenly concentrated relative to the population density (Berhanu, Seleshi, & Melesse, 2014; Mengistu, Demlie, & Abiye, 2019). According to literature, southern, southwest, and southeast regions would experience up to a 20% decrease in rainfall as a result of climate change (Hailemariam, 1999; Seleshi & Zanke, 2004).

Due to the lack of surface water in the study area, groundwater is the best option for satisfying the water demand. A groundwater investigation is a fundamental theme to research in the region because it is the only source of water supply. (Devereux, 2010; Gebrewahid, KASA, GEBREHIWOT, & Adane, 2017) The potential and characteristics of groundwater are poorly understood, despite the study area's dependence on its groundwater resources. Identification of groundwater potential sites is therefore a crucial undertaking that improves the management of water resources in the semi-arid region in general and the Shinile sub-basin in particular in order to reduce the occurrence of recurrent droughts.

The primary objective of this research is to use GIS and remote sensing techniques to define the groundwater potential zones in the Shinile sub-basin. Ten variables that affect the subbasin's groundwater potential were used in the study. The layers are arranged in categories such as geology, geomorphology, rainfall, land use and land cover (LULC), slope, soil, lineament density, drainage density, topographic wetness index (TWI), and topographic roughness index (TRI). The results of this research will give a basic understanding of how various hydro-climatological factors affect regional groundwater resources. Additionally, this methodology is applicable to other arid and semi-arid regions.

2. Previous works

Groundwater is a hidden resource and its explorations by drilling test and stratigraphy analysis methods are either cost or time taking and also often require skilled manpower (Kumar, Herath, Avtar, & Takeuchi, 2016) These methods are not feasible for developing nations like Ethiopia. The best and most cost-effective solutions to these problems are using remote sensing (RS) and geographical information system (GIS) for assessing and managing groundwater resources (Mallick, Singh, Al-wadi, Ahmed, Rahman, Shashtri, & Mukherjee, 2014)

Exploring water resources in general and groundwater study, in particular, can benefit greatly from the use of GIS and remote sensing. Many studies have employed GIS and remote sensing techniques for geological mapping. (Mohamed, Al-Naimi, Mgbeojedo, & Agoha, 2021; Yamusa, Danbatta, & Najime, 2018) The most common applications include groundwater resources assessment, recharge and discharge site identification, pollution investigation, and groundwater quality studies (Dandge & Patil, 2022; Senthilkumar, Gnanasundar, & Arumugam, 2019).

Studies using GIS and multi-criteria decision-making to investigate groundwater potential zones in Ethiopia are available (Kabeto, Adeba, Regasa, & Leta, 2022; Yihunie & Halefom, 2020) In the study catchment, there is scant research on water resources (Ketema, Lemecha, Schucknecht, & Kayitakire, 2016; Riché, Hachileka, Awuor, & Hammill, 2009). The majority of these studies focus on the effects of climate change and related problems (Devereux, 2006; Girmay, Gebreselassie, & Bajigo, 2018; Solomon, 2013). The main investigation into the groundwater potential of the studied region is that conducted by Ketema and colleagues (Ketema et al., 2016) on hydrogeological characteristics in Shinile woreda. They investigated the subbasin's Shinile woreda's hydrogeological aspects. But rather than a hydrological boundary, their investigation was restricted to the woreda level (political administrative boundary). Furthermore, their study only uses a small number of thematic factors to classify groundwater potential, which could reduce the analysis's accuracy. Groundwater potential mapping has not received much attention in the past in the region. The current study used remote sensing and GIS to investigate the potential for groundwater in detail.

3. Methodology

3.1. Description of the study area

The Shinile sub-basin is found in the eastern extreme part of the Awash river basin. Geographically the sub-basin is located between $9^0$24’ to $10^0$55’ north and $41^0$19’ to $43^0$17 having 19963sq.km area coverage. The drainage of the sub-basin follows a south-eastern to north-western orientation (Figure 1). The area is characterized by an arid and semi-arid climate and drought occurrence is the main challenge in the region. (Berhanu, Melesse, &

Seleshi., 2013). The mean annual rainfall ranges from 200-800 mm and the average temperature range from 28 to 38 ºC. The inhabitant of the area follows a pastoralist and agro-pastoral way of life. Livestock production is the backbone of the economy in the region (Hundera, 2010) Majority of the sub-basin, particularly the central part covered by the quaternary formation. Tertiary volcanic are also cover areas in the upper catchment border area and the northeastern stripes (Kebede, 2013).

3.2. Input data acquisition

The climatic parameters were obtained from National Meteorological Agency. The topographic and hydrological factors were collected and produced from SRTM digital elevation model (DEM) data on the USGS website. Hardcopy maps of the study area were obtained from the Ethiopian geological survey institute, the ministry of water, and literature. The USGS and Copernicus hub websites were used as a source to download Sentine2 satellite imagery (https://earthexplorer.usgs.gov). The flow chart of the study includes all the thematic parameters with the methodology followed (Figure 2).

3.3. Groundwater influencing factors

For delineating the groundwater potential zone, the study applied influencing factors geology, geomorphology, rainfall, land use land cover (LULC), slope, soil, lineament density, drainage density, topographic wetness index (TWI), and topographic roughness index (TRI). For common projection, all the thematic maps were converted and geo-referenced to the same projection. ArcGIS 10.3 software was the main manipulation environment in thematic map preparations. Additionally, the Rockwork 16, ERDAS Imagine, and Surfer software were used in this study for data processing.

3.4. Multi-Criteria Decision Making (MCDM) approach

The study applied the analytic hierarchy process technique of the multi-criteria decision-making approach. AHP is a matrix-based technique and works according to Saaty's scale 1-9 to measure the relative weight of criteria. (Saaty, 1987, 2002; Zhang, Sekhari, Ouzrout, & Bouras, 2014) The pairwise comparison matrix table (table 1) indicates the relative weight of each criterion with the AHP technique of the MCDM method. The sum of each column of the pairwise matrix table value multiplied by each weight value gives the normalized pairwise matrix. To get the weight of each criterion the average value of the normalized pairwise matrix was calculated.

3.5. Consistency examination

The agreement of the calculated weight of each criterion should be checked before using it for overlay analysis. So, the hesitation that can occur in the ranking and weight giving was checked using consistency index and consistency ratio values.

$$Consistency\ ratio(CR) = \frac{consistency\ index(CI)}{Random\ consitency\ Index(RCI)}, CI$$

$$= \left(\frac{\lambda_{max} - n}{n-1}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where λ_{max} is the maximum eigenvalue (the product between each element of the priority matrix table and sum total) λ_{max} =10.709; and n is the matrix size (number of criteria used, n=10). So, the consistency index value becomes (CI=0.0.78). Taking the value of random consistency index from the table value for n=10, RCI =1.49 (Saaty & Katz, 1990; Tummala, V. M, Ling, & Ling, 1996). So, the consistency ratio of the analysis CR=0.078/1.49=0.053<<0.1 and acceptable for groundwater potential mapping.

