Iraqi National Journal of Earth Science
www.earth.uomosul.edu.iq

Prediction and Prospection of Groundwater in the Iraqi Western Desert Using Remote Sensing and GIS

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Article information

Received: 19 -Jul -2024

Revised: 30 -Sep -2024

Accepted: 19- Jan -2025

Available online: 01- Jan -2026

Keywords:
Groundwater,
Lineaments,
Iraqi Western Desert,
Remote Sensing,
GIS.

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ABSTRACT

Groundwater resources are receiving a lot of attention, especially in arid and semi-arid areas, as a result of the growing demands for water brought on by urbanization, population growth, and agricultural development. Finding the most significant contributing parameters, such as lineament density, frequency, and junction nodes that reveal the groundwater potential, is the foundation of this investigation. To determine suitable sites for drilling wells, analysis of linear structures is necessary to detect and exploit groundwater sustainably. This study highlights the importance of geospatial systems, including remote sensing and geographic information system technologies, to effectively explore and manage groundwater resources. To identify linear structures in the study area, different image enhancement techniques are applied, such as band composite (BC) and high-pass filtering (HPF). These methods work well, and they are suitable for identifying these structures. The results show that the area contains a large number of short and long fractures, most of which have an orientation from northwest to southeast, and that it is possible to explore groundwater in areas with a high density of areas with intersections in linear structures. The area, where groundwater occurrence is most promising for sustainable use of groundwater, has been identified within the region. Using remote sensing (RS) data and geographic information systems (GIS), a thematic map of each parameter is created. The final groundwater potential zones of the studied region are created by combining these input layers using the GIS Raster Calculate Module. Different groundwater prospective potential zones are depicted on the final output map: very high (49 km^2), high (261 km^2), and moderate (1041 km^2).

DOI: 10.33899/injes.v26i1.56113, ©Authors, 2026, College of Science, University of Mosul.

التنبؤ والتنقيب عن المياه الجوفية في الصحراء الغربية العراقية باستخدام الاستشعار عن بعد ونظم المعلومات الجغرافية

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معلومات الارشفة

تاريخ الاستلام: 19- يوليو- 2024
تاريخ المراجعة: 30- سبتمبر- 2024
تاريخ القبول: 19- يناير- 2025
تاريخ النشر الالكتروني: 01- يناير- 2026

الكلمات المفتاحية:
المياه الجوفية،
التراكيب الخطية،
الصحراء الغربية العراقية،
الاستشعار عن بعد،
نظم المعلومات الجغرافية.

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الملخص

تحظى المياه الجوفية باهتمام واسع، ولا سيما في المناطق القاحلة وشبه القاحلة، بسبب ازدياد الطلب على المياه الناتج عن التوسع العمراني ونمو السكان وتطور الزراعة. يعتمد هذا البحث على تحديد أهم المؤشرات المرتبطة بالمياه الجوفية، مثل كثافة الخطوط، وتكرارها، ونقاط التقاطع بينها، لأنها تساعد في الكشف عن المناطق ذات الإمكانات الجيدة للمياه الجوفية. يعدّ تحليل التراكيب الخطية أمرًا مهمًا لتحديد المواقع المناسبة لحفر الآبار، لأنه يساعد في الكشف عن المياه الجوفية واستثمارها بصورة مستدامة. وتركّز هذه الدراسة على دور التقنيات الجغرافية المكانية، مثل الاستشعار عن بعد ونظم المعلومات الجغرافية، في استكشاف وإدارة موارد المياه الجوفية بشكل فعّال. لتحديد التراكيب الخطية في منطقة الدراسة، جرى تطبيق عدة تقنيات لتحسين الصور، مثل التركيب اللوني (BC) للنطاقات والترشيح عالي التمرير (HPF) نجحت هذه الأساليب وكانت مناسبة لتحديد التراكيب الخطية. وأظهرت النتائج أن منطقة الدراسة تحتوي على عدد كبير من الكسور القصيرة والطويلة، ويتجه معظمها من الشمال الغربي إلى الجنوب الشرقي. كما تشير النتائج إلى إمكانية استكشاف المياه الجوفية في المناطق التي تزداد فيها كثافة هذه التراكيب ونقاط تقاطعها. تم تحديد المناطق الأكثر وعدًا لوجود المياه الجوفية من أجل الاستغلال المستدام داخل منطقة الدراسة. وباستخدام بيانات الاستشعار عن بعد (RS) ونظم المعلومات الجغرافية(GIS) ، تم إعداد خريطة لكل عامل من العوامل المدروسة، ثم جرى دمج هذه الخرائط باستخدام وحدة الحساب الراستري في GIS Rasterللحصول على خريطة إمكانات المياه الجوفية النهائية. وقد بينت الخريطة وجود ثلاث فئات من إمكانات المياه الجوفية: عالية جدًا (49 كم^2)، وعالية (261 كم^2)، ومتوسطة (1041 كم^2). عالية جدًا (49 كم^2)، وعالية (261 كم^2)، ومتوسطة (1041 كم^2).

