CME LIVE OPEN ACCESS

Journal of
Earth & Environmental Waste Management

Research Article

ISSN: 3065-8799

Delineation of Groundwater Recharge Zones and Identification of Flow Direction: The Case of Meki Watershed, Central Rift Valley, Ethiopia

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Received: 2024 Sep 02 **Accepted:** 2025 Jan 02 **Published:** 2025 Jan 27

Abstract

The delineation of groundwater recharge and flow direction is important for the sustainability of groundwater for irrigation, domestic water supply, and several others. Groundwater contamination results from improper disposal of waste on the land surface. This study aimed to delineate groundwater recharge zones and flow direction in the Meki watershed, Ethiopia. Physical features such as land use, land cover, and groundwater depth were used. Surfer 17 software was used to delineate groundwater recharge zones in the study area. Land use and land cover were prepared from the SPOT satellite image of 2016. Groundwater flow direction was identified and indicated on the contour map of the study watershed. As per the result, the major recharge of groundwater occurs in the northwest and southwest parts of the study area, whereas discharge zones are located in the eastern and southern parts. Groundwater flow direction was analyzed with a direction of lineament map using Rockworks 17 software. According to groundwater flow lines and contour maps, groundwater flows from the eastern highland parts of the catchment towards the plain areas in the western direction. When groundwater flows from the Northwest to the Southeast, the Southeast region may be vulnerable to groundwater contamination. Therefore, it is advisable to locate groundwater wells for potable domestic water supply in the northwest and the sanitary site in the southeast part of the study area so as to minimize groundwater contamination. Therefore, this study's results could enable smallholder farmers to further use the groundwater for various purposes with proper management.

Keywords: Groundwater Recharge, Surfer Model, Flow Direction, Meki Watershed

1. Introduction

Groundwater is the most important source of fresh water for drinking and in some cases for irrigation purposes. Groundwater recharge refers to the amount of water added to the aquifer and joins the groundwater from external sources such as rivers, rainfall, lakes, or any other adjacent aquifer after infiltration and percolation following rainfall events [1]. Groundwater recharge also defined as it is the infiltration of water from the unsaturated zone to the saturated zone through porosity and permeability of the earth materials above the water table influenced by geologic and physiographic factors. Delineation of groundwater recharge zones plays an important role for groundwater resources management [2,3].

The detection of lineament structures like faults and joints that are analyzed by lineament direction may be facilitate the identification of groundwater recharge and flow direction in the study area. The direction of groundwater flow can be considered as a gradient of topographic slope. Groundwater does not usually stationary but it moves underground due to force acting on it like gravity force related to natural slope and external pressure caused by pumping wells which changes natural groundwater flow direction. Groundwater would flow from higher hydraulic gradient to lower hydraulic gradient in the direction of maximum change in gradient [4-6]. Static water level may be used to produce water table map (contour) and to predict groundwater flow direction. Ground water flow implies that ground water is recharged over broad upland areas and discharged at relatively focused lowland areas as surface water [7,8]. Mapping groundwater contour is important to identify groundwater flow direction. According to flow line diverges from recharge area and converges towards the discharge area [9]. Groundwater flows from recharge area to discharge area. Soil that have high infiltration capacity and increased rainfall distribution was taken into account to identify preferential groundwater recharge area [10]. Surfer model is a physical based model used for groundwater recharge under the influences of groundwater depth, elevation and topography [11,12]. The topography, slope, landform, land use and land cover, and climatic circumstances of the area have a significant role in determining the link between rainfall and natural groundwater recharge [12,13]. Global precipitation has decreased as a result of climate change, which has lowered groundwater recharge.