3.6. Delineation of groundwater potential Map

The groundwater potential zone map was prepared using a weighted overlay of the spatial analyst tool of ArcGIS. The groundwater potential index (GWPI) is defined as:

$$GWPI = \sum_{i=1}^{n} (W_i * R_i) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)$$

Where *Wi* is the weight of each thematic layer and Ri is the rank of the sub-classes of each thematic layer. The results of the study were validated using the water point data of the field and their distribution. (B. Das & Pal, 2020; Fashae, Tijani, Talabi, & Adedeji, 2014)

4. Results and Discussion

In this part of the study, the results of thematic maps developed for overlay analysis and the discussion are presented. Table (2) present the weightage of each thematic layer and the ranks given for the sub-classes of the thematic layer.

Geology

The geological features of the area collected from Ethiopia geological survey institute in "pdf" and "jpg" formats were used by georeferencing and digitizing in ArcGIS software. According to a geological survey report (Geological Survey of Ethiopia, 1996), the quaternary formation covers a major area of the central part of the sub-basin. The upper catchment border area and the north-eastern stripes consist of very deep tertiary volcanic aquifers (Kebede, 2013). The major features in the study area (Figure 3) are alluvial and lacustrine sediments, afar series, and the Hamanlei Formation which cover 45%, 24%, and 12 % of the study area. Basalt flows, spatter cones, and hyaloclastites and the Alghe group have indispensable coverage in southern and south-eastern strips each covering 7% of the area.

Geomorphology

The terrain of the study area is characterized by a huge difference in elevation between 346 to 3022m above m.s.l. There are two basic landforms in the study area: undulating ridge land on the upper catchment and the alluvial plain covering much of the area on the central part. The geomorphological classes of the study area (Figure 3) are valley, middle slope, plains, hills, and high ridges and mountains. The respective area areal coverage is: 3.04%, 14.72%, 69.91%, 10.02% and 2.29%. Mountains are sloping surfaces and facilitate surface runoff rather than infiltration and are ranked to the lowest.

Rainfall

Rainfall is one of the main parameters that influence the hydrogeological condition of an area. The amount of rainfall has a direct effect on the groundwater zone as the main source of recharge. The rainfall point data for the study area as well as neighboring stations was collected from National Meteorological Agency. The study area experienced average annual rainfall of 612 mm. A spatial rainfall map of the study area was done using the inverse distance weighting (IDW) interpolation method.

Slope

The slope of the surface is a degree of inclination and is directly proportional to the surface runoff. The slope is an important topographic parameter that can influence surface water distribution. The higher the slope, the steeper the surface and the higher will be the surface runoff, which decreases the infiltration capacity(Morbidelli, Saltalippi, Flammini, & Govindaraju, 2018). The slope map of the study area was produced from DEM data using ArcGIS. The slope value was then reclassified into five subclasses (flat sloping, gentle sloping, strong sloping, moderate steep sloping, and very steep sloping). The mountains in the upper catchment area are very steep sloping and taken as lower capability of groundwater potential.

Lineaments and lineament density

Lineament is a linear structural feature found on a land surface that infers the characteristics of underline geological features of an area. Lineament can be a structure like a fault, fracture, or joint on the landscape. (Caran, Woodruff, & Thompson, 1981) The concept of lineaments was familiarized for the first time by Hobbs (1904). He used the idea of lineament to describe; crests of ridges, drainage lines, coastlines, and boundary lines of rock formations. The lineament orientations in the study area follow NE-SW trends (Figure 5). The lineament's density (L_d) of an area is defined as the proportion of the total length of the lineament structure to the areal coverage (Figure 6).

Land use and land cover (LULC)

The cover of the earth's surface is one of the main characteristics that can influence water availability in any region. LULC of the surface has a huge influence on hydrological as well as hydrogeological systems. The bare land area becomes more susceptible to surface runoff than infiltration (Guzha, Rufino, Okoth, Jacobs, & Nóbrega, 2018; Srivastava, Kumari, & Maza, 2020). To produce and classify the LULC the study used Sentinel 2 satellite imagery. The LULC of the study area presented in (Figure 4) is classified into six categories: agricultural land, settlement, forest land, barre land, shrubland, rock out crop, and grassland.

Drainage Density

The drainage density is defined as the closeness of a channel in any particular catchment. The drainage density of a particular area depends on the hydroclimatic and surface characteristics. (Das, Gupta, & Ghosh, 2017; Krause, Jacobs, & Bronstert, 2007) Drainage density is inversely proportional to the groundwater potential zone. The drainage density of a catchment is defined as the ratio of the total length of the stream to the area of the catchment. The map of the study in (km/km^2) value classified in five from very low to very high (Figure 6).

Soil

Soil hydraulic property has a huge role in subsurface percolation and the water-holding capacity of the soil. This characteristic of soil determines the groundwater movement and infiltration capacity (Berhanu et al., 2013). Fine texture soil has a lower infiltration capacity that minimizes the groundwater recharge. (Das et al., 2017; Ma W, Zhang, Zhen, & Zhang,

2016) The soil in the study area (Figure 4) is composed of clay, loam, loamy sand, and sandy loam textures.

Topographic Wetness Index

The topographic wetness index (TWI) is also used to describe the effects of topography on pondage and runoff occurrence (Bera, Mukhopadhyay, & Barua, 2020; Pham, Jaafari, Prakash, Singh, Quoc& Bui, 2019). TWI was used for moisture distribution with elevation data of the study area. The topographic wetness has a direct relationship to recharge. The higher value of TWI, the higher the water accumulation the higher will be the recharge, the give higher the groundwater potential zone, and vice versa. (Wilson & Gallant, 2000) The TWI is defined as:

$$TWI = \ln\left(\frac{A_s}{tan\beta}\right) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3)$$

Where: $A_s = upsloe\ contributing\ area, \beta = topgraphic\ gradient(slope) in\ degree$

Topographic Roughness Index

The topographic roughness index is a morphologic parameter that can influence the groundwater potential zone of an area. Terrain roughness implies the texture of the surface that can be rough or smooth. The smoother the surface the flatter the slope this favors the water particle to infiltrate to the sub surface and vice versa. (Roy, Chakrabortty, Chowdhuri, Malik, Das, & Pal, 2020) Topographic roughness index (TRI) is given as:

$$TRI = \frac{FS_{mean} - FS_{min}}{FS_{max} - FS_{mn}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

Where: FS_{mean} mean focal statistic, FS_{max} maximum focal statistics amd FS_{min} minimum focal statistic of a surface(Mukherjee & Singh, 2020).