DOI: 10.33899/injes.v26i1.56113,

Introduction

Groundwater potential studies have been increasingly popular across the world in recent years because of the requirement of achieving Sustainable Development Goal #6. Most of these investigations depend on the techniques of remote sensing, geographic information systems, and geophysics; however, some of these studies (Al-Djazouli et al., 2021; Saadi et al., 2021; Owolabi et al., 2020; Mpofu et al., 2020; Adeyeye et al., 2019; Magaia et al., 2018; Delgado, 2018) depend on data from the borehole.

A lot of consideration goes into choosing locations for groundwater exploration while doing lineament analysis. It should be mentioned that areas where many fractures converge frequently experience strong water flow and fractures (Coulibaly et al., 2021). To explore groundwater resources, linear structural studies are now essential (Dembele and Ye, 2017). This study aims to identify possible locations for water drilling sites in the investigated area by utilizing drilling flows.

Elongations are natural linear structures of geological origin with a long extension that exceeds 10 km and reaches more than 1000 km. They are observed from satellite images in a straight or slightly curvature direction, and their presence is linked to geological structures (faults and folds) (AlFasatwi and Dijk, 1990). Linear structures are two-dimensional and their inclination is difficult to determine on satellite images. Therefore, they are considered to have vertical or nearly vertical surfaces, reflecting deep subsurface structures that may reach the basement rocks (Siegel and Gillespie, 1980).

Most previous studies of the region were limited to detailed studies conducted in the Western Desert region of Iraq. One of these studies was conducted by Al-Amiri in 1978 using satellite images to study the tectonics of the region extending from the west of the Euphrates to the international border and through the analysis of linear phenomena. The researcher used the same data in 1979 to determine the importance of these structures and drew a map of the linear structures. Another previous study of the region was the study carried out by Al-Hiti in 1985, which included a field study of the microseismicity of the Al-Kaara area. Al-Rawi (1986) studied the use of spectral technology to estimate the depth of basement rocks. As for Al-Sulaiman (1989), he studied fracture systems in the Western Desert using satellite images in addition to a field study of fractures in selected areas. Regarding Al-Azzawi (1988), he used data from remote sensing to examine the tectonics of the area west of the Euphrates River. There are other studies carried out by Abdul Qadir (2002) and Al-Jaf (2008) in which satellite data were used to identify active areas containing groundwater in the Western Desert of Iraq, in addition to studying some of the geological phenomena and the mineral deposits in the Western Desert of Iraq. Al-Moaden (2009) studied the northern part of the Iraqi Western Desert structurally using satellite images. Hasan et al. (2022) also studied the deformation in the drainage pattern, which was investigated using remote sensing data. A variety of distinct drainage pattern types were identified, and the patterns were examined using various satellite images at various scales.

The study region is located in the elevated part of the Rutba-Jazira region and the western desert of Iraq (Fig. 1). This region falls within Iraq's stable shelf (Jassim and Goff, 2006). The research region, which covers 3151 square kilometers, is situated between longitudes (40°30´ - 41°30´) east and latitudes (32°30´ - 33°30´) north. At a maximum elevation of 734 meters and a minimum elevation of 363 meters above sea level, the Earth's surface progressively rises from east to west.

Geological formations in the study area date back to the Paleozoic, Mesozoic, and Cenozoic eras (Fig. 2). The oldest formation in the region is the Ga'ara, which is dated to the Permian age (Sissakian and Mohammed, 2007).

Materials and Methods

In the study, linear structures are identified and inferred using a Landsat-7 satellite image. The ETM+ sensor image is used for this investigation due to the vastness of the study area and the spatial resolution of the available satellite images. With a resolution of 30 meters, linear structures are visible in this image. Three distinct software packages (ERDAS IMAGINE version 11, ArcGIS version 10.8, and ROCK WARE version 15) are employed in this investigation since no one program could handle every step of the study. The ArcGIS application is utilized for linear structural analysis, whereas the ERDAS IMAGINE program handles all satellite image processing tasks. The Rose diagram is created using the ROCK WARE software to comprehend the linear structures.