The studies of groundwater become quite important due to the surface water which is unable to meet ever increasing water demand and decreasing in water quality. Due to rapidly increasing of population, development of industry and expansion of agricultural activities have led to a substantial increase in water consumption, the peoples can enforce to use groundwater for their uses through delineation of groundwater recharge zone. Organic pollutants' most significant impacts on freshwater and inappropriate waste management act as a vector to transport contaminants into the groundwater, which diminish groundwater quality and cause harmful compounds to form during disinfection, among others, represent a global hazard [14]. As a result, proper demarcation of groundwater recharge zones therefore constitutes a viable option for potable water provisions, as citizens require access to significant quantities and a high-quality groundwater supply for their daily activities. Even though the importance of groundwater recharge delineation is crucial for sustainable utilization of groundwater resources; improper delineation of groundwater recharge is the most a challenging problem in Meki watershed. Other challenging problem in groundwater recharge delineation is accurately delineation of its spatial distribution in a hydrological and geographically variable watershed. Also, there is lack of sufficient information about groundwater flow direction which is essential for planning and development of groundwater resources in the study watershed. Groundwater contamination most often results from improper disposal of wastes on the land surface [15]. Due to this, it is difficult to have information about groundwater recharge and flow direction required for wise use and location of water resources. Therefore, the objectives of the present study are to:

- Delineate and evaluate the groundwater recharge zones of the study area.
- Produce a groundwater contour and flow direction in the study area.
- Analyzes the regional lineament map with groundwater flow direction.

To this end, it becomes necessary to identify the pattern of groundwater flows and recharge zones so as to predict the likely pattern of pollutants transport and recharge demarcation and to propose reliable recommendations.

1.1. Description of the Study Area

1.1.1. Location and Topography

The study was conducted in the Meki watershed of the Rift Valley Lakes basin, which is located in central Ethiopia. Meki town is located about 134km south of Addis Ababa. Geographically, it is located approximately between 7˚49'N to 8˚27'N latitude and 38˚12'E to 38˚47'E longitude, as demonstrated in Figure 1 below. The spatial extent of the study area covers about 2031 km2. The study area lies within the altitude range of 1636 to 3612m a.m. s.l.