4.1. Groundwater Potential Zone map

Modeling the groundwater potential with ten thematic layers involves the integration of these layers in to one raster map that shows the groundwater potential zone (Dhar, Sahoo S., & Sahoo M., 2015; Panigrahi, Nayak, & Sharma, 1995). All the thematic layers were converted into raster format for overlay analysis. The weights were given according to the influence of each criterion on groundwater recharge. The ArcGIS weighted overlay analysis results in low, moderate, and high groundwater potential zone. High groundwater potential areas are alluvial and lacustrine sediment areas (Figure 7), this clearly assure that the alluvial plain has very good for groundwater potential development.

4.2. Validation

Literature showed that one of the methods of validation of groundwater potential zone maps was through borehole and spring data. (Andualem & Demeke, 2019; Senapati & Das, 2022) In order to validate the groundwater potential model area under the curve (AUC) of the receiver operating curve (ROC) the method was applied (Figure 8). The predicted value shows a very good potential (94.1%). This gives clues to the accuracy of GIS and remote sensing methods for groundwater potential zone mapping in the study area.

5. Conclusion

Studying and developing groundwater resources is crucial for ensuring sufficient food security and sustainable development in arid and semi-arid regions like the Shinile sub-basin.

The current study aimed to investigate the groundwater potential zone in the Shinile sub-basin using GIS and remote sensing with the AHP technique. Ten elements that significantly affect the groundwater potential zones of the study's inclusion criteria. The ultimate groundwater potential area has three levels, with a total area of 19478.83 sq.km: low (310.04 sq.km), intermediate (8392.73 sq.km), and high (10776.06 sq.km). The results indicate that 55.32% of the area is covered by a high groundwater zone. The high groundwater development potential of the alluvial plain is evident in the alluvial and lacustrine sediment deposits. The area under the ROC curve for the model shows very great performance (94.1%). This study shows that zoning groundwater potential by taking into account a variety of influencing elements can increase the accuracy of the investigation. If more accurate data are available, the methodology used in this study could be applied in other locations in a similar hydroclimatic region. The result could be utilized by planners and policy makers in the region's water resources sector.

Conflict of interest

There is no conflict of interest to disclose.

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References

Andualem, T. G., & Demeke, G. G. (2019). Groundwater potential assessment using GIS and remote sensing: A case study of Guna tana landscape, upper blue Nile Basin, Ethiopia. *Journal of Hydrology: Regional Studies*, *24*. https://doi.org/10.1016/j.ejrh.2019.100610

Bera, A., Mukhopadhyay, B. P., & Barua, S. (2020). Delineation of groundwater potential zones in Karha river basin, Maharashtra, India, using AHP and geospatial techniques. *Arabian Journal of Geosciences*, *13*(15). https://doi.org/10.1007/s12517-020-05702-2

Berhanu, B., Melesse, A. M., & Seleshi, Y. (2013). GIS-based hydrological zones and soil geo-database of Ethiopia. *Catena*, *104*, 21–31. https://doi.org/10.1016/j.catena.2012.12.007

Berhanu, B., Seleshi, Y., & Melesse, A. M. (2014). Surface water and groundwater resources of Ethiopia: Potentials and challenges of water resources development. In *Nile River Basin: Ecohydrological Challenges, Climate Change and Hydropolitics* (Vol. 9783319027203, pp. 97–117). Springer International Publishing. https://doi.org/10.1007/978-3-319-02720-3_6

Caran, C., Jr, C. W., & Thompson, E. (1981). *Lineament Analysis and Inference of Geologic Structure--Examples from the Balcones/Ouachita Trend of Texas (1)*. https://archives.datapages.com/data/gcags/data/031/031001/0059.htm

Dandge, K. P., & Patil, S. S. (2022). Spatial distribution of ground water quality index using remote sensing and GIS techniques. *Applied Water Science*, *12*(1), 1–18. https://doi.org/10.1007/S13201-021-01546-7/FIGURES/5

Dargo, F., Madalcho, A., Dargo Girmay, F., Gebreselassie, G., & Bajigo, A. (2018). Climate Change Risk Management and Coping Strategies for Sustainable Camel Production in the Case of Somali Region, Ethiopia. *Researchgate.Net*, *4*(9), 66–75. https://doi.org/10.32861/jbr.49.66.75

Das, B., & Pal, S. C. (2020). Assessment of groundwater recharge and its potential zone identification in groundwater-stressed Goghat-I block of Hugli District, West Bengal, India. *Environment, Development and Sustainability*, *22*(6), 5905–5923. https://doi.org/10.1007/s10668-019-00457-7

Das, S., Gupta, A., & Ghosh, S. (2017). Exploring groundwater potential zones using MIF technique in semi-arid region: a case study of Hingoli district, Maharashtra. *Spatial Information Research*, *25*(6), 749–756. https://doi.org/10.1007/s41324-017-0144-0

Devereux, S. (2006). *Vulnerable livelihoods in Somali region, Ethiopia*. https://dlci-hoa.org/assets/upload/combined-documents/20200804033942909.pdf

Devereux, S. (2010). Better marginalised than incorporated? Pastoralist livelihoods in Somali Region, Ethiopia. *European Journal of Development Research*, *22*(5), 678–695. https://doi.org/10.1057/EJDR.2010.29/FIGURES/1

Dhar, A., Sahoo, S., & Sahoo, M. (2015). Identification of groundwater potential zones considering water quality aspect. *Environmental Earth Sciences*, *74*(7), 5663–5675. https://doi.org/10.1007/s12665-015-4580-7

Ethiopian Ministry of Mines Geological Survey of Ethiopia. (1996).

Fashae, O. A., Tijani, M. N., Talabi, A. O., & Adedeji, O. I. (2014). Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach. *Applied Water Science*, *4*(1), 19–38. https://doi.org/10.1007/s13201-013-0127-9

Gebrewahid, M., KASA, A., … K. G.-E. J. of, & 2017, undefined. (2017). Analyzing drought conditions, interventions and mapping of vulnerable areas using NDVI and SPI indices in Eastern Ethiopia, Somali region. *Ejesm.Org*, *10*(9), 1998–0507. http://ejesm.org/wp-content/uploads/2017/11/ejesm.v10i9.3.pdf

Guzha, A. C., Rufino, M. C., Okoth, S., Jacobs, S., & Nóbrega, R. L. B. (2018). Impacts of land use and land cover change on surface runoff, discharge and low flows: Evidence from East Africa. In *Journal of Hydrology: Regional Studies* (Vol. 15, pp. 49–67). Elsevier B.V. https://doi.org/10.1016/j.ejrh.2017.11.005

Hailemariam, K. (1999). Impact of climate change on the water resources of Awash River Basin, Ethiopia. *Climate Research*, *12*(2–3), 91–96. https://doi.org/10.3354/CR012091

Hundera, M. B. (2010). *Masters of Professional Thesis*.