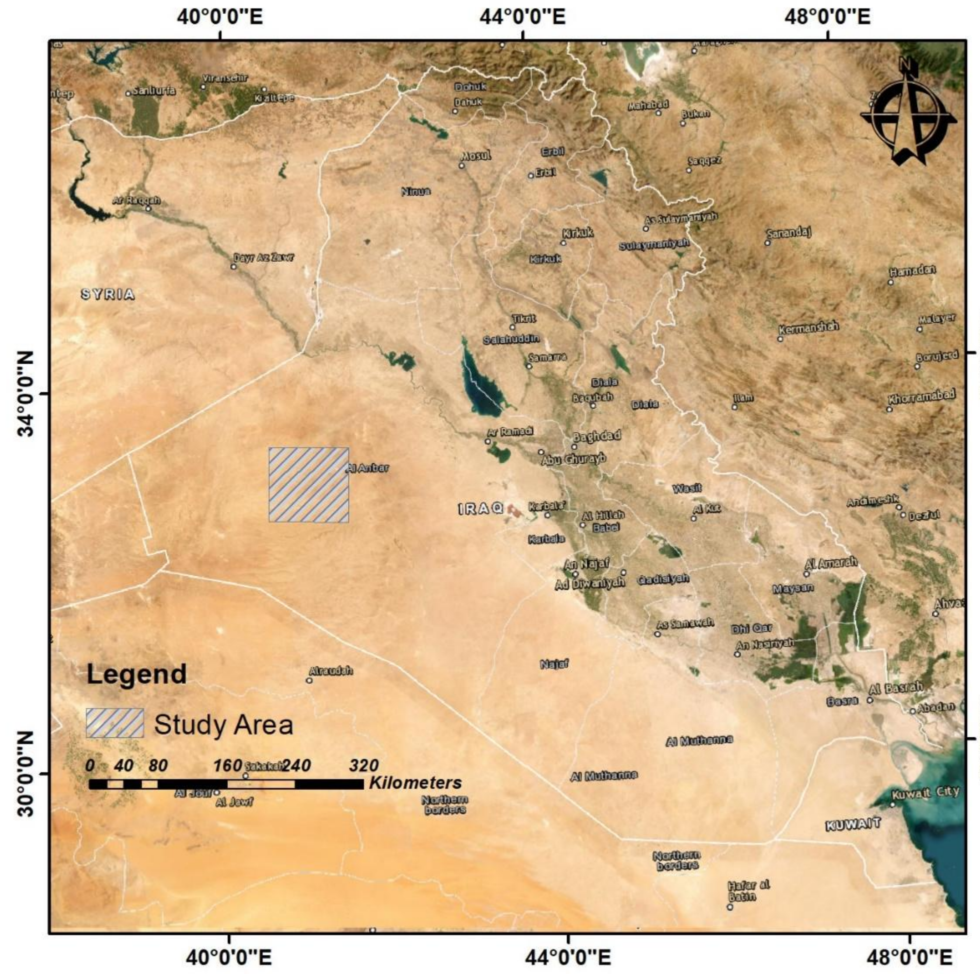

Fig. 1. Map of the study region.

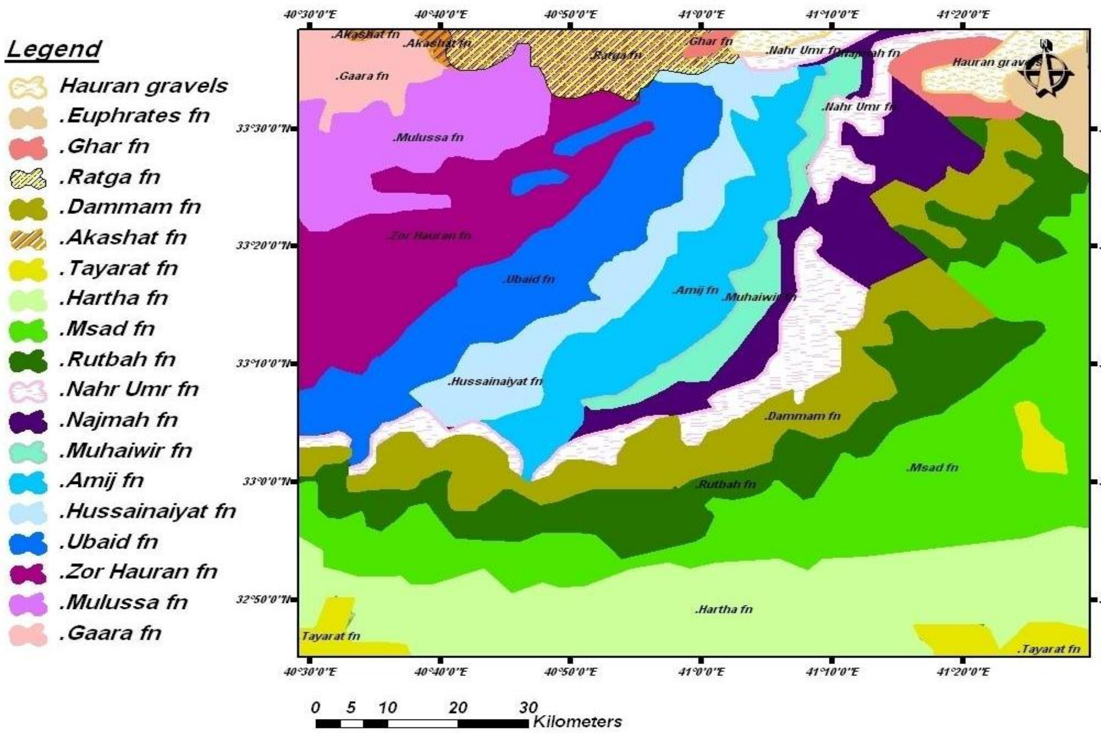

Fig. 2. Geologic map of the studied area (Sissakian, 2000).