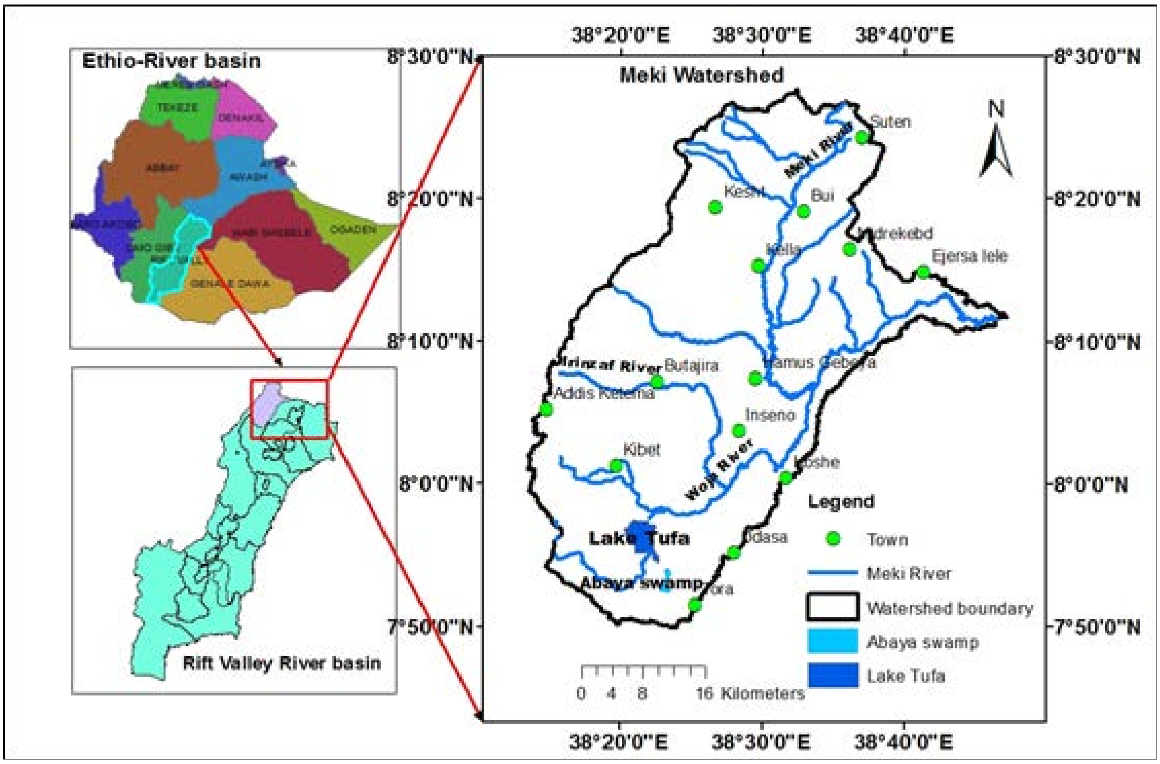

Figure 1: Location Map of the Study Area

Topographic features show the major landforms, namely, plateaus, escarpments, flat plains, and water bodies, in the study area. The three-dimensional view (Figure 2) and cross-sectional view (Figure 3) shown below indicate these topographical features. From a geomorphological point of view, the groundwater flow may follow a surface drainage system. The three-dimensional view indicated in Figure 2 clearly shows what the landform of the study area looks like.

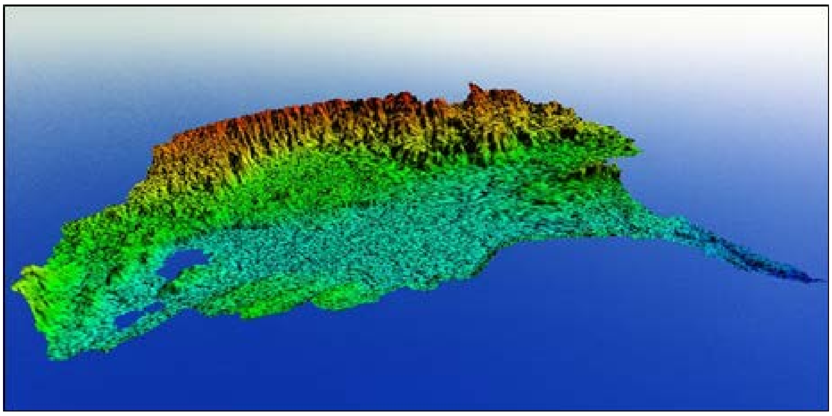

Figure 2: Three Dimensional View of Meki Watershed

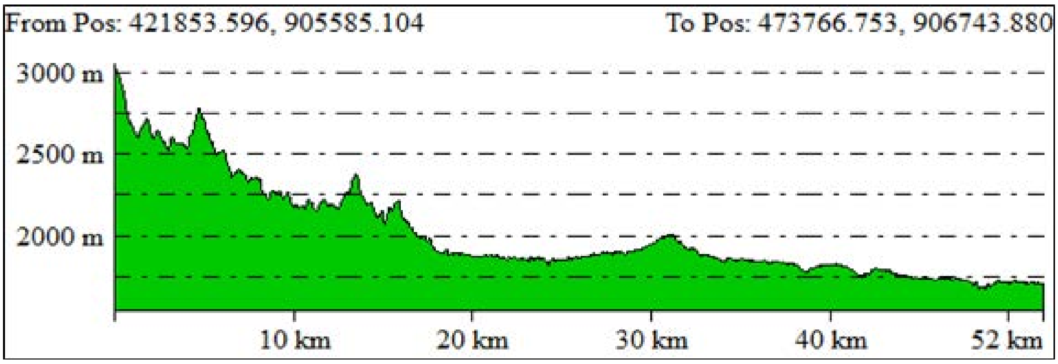

Figure 3: Northwest to Southeast Cross Sectional View of Meki Watershed

The majority of the study area (the eastern and southern sides) belongs to nearly flat terrain, occupying a slope category of 0–3º and a very steep slope on the western side (Figure 4).