Kabeto, J., Adeba, D., Regasa, M. S., & Leta, M. K. (2022). Groundwater Potential Assessment Using GIS and Remote Sensing Techniques: Case Study of West Arsi Zone, Ethiopia. *Water (Switzerland)*, *14*(12). https://doi.org/10.3390/w14121838

Kalantar, B., Al-Najjar, H. A. H., Pradhan, B., Saeidi, V., Halin, A. A., Ueda, N., & Naghibi, S. A. (2019). Optimized conditioning factors using machine learning techniques for groundwater potential mapping. *Water (Switzerland)*, *11*(9). https://doi.org/10.3390/w11091909

Kebede, S. (2013). Groundwater in Ethiopia: Features, numbers and opportunities. In *Groundwater in Ethiopia: Features, Numbers and Opportunities*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-30391-3

Ketema, A., Lemecha, G., Schucknecht, A., & Kayitakire, F. (2016). *Hydrogeological study in drought affected areas of Afar, Somali, Oromia and SNNP regions in Ethiopia*. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC103616/unicef-jrc_hydrogeologicalstudyethiopia_part1_2016-11-04_final.pdf

Krause, S., Jacobs, J., & Bronstert, A. (2007). Modelling the impacts of land-use and drainage density on the water balance of a lowland-floodplain landscape in northeast Germany. *Ecological Modelling*, *200*(3–4), 475–492. https://doi.org/10.1016/j.ecolmodel.2006.08.015

Kumar, P., Herath, S., Avtar, R., & Takeuchi, K. (2016). Mapping of groundwater potential zones in Killinochi area, Sri Lanka, using GIS and remote sensing techniques.

Sustainable Water Resources Management, *2*(4), 419–430. https://doi.org/10.1007/S40899-016-0072-5

Ma, W., Zhang, X., Zhen, Q., & Zhang, Y. (2016). Effect of soil texture on water infiltration in semiarid reclaimed land. *Water Quality Research Journal of Canada*, *51*(1), 33–41. https://doi.org/10.2166/wqrjc.2015.025

Mallick, J., Singh, C. K., Al-wadi, H., Ahmed, M., Rahman, A., Shashtri, S., & Mukherjee, S. (2014). *Geospatial and geostatistical approach for groundwater potential zone delineation*. https://doi.org/10.1002/hyp.10153

Manap, M. A., Sulaiman, W. N. A., Ramli, M. F., Pradhan, B., & Surip, N. (2013). A knowledge-driven GIS modeling technique for groundwater potential mapping at the Upper Langat Basin, Malaysia. *Arabian Journal of Geosciences*, *6*(5), 1621–1637. https://doi.org/10.1007/S12517-011-0469-2

Mengistu, H. A., Demlie, M. B., & Abiye, T. A. (2019). Review: Groundwater resource potential and status of groundwater resource development in Ethiopia. *Hydrogeology Journal*, *27*(3), 1051–1065. https://doi.org/10.1007/s10040-019-01928-x

Mohamed, M. T. A. M., Al-Naimi, L. S., Mgbeojedo, T. I., & Agoha, C. C. (2021). Geological mapping and mineral prospectivity using remote sensing and GIS in parts of Hamissana, Northeast Sudan. *Journal of Petroleum Exploration and Production*, *11*(3), 1123–1138. https://doi.org/10.1007/s13202-021-01115-3

Morbidelli, R., Saltalippi, C., Flammini, A., & Govindaraju, R. S. (2018). Role of slope on infiltration: A review. *Elsevier*, *557*, 878–886. https://doi.org/10.1016/j.jhydrol.2018.01.019

Mukherjee, I., & Singh, U. K. (2020). Delineation of groundwater potential zones in a drought-prone semi-arid region of east India using GIS and analytical hierarchical process techniques. *Catena*, *194*. https://doi.org/10.1016/j.catena.2020.104681

Panigrahi, B., Nayak, A. K., & Sharma, S. D. (1995). Application of remote sensing technology for groundwater potential evaluation. *Water Resources Management*, *9*(3), 161–173. https://doi.org/10.1007/BF00872127

Pham, B. T., Jaafari, A., Prakash, I., Singh, S. K., Quoc, N. K., & Bui, D. T. (2019). Hybrid computational intelligence models for groundwater potential mapping. *Catena*, *182*. https://doi.org/10.1016/j.catena.2019.104101

Riché, B., Hachileka, E., Awuor, C., report, A. H.-I., & 2009, undefined. (2009). Climate-related vulnerability and adaptive capacity in Ethiopia's Borana and Somali communities. *Cakex.Org*. https://www.cakex.org/sites/default/files/climate_ethiopia_communities_0.pdf

Roy, P., Chakrabortty, R., Chowdhuri, I., Malik, S., Das, B., & Pal, S. C. (2020). *Development of Different Machine Learning Ensemble Classifier for Gully Erosion Susceptibility in Gandheswari Watershed of West Bengal, India* (pp. 1–26). https://doi.org/10.1007/978-981-15-3689-2_1

Saaty, T. L. (1987). A NEW MACROECONOMIC FORECASTING AND POLICY EVALUATION METHOD USING THE ANALYTIC HIERARCHY PROCESS. In *Moth/ Modelling* (Vol. 9, Issue 5).

Saaty, T. L. (2002). Decision making with the Analytic Hierarchy Process. *Scientia Iranica*, *9*(3), 215–229. https://doi.org/10.1504/ijssci.2008.017590

Saaty, T. L., & Katz, J. M. (1990). How to make a decision: The Analytic Hierarchy Process. In *European Journal of Operational Research* (Vol. 48).

Seleshi, Y., & Zanke, U. (2004). Recent changes in rainfall and rainy days in Ethiopia. *International Journal of Climatology*, *24*(8), 973–983. https://doi.org/10.1002/JOC.1052

Senapati, U., & Das, T. K. (2022). GIS-based comparative assessment of groundwater potential zone using MIF and AHP techniques in Cooch Behar district, West Bengal. *Applied Water Science*, *12*(3). https://doi.org/10.1007/s13201-021-01509-y

Senthilkumar, M., Gnanasundar, D., & Arumugam, R. (2019). Identifying groundwater recharge zones using remote sensing & GIS techniques in Amaravathi aquifer system, Tamil Nadu, South India. *Sustainable Environment Research*, *1*(1), 1–9. https://doi.org/10.1186/S42834-019-0014-7/TABLES/3

Solomon, T. (2013). *Rationale and Capacity of Pastoral Community Innovative Adaptation to Climate Change in Ethiopia*. https://www.africaportal.org/publications/rationale-and-capacity-of-pastoral-community-innovative-adaptation-to-climate-change-in-ethiopia/

Srivastava, A., Kumari, N., & Maza, M. (2020). Hydrological Response to Agricultural Land Use Heterogeneity Using Variable Infiltration Capacity Model. *Water Resources Management*, *34*(12), 3779–3794. https://doi.org/10.1007/s11269-020-02630-4

Tummala, V. M. R., & Ling, H. (1996). Sampling distribution of the random consistency index of the analytic hierarchy process (AHP). *Journal of Statistical Computation and Simulation*, *55*(1–2), 121–131. https://doi.org/10.1080/00949659608811754

Wilson, J. P. (John P., & Gallant, J. C. (2000). *Terrain analysis : principles and applications*. Wiley.