Determining linear structures

The Earth's crust's linear features have fascinated Earth scientists and hydrologists. Faults, folds, and fractures are examples of linear features that might provide information for groundwater and mineral resource research. They are also crucial in various technical applications, such as building highways, power plants, and dams, and identifying potential locations for new settlements (Maina and Tudunwada, 2017).

Linear structures are important and key to drawing regional structures and studying regional tectonic analysis to use them in petroleum and mineral exploration and hydrological studies. The process of interpreting linear structures is considered one of the most important elements of analyzing satellite images in geological and tectonic studies, as they represent the surface appearance of deep subsurface fault systems and are areas where hydrocarbons, mineral ores, and groundwater collect (AlFasatwi and Dijk, 1990).

Maps, satellite images, and aerial photos may all be used to identify elongations, which are topographic characteristics that are linear and indicate areas of structural weakness. It is regarded as the main tool for analyzing regional tectonics, creating regional geological maps, and using the results in hydrological and structural studies, and mineral and oil exploration. After processing the digital image, linear structures are visually interpreted and retrieved from the satellite images. In satellite images, these structures appear as straight lines. The interpreter's experience is the key point in identifying these structures, especially in connecting unconnected parts with a longer line (Wang, 1990). However, some key features assist in identifying linear structures such as straightness in parts of major valleys, variation in the intensity of color and texture of soil or rock due to variation in moisture and water content, linear arrangement of vegetation, and sudden change in drainage networks, ridges, or slopes. Straight lines and sudden changes in rock exposures were identified (Lillisand et al., 2015).

According to Lloyd (1999) and Youan Ta (2008), geomorphological features like aligned ridges and valleys, displacement of ridge lines, escarpments, straight drainage channels, breaks in rock masses, and aligned surface depressions are commonly used in geological structural investigations**,** including lineament mapping.

Several image enhancement techniques can contribute to manually identifying linear compositions. In this study, filtering and band composite processes are used to prepare the final linear structure map.

Filtering process (FP)

Lineament detection is accomplished by the use of high-pass filters. The most common filters for hydrogeologic research are gradient or high-pass filters (Meijerink et al., 2007).

A characteristic of satellite images that sets them apart is the spatial frequency parameter, which may be described as the quantity of brightness value variations per unit distance for a specific area of the image. A section of an image is said to have low frequency if there are relatively few variations in the brightness value over that area. On the other hand, this is a region of high-frequency detail if brightness levels vary dramatically over short distances (Jensen, 1996). Thus, the significance of spatial frequency in the image can be emphasized or diminished by the application of filtering procedures. The frequency in question can be explained by the existence of local lineages. Stated differently, the filtering procedure will make the distinctions between neighboring units clearer.

The main drawback of the filtering process is the ability to efficiently extract linear structures in low-contrast areas, where structures extend in sun-parallel directions and in mountain shadows (Koike et al., 1995).

Moving a window with specified kernel sizes (3*3, 5*5, 7*7, etc.) is a typical filtering procedure. As seen in Fig. 5, a new numerical value is computed beneath each pixel in the output file (resulting image) and substituted with the window's center pixel. High-frequency spatial components, which comprise the majority of the visual information, are preserved while the high-pass filter (HPF) (Sarp 2005), selectively enhances large-scale phenomena, or low-frequency components. Figures (3, 4, and 5) display the results of the 3*3, 5*5, and 7*7 high-pass filters.

Band composite (BC)

A brief foray into color-coded band combinations is helpful since a large portion of the hydrogeologic implementation of remote sensing data involves visual interpretation. For the best picture fusion, such as integrating three multi-spectral bands with an orthophoto or high-resolution panchromatic satellite image, some knowledge of color and intensity information is required (Meijerink et al., 2007).

This technology relies on collecting three multispectral bands and displaying them over a range of visible wavelengths to be visible to the human eye. This technology displays three spectral bands, each band has a specific color: red (0.7-0.6), and green (0.6-0.5). The blue color (0.5-0.4) micrometers are called RGB. The basis for displaying beams depends on the intensity of the reflectivity of the metal to be shown in that beam. Beam mixing is a spectroscopic technique applied in the studied area to digitally enhance images. It is one of the basic methods of image usage in first-order analysis of remote sensing data (Mustard and Sunshine, 1999). To highlight severe spectral anomalies and make the image easier to comprehend, spectral data are stored in several bands that are then integrated by merging them into a single band (Zumsprekel and Prinz, 2000).

Three images (bands) are combined to generate color composites. The first band is shown in various red tones, while the remaining two bands are shown in various green and blue tones.

Because they make the data easier to read, false color graphics are created to interpret lines. The highest visual quality is achieved using a fake color image employing three bands, 4, 3, and 2 (red, green, and blue, respectively), after experimenting with different combinations of the three bands. It is simpler to recognize linear vegetation patterns, river channels, geological weakness zones, and limits of geological formations using this fake color combination. Fig. 6 displays the operation's outcome.