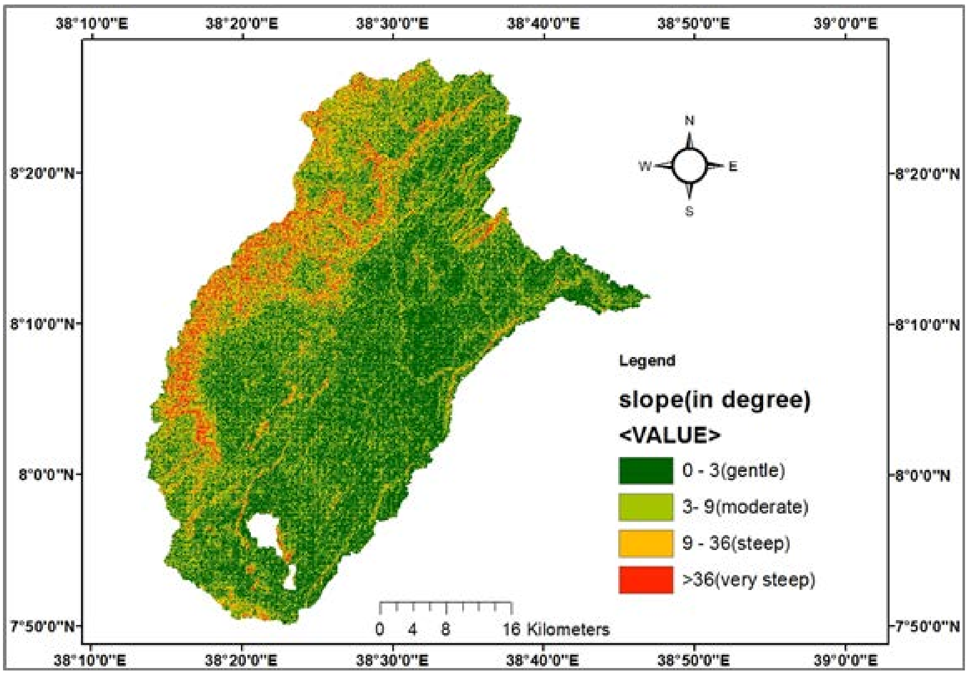

Figure 4: Slope Map of the Study Area

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1.2. Land Use and Soil

The soil texture classes that encompass the study area are sandy loam, silt loam, clay, and sandy loam. The permeability and porosity of the soil determine how surface water enters ground water and moves through it [16]. Land use is the description of how the land is being used by the people with respect to its suitability for a particular use. Information on the rate of changes in land resources is essential for proper planning, management, and regulation of the use of land resources. The major land uses and land cover of the study area are mixed forest, grassland, agriculture, settlement, shrub land, water bodies, and marshland, as shown in Figure 5 below.