Yamusa, I. B., Yamusa, Y. B., Danbatta, U. A., & Najime, T. (2018). Geological and structural analysis using remote sensing for lineament and lithological mapping. *IOP Conference Series: Earth and Environmental Science*, *169*(1). https://doi.org/10.1088/1755-1315/169/1/012082

Yihunie, D., & Halefom, A. (2020). Investigation of groundwater potential zone using Geospatial Technology in Bahir Dar Zuria District, Amhara, Ethiopia. *An International Scientific Journal*, *146*(June), 274–289. http://psjd.icm.edu.pl/psjd/element/bwmeta1.element.psjd-04d26e86-c8bd-4d6b-9eb4-ca545d8bec55

Zhang, H., Sekhari, A., Ouzrout, Y., & Bouras, A. (2014). Deriving consistent pairwise comparison matrices in decision making methodologies based on linear programming method. *Journal of Intelligent and Fuzzy Systems*, *27*(4). https://doi.org/10.3233/IFS-141164ï

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Figure 1 Location map of Shinile sub-basin

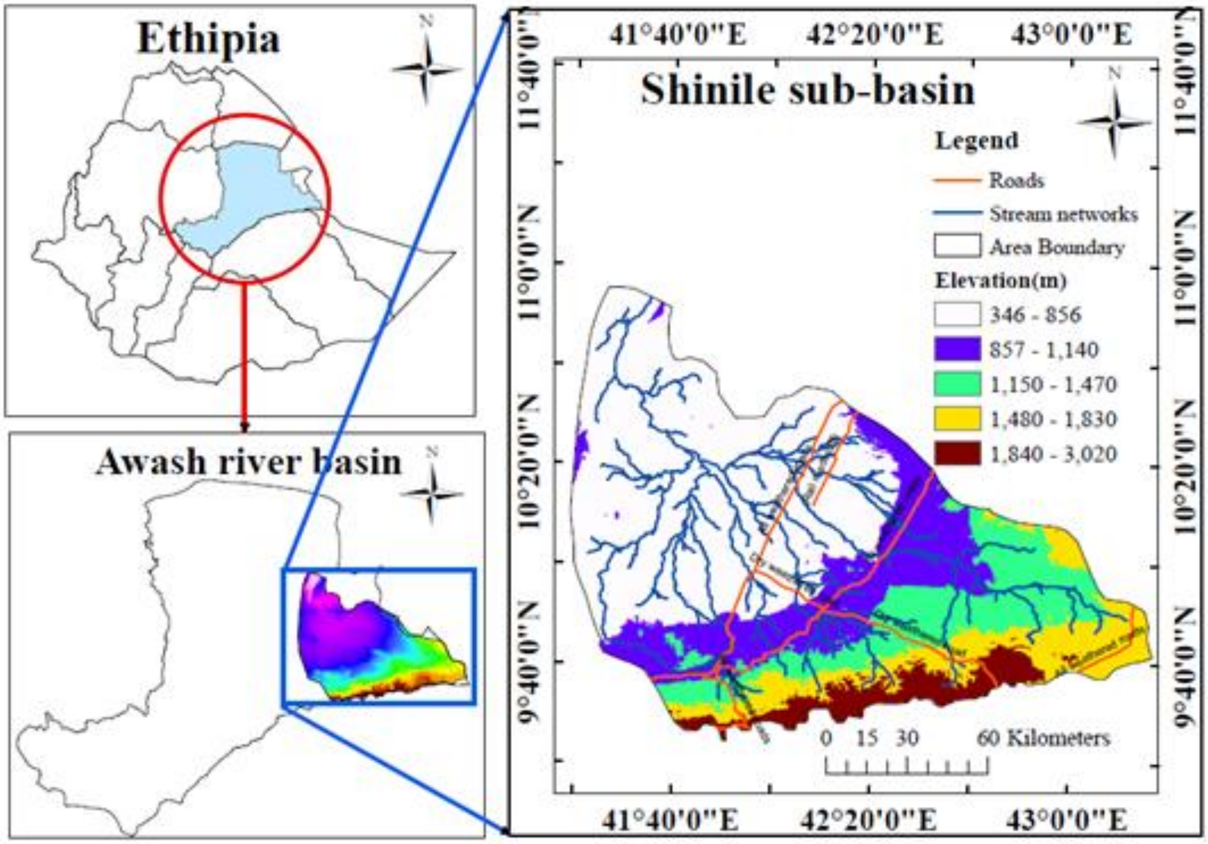

Figure 2 Methodology flow chart of the study

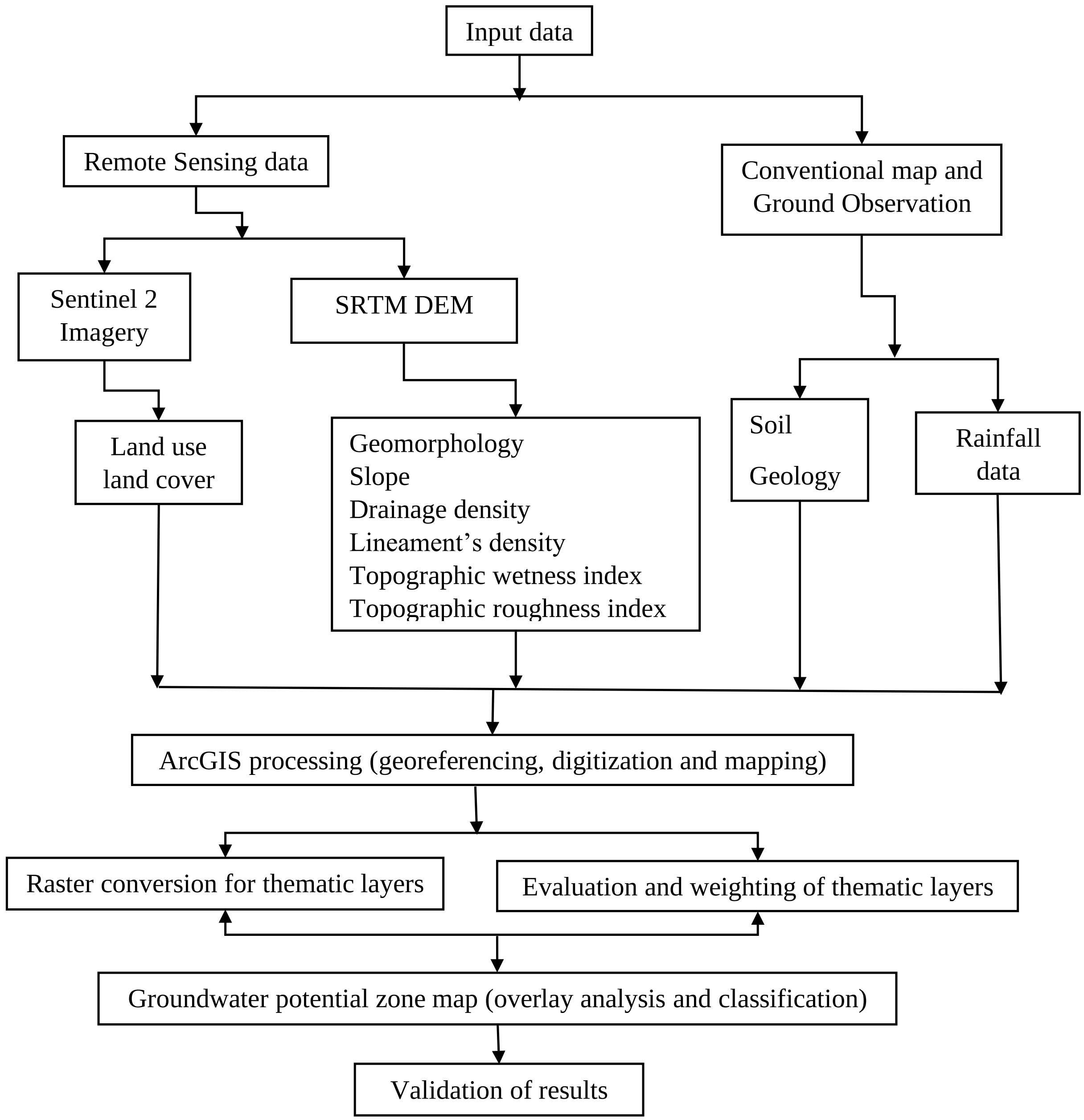

Figure 3 (a) Geological features and (b) Geomorphological class in Shinile sub-basin