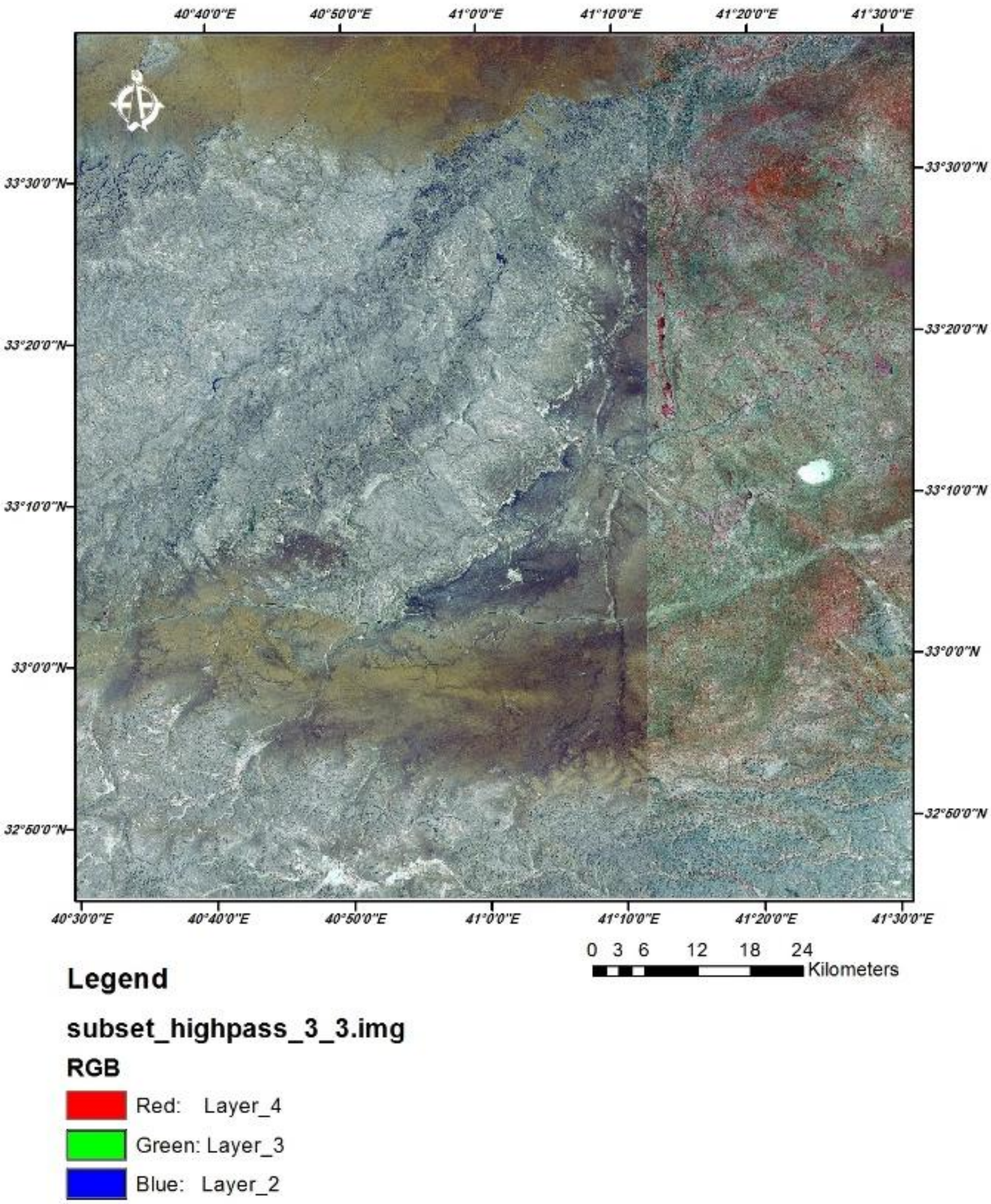

Fig. 3. Image of the high-pass filtering, kernel (3*3).