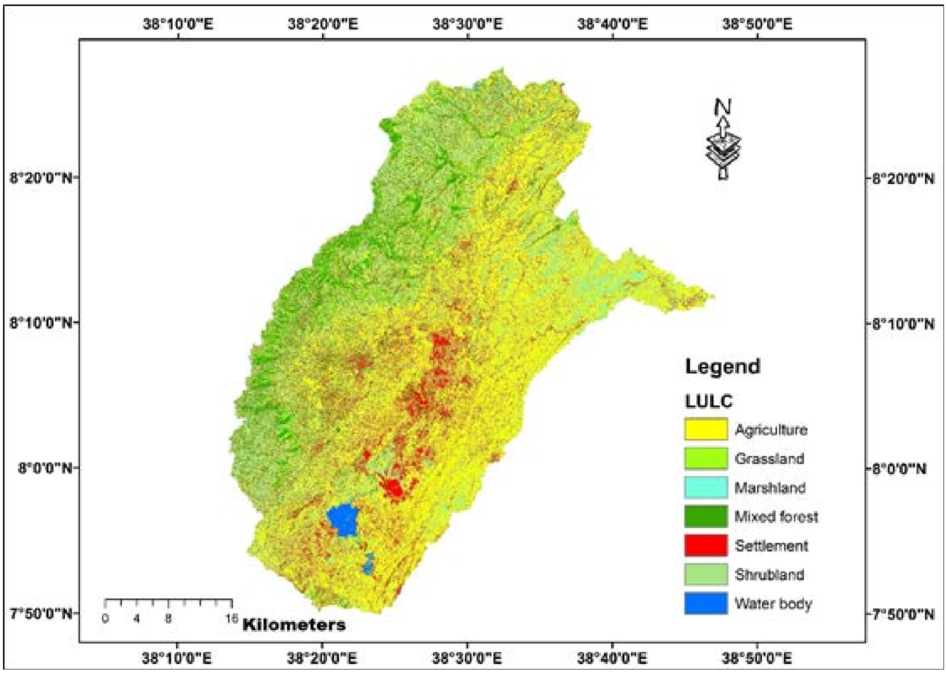

Figure 5: Land Use/Land Cover Map of the Study Area

1.3. Geology

Geologically, the lakes and the lower reaches of the rivers are situated in the tectonically active volcanic terrain. The geology and geomorphologic features are the result of Cenozoic volcano- tectonic and sedimentation process [17]. Geological formation of the study area can influence groundwater flow directions.

2. Materials and Methods

2.1. Data Sources and Preparation

Hydro metrological data was obtained from the National Meteorological Agency of Ethiopia. The soil map of Ethiopia was obtained from the Ministry of Water, Irrigation, and Electricity. A satellite image was purchased from the Geospatial Information Institute of Ethiopia for the LULC thematic map and lineament orientation preparation. Existing water point inventory data has been collected from the Ethiopian Ministry of Water, Irrigation, and Electricity to generate a groundwater contour map and flow direction. The data were analyzed using Microsoft Excel, Arc GIS 10.4, Global Mapper 11, Rock Works 17, and Surfer 17.

2.2. Delineation of Groundwater Recharge Zones and Flow Direction

A groundwater level map (contour map) was generated from groundwater level data using Surfer17 software in order to identify groundwater recharge zones and flow direction [7]. Ground water level (static water level) was obtained by subtracting depth to water level in the wells from ground surface elevation. Based on this, a map of the static water level/groundwater level map of the study area was developed. Finally, a groundwater contour map was delineated in order to map groundwater recharge zones, and groundwater flow direction was also identified using a groundwater level map.

2.3. Lineament Analysis

Groundwater flow direction was analyzed with a direction of lineament map using Rockworks 17 software. Lineament orientation was analyzed by creating a rose diagram using Rockworks 17 software. It represents the number of lineaments dominating in a particular direction. The lineament map of the study area was derived from SPOT7 imagery using an automatic lineament extraction processing tool (line extraction) in PCI Geomatica 10.3. ENVI 5.1 was used to prepare the principal component analysis (PCA) for PCI Geomatica. The Rockworks 17 package was used to prepare the lineament direction and its orientation (rose diagram).

3. Results and Discussion

3.1. Delineation of Groundwater Recharge Zones and Flow Direction

The groundwater contour map and horizontal flow direction of the Meki watershed in two and three dimensions are shown in Figures 6 and 7, respectively. The flow pattern of the aquifer system revealed that the groundwater direction was towards the eastern and southeast regions. According to groundwater flow vectors and contour maps, groundwater flows from the highest contour elevation to the lowest elevation [6]. The bar indicates the static water level (elevation of groundwater) (right) in meters (Figures 6 and 7). The result depicts that groundwater flows from the Western Highlands and Northwestern to the Eastern and Southeast regions (valley floor). The three-dimensional map clearly provides groundwater flow direction. The two-dimensional map indicated in Figure 6 shows the convergence and divergence of the flow lines to identify recharge and discharge zones in the study area. The main recharge area of the watershed is the high land area, which is located at a higher elevation. When compared to its surrounding low-land area, this area gets high rainfall. This indicates that groundwater recharge increased in direct proportion to rainfall. The results of earlier studies suggest that rainfall has a greater impact on the potential for groundwater recharge. The watershed has a discharge area on the valley floor. A low-lying area is an indicator of the groundwater discharge zone. Generally, recharge zones were located in the northwest and southwest parts of the study area, as indicated in Figure 6 by the red color whereas discharge zones were located in the eastern and southern parts, as indicated by the yellow color on the contour color map. The delineation of groundwater recharge in the study area has many implications for regulating the level of groundwater in the area. This study can be used to enhance the regional groundwater recharge potential, maintain groundwater levels, and meet the ever-increasing water demand. Groundwater recharge zone delineation can be considered a prerequisite for sustainable groundwater management. Therefore, delineating the groundwater recharge zone might be viewed as a necessary step towards sustainable groundwater management.