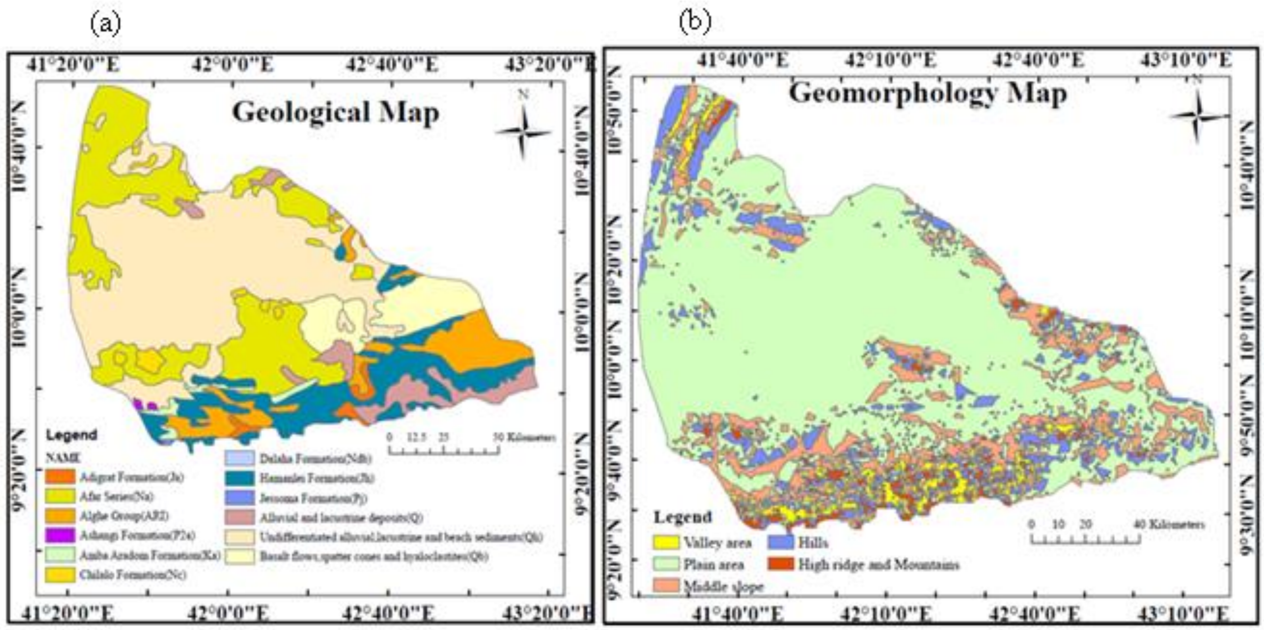

Figure 4 (a) LULC classification and (b) Soil texture class of the study area

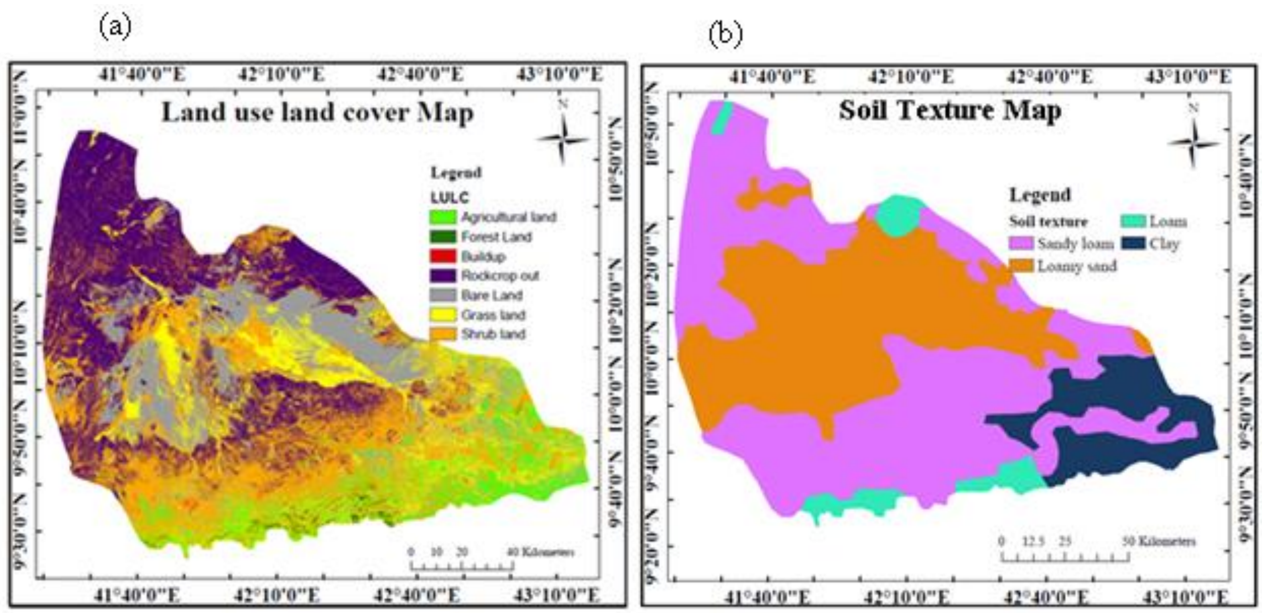

Figure 5 (a) Lineaments distribution in Shinile Sub-basin and (b) Rose diagram showing lineament orientation.