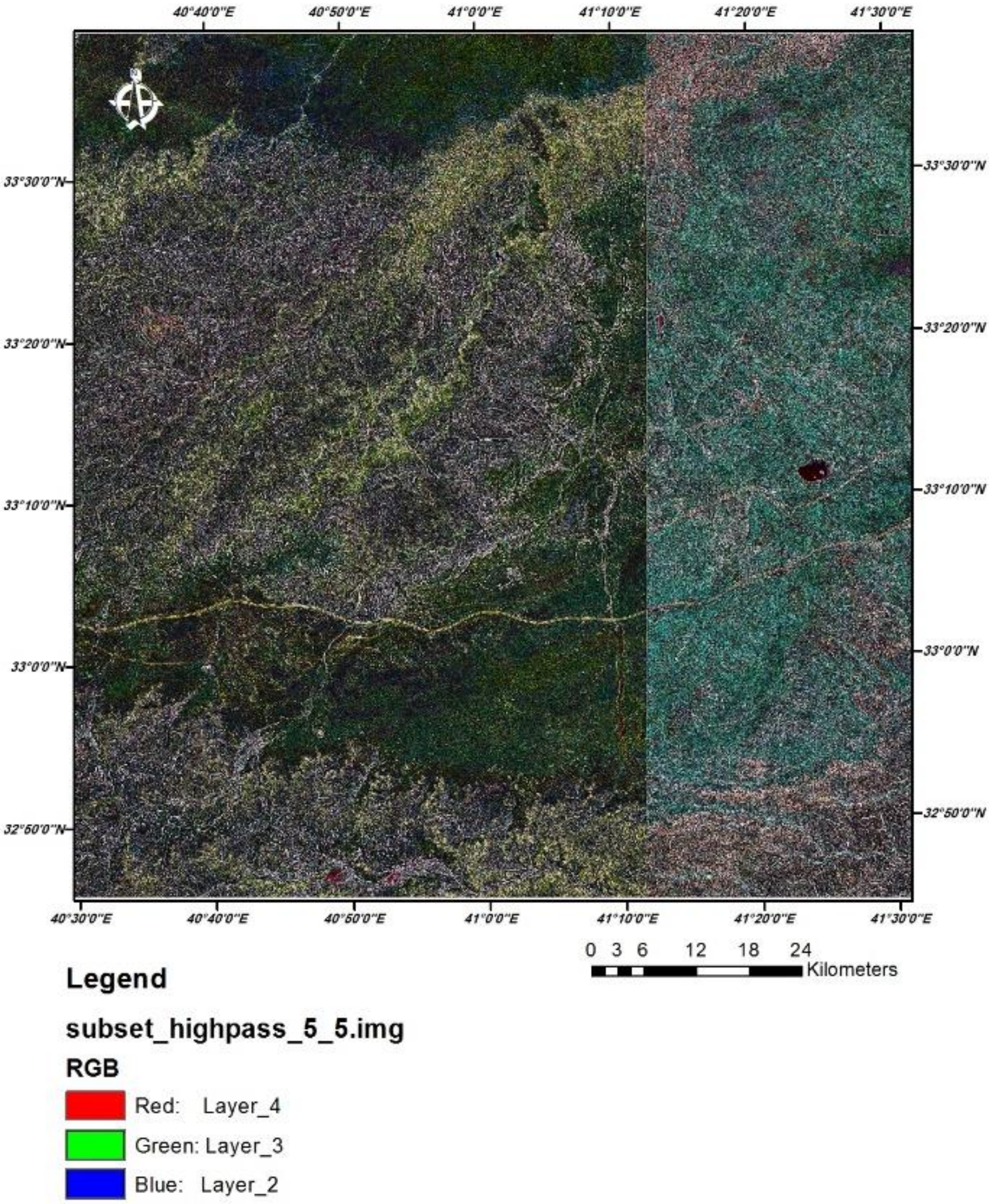

Fig. 4. Image of the high-pass filtering kernel (5*5).