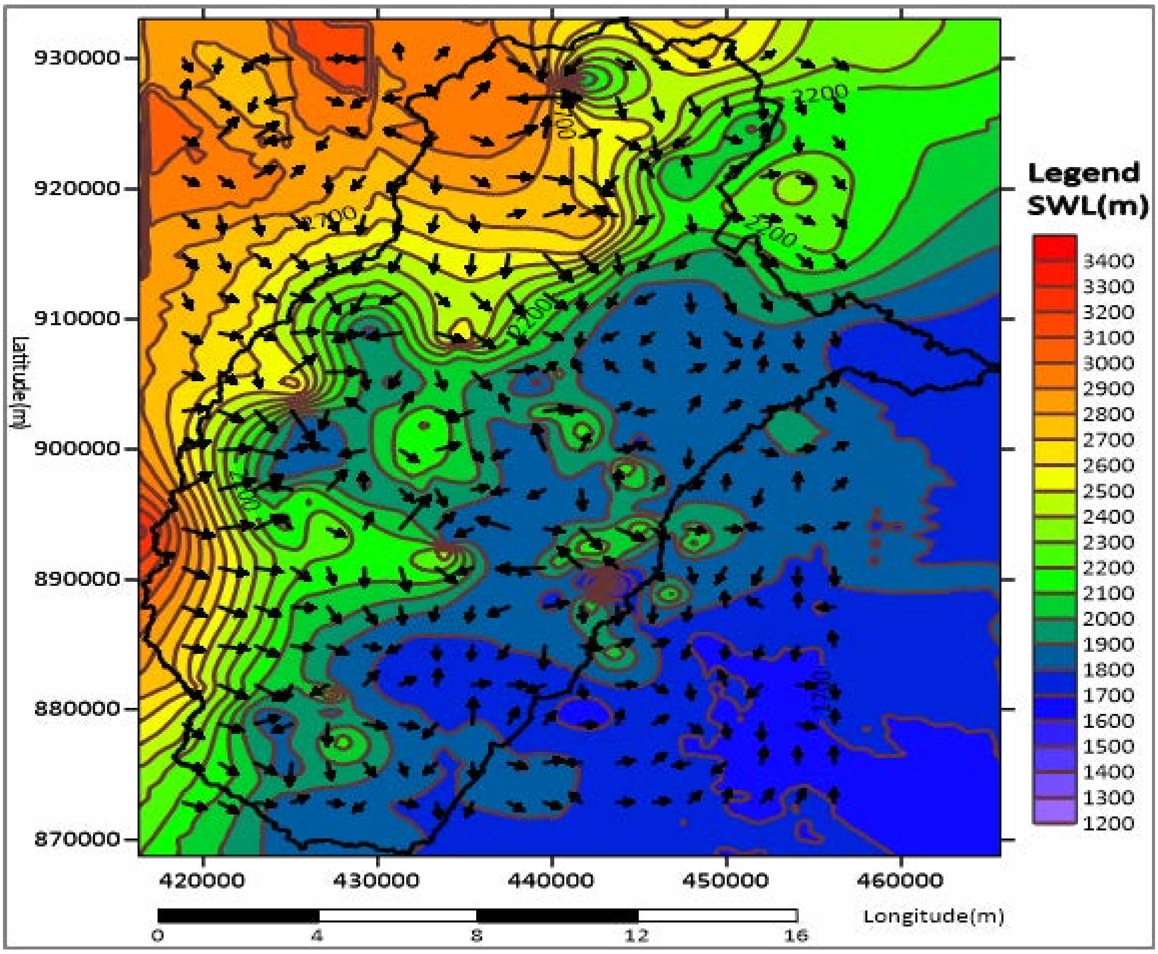

Figure 6: 2D Groundwater Flow and Contour Map Showing Recharge and Discharge Zone