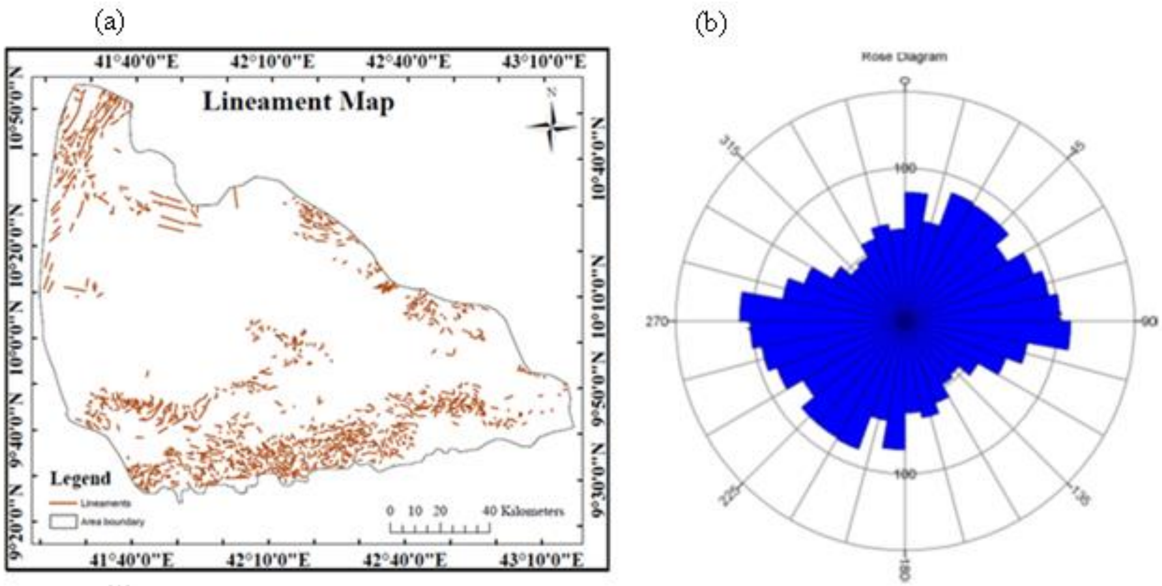

Figure 6 (a) Lineaments density map and (b) Drainage density map

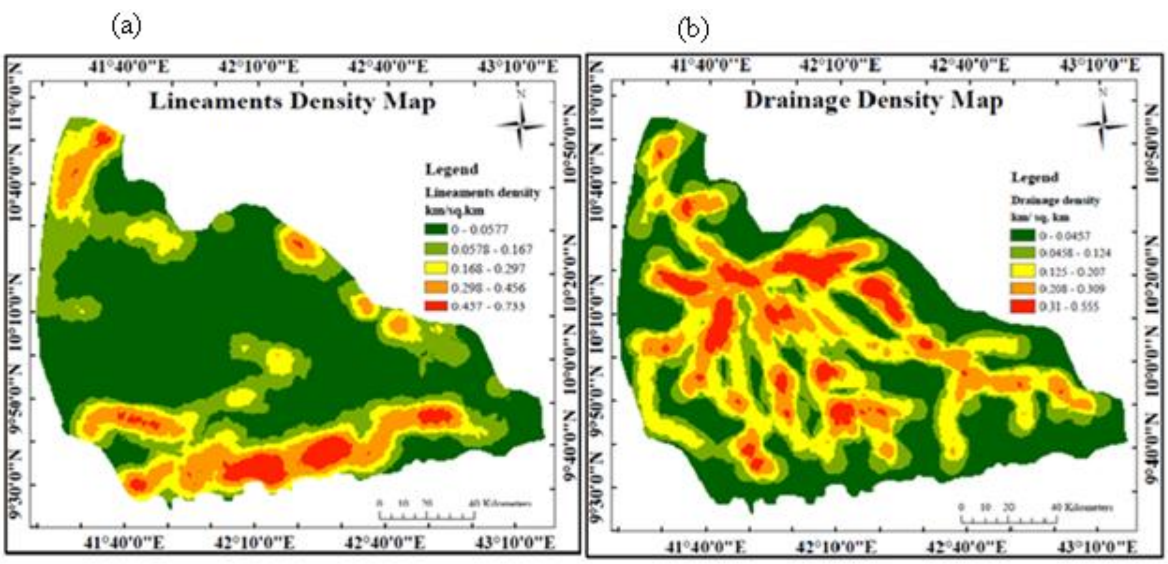

Figure 7 Map of groundwater potential classification

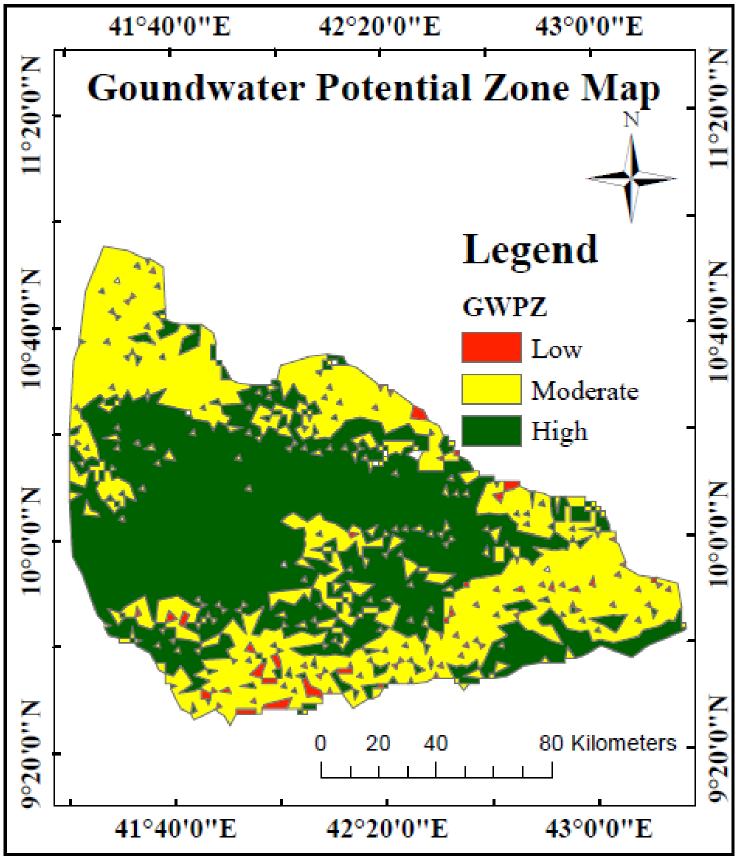

Figure 8 Receiver Operating curve (ROC)

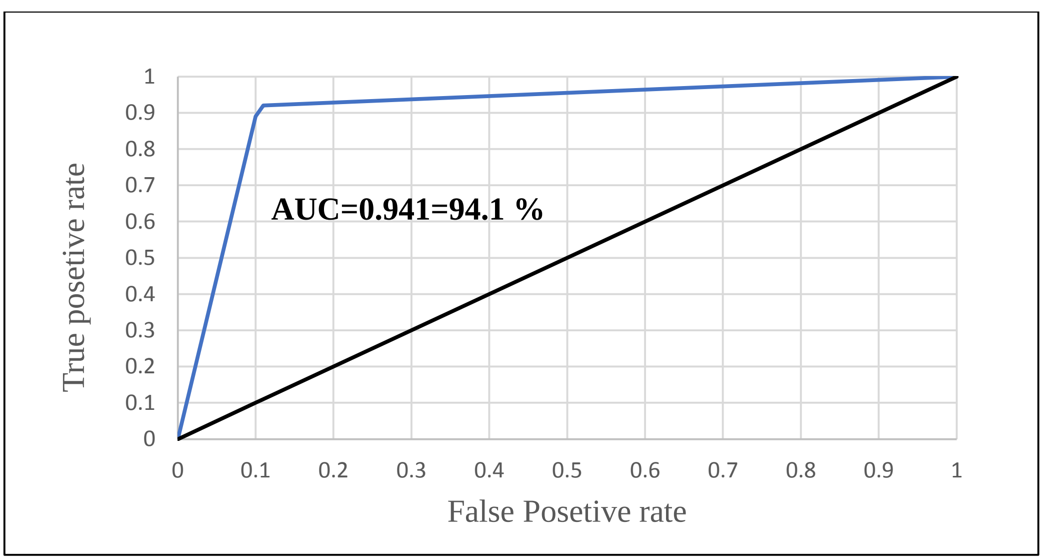

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Table 1 pairwise comparison matrix

	G	Gm	RF	Slope	LD	LULC	DD	Soil	TWI	TRI
G	1	3	3	3	3	5	5	6	5	7
Gm	0.333	1	3	3	3	5	5	5	6	7
RF	0.333	0.333	1	1	3	3	5	5	5	7
Slope	0.333	0.333	1	1	1	2	3	3	5	5
LD	0.333	0.333	0.333	1	1	1	3	3	5	5
LULC	0.200	0.200	0.333	0.5	1	1	1	3	3	5
DD	0.200	0.200	0.200	0.333	0.333	1	1	1	3	3
Soil	0.167	0.200	0.200	0.333	0.333	0.333	1	1	3	3
TWI	0.200	0.167	0.200	0.200	0.200	0.333	0.333	0.333	1	1
TRI	0.143	0.143	0.143	0.200	0.200	0.200	0.333	0.333	1	1

Note: G: geology; Gm: Geomorphology; RF: rainfall; LD: Lineament Density; LULC: Land use/Land cover; DD: Drainage Density; TWI: topographic wetness index; and TRI: topographic roughness index.

Table 2 Thematic maps and their weightage with the assigned ranks for each subclass

No	**Thematic layers**	**Weightage**	**Sub-classes**	**Ranks**	**Overall weight**
1	**Geology**	**26**	Alluvial and lacustrine deposits(Q)	5	130
			Undifferentiated alluvial, lacustrine and beach sediments (Qh)	5	130
			Basalt flows, spatter cones and hyaloclastites (Qb)	4	104