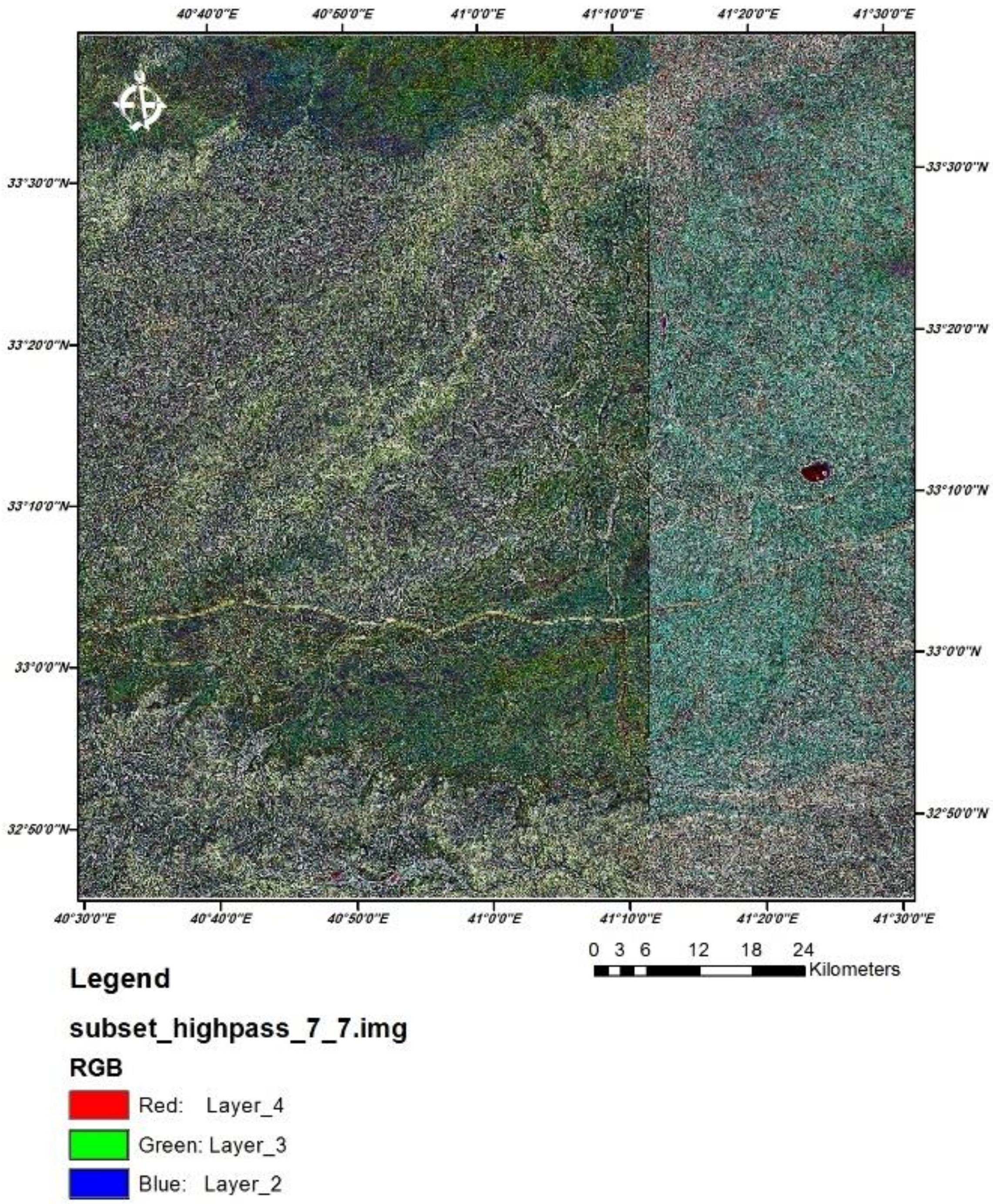

Fig. 5. Image of the high-pass filtering kernel (7*7).

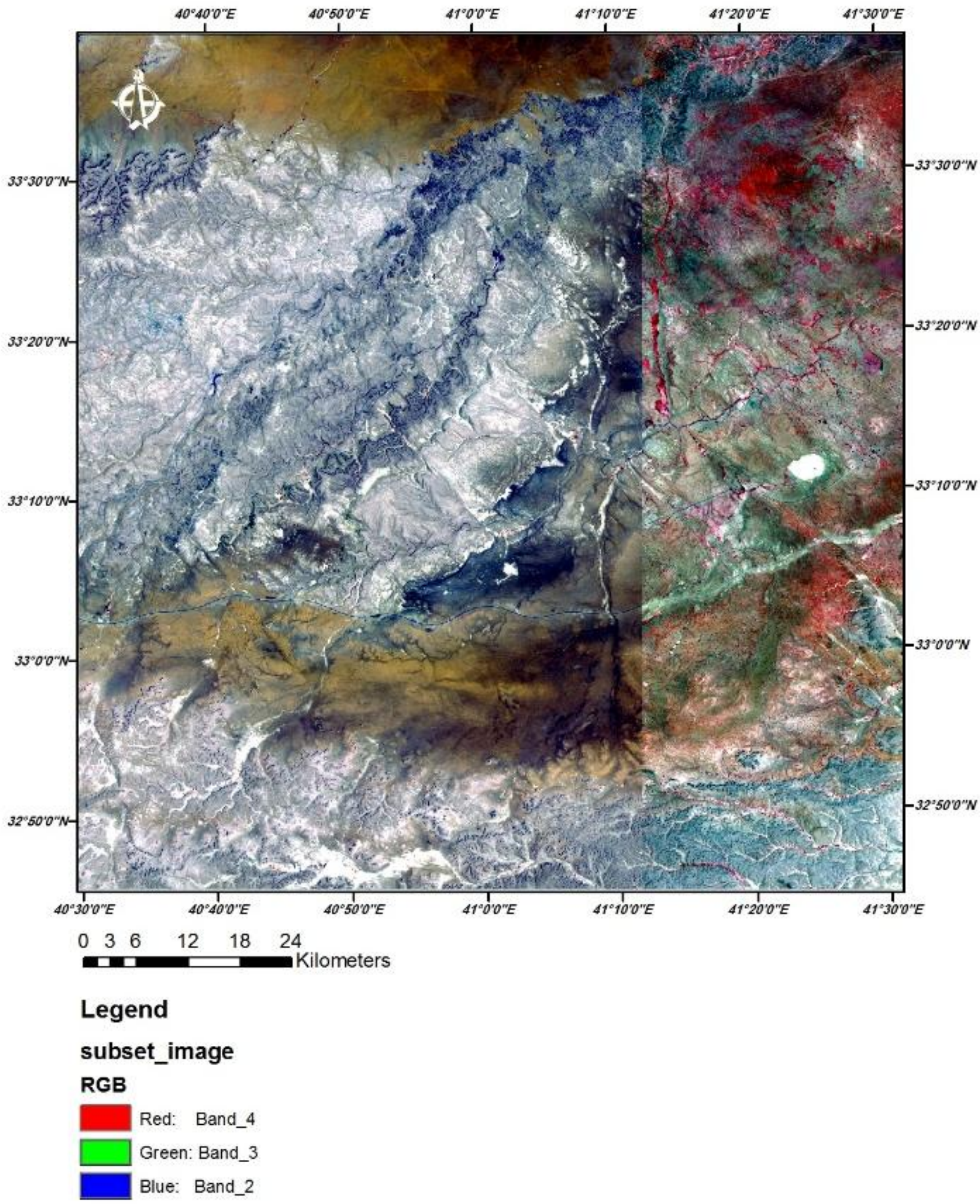

Fig. 6. Color composite of the band 4 (Red), 3 (Green), 2 (Blue).