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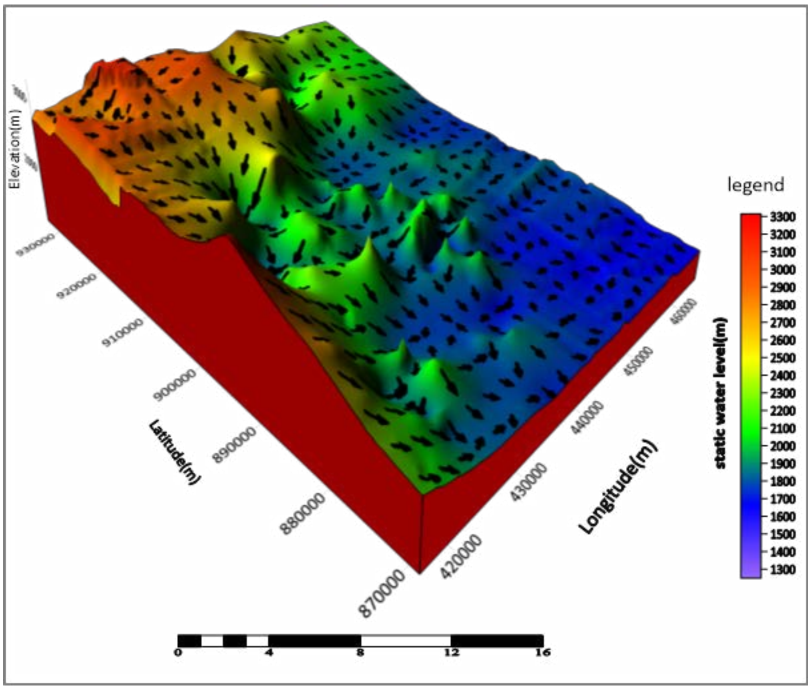

Figure 7: Three Dimensional Groundwater Flow Direction of Meki Watershed

3.2. Lineament Analysis with Groundwater Flow Direction

The directional analysis (rose diagram) indicates that the lineament orientations are predominantly along NW-SE directions, and a few are along NE-SW and S-N directions. The area of high lineament intersection identified indicates a high degree of rock fracturing over the study area. The two predominant directional analyses are more correlated with groundwater flow direction, which can be an indication of groundwater movement. A rose diagram, as indicated by Figure 9 presented the analyzed lineament map. From a hydro-geological point of view, groundwater flow direction follows the orientation of lineament direction. The identified groundwater flow direction was analyzed with lineament orientation and more coincident with each other. The result indicates that groundwater flow direction can be more affected by the lineament or linear geological features of rock aquifers [18]. The lineament analysis is also required for proper setting of boreholes in groundwater studies. Figure 8 and Figure 9 show the lineament map and rose diagram, respectively.