			Jessoma Formation (Pj)	3	78
			Hamanlei Formation (Jh)	3	78
			Adigrat Formation (Ja)	2	52
			Ashangi Formation(P2a)	2	52
			Afar Series (Na)	4	104
			Amba Aradom Formation (Ka)	3	78
			Chilalo Formation (Nc)	2	52
			Dalaha Formation (Ndb)	2	52

			Alghe Group (ARI)	1	26
2	**Geomorphology**	**21**	Valley	5	105
			Open slope	4	84
			Plain area	4	84
			Hills	2	42
			High ridge and Mountains	1	21
3	**Rainfall**	**14**	426-521	1	14
			522-585	2	28
			586-631	3	42
			632-676	4	56
			677-798	5	70
4	**Slope**	**10**	Level to gentle slope	5	50
			Moderate sloping	4	40
			Strong slope	3	30
			Moderate steep	2	20
			Steep to very steep	1	10
5	**Lineaments Density**	**9**	0-0.146	1	9
			0.147-0.292	2	18
			0.293-0.438	3	27
			0.439-0.584	4	36
			0.585_0.73	5	45
6	**LULC**	**7**	Forest Land	5	35
			Agricultural land	5	35
			Shrub land	3	21
			Build up area	2	14
			Rock out crop	1	7
			Grass Land	4	28
			Bare land	1	7
7	**Drainage density**	**5**	0-0.18	5	25
			0.181-0.359	4	20
			0.36-0.539	3	15
			0.54-0.719	2	10
			0.72-0.898	1	5
8	**Soil**	**4**	Clay	1	4
			Loam	3	12
			Loamy sand	5	20
			Sandy loam	4	16
9		**2**	2.67-7.02	1	2

	Topographic wetness index		7.03-8.79	2	4
			8.8-11.3	3	6
			11.4-14.7	4	8
			14.8-25.3	5	10
10	**Topographic roughness index**	**2**	0.111-0.364	5	10
			0.365-0.471	4	8
			0.472-0.566	3	6
			0.567-0.675	2	4
			0.678-0.889	1	2