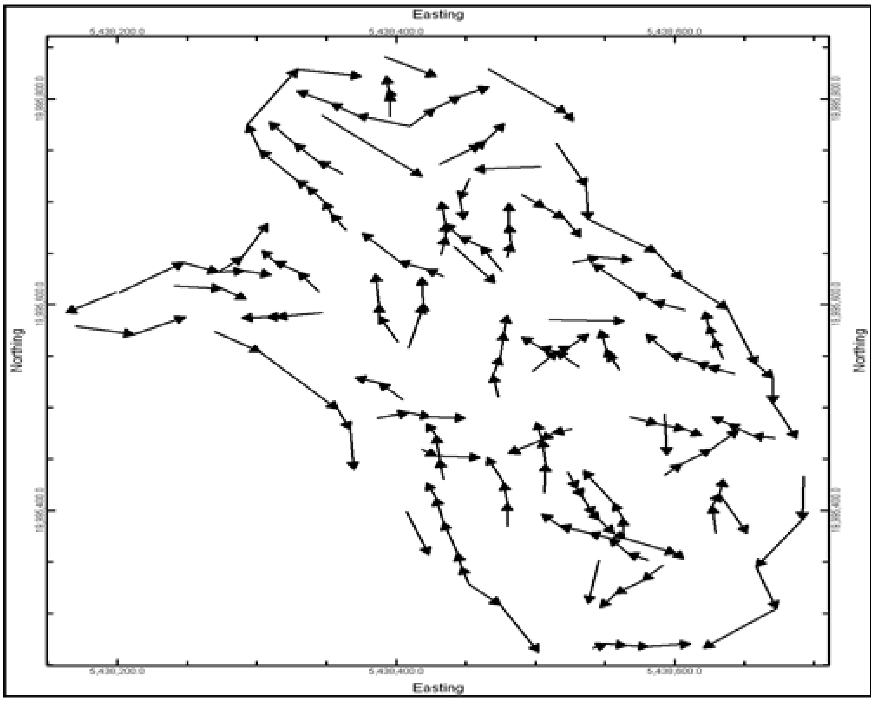

Figure 8: Lineament Map and its Direction using Rockworks 17 Software

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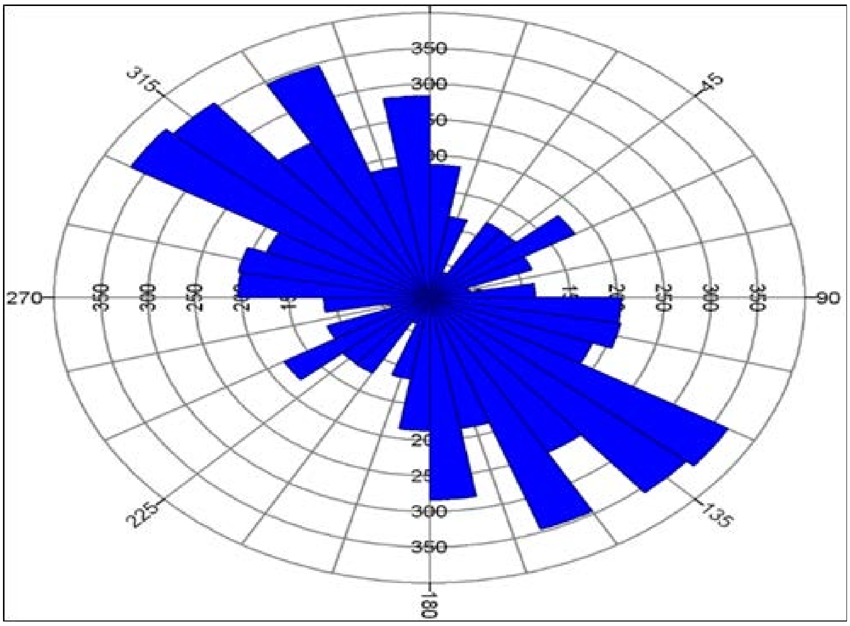

Figure 9: Rose Diagram Showing the Orientations of Extracted Lineaments

4. Conclusions

According to the groundwater flow vector, groundwater flows predominantly from the northwest to the southeast. This will be useful for the planning and management of groundwater contamination. Since many water resource projects are greatly influenced by the groundwater flow system, it is crucial to ascertain the location of the groundwater level and the direction in which groundwater flows. Hence, in order to minimize groundwater contamination from dumpsites, mainly in the southern parts of the catchment, dumpsites should not be sited in the northwest parts of the catchment. Likewise, hand-dug wells for potable water should not be cited in the Northwest. The result indicates that groundwater flow direction can be more affected by the lineament or linear geological features of the rock aquifer. This also has reasonable implications for the direction of groundwater flow since it follows the orientation of lineaments in the region. Thus, in addition to delineating groundwater recharge zones, it is also necessary to identify groundwater flow direction during groundwater studies.

Acknowledgements

The authors would like to thank the Ethiopian Ministry of Water, Irrigation, and Electricity for providing the hydrological data and the Ethiopian mapping agency for providing the satellite data.

Data Availability

Data pertaining to this study will be available from the corresponding author upon reasonable request.

Declaration

All references and materials used in the research work are acknowledged and cited properly in the text. The study was not funded by any government agency, and therefore no funding was received for its completion.

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