Linear structure analysis

The most important element of analyzing space visuals in tectonic studies is the analysis of linear structures, as they represent the surface appearance of deep subsurface fault systems (AlFasatwi and Dijk, 1990). The final lineaments map is created after adding all the linear structures and deleting those that matched the roads (Fig. 7). The total number of inferred linear structures found through various methods is 354 linear structures in the region. The linear structures in the region are categorized based on El-Etr's (1974) categorization as well as on their lengths (Fig. 8), which is a function of the depth of their extension within the rock units into:

- Structures longer than 2 km are marked in red.

- Structures less than 2 km long are marked as blue.

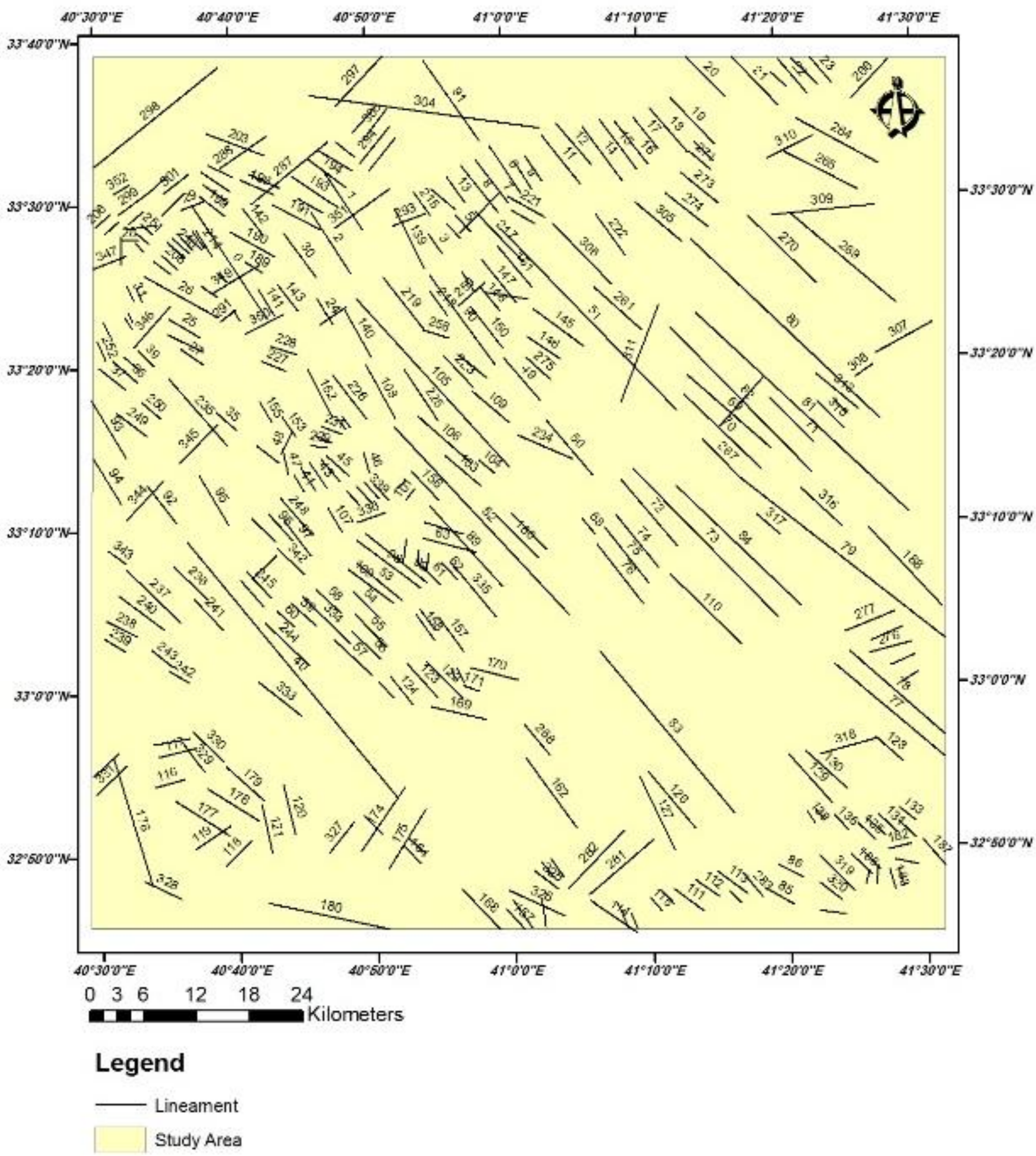

Fig. 7. Final map of linear structures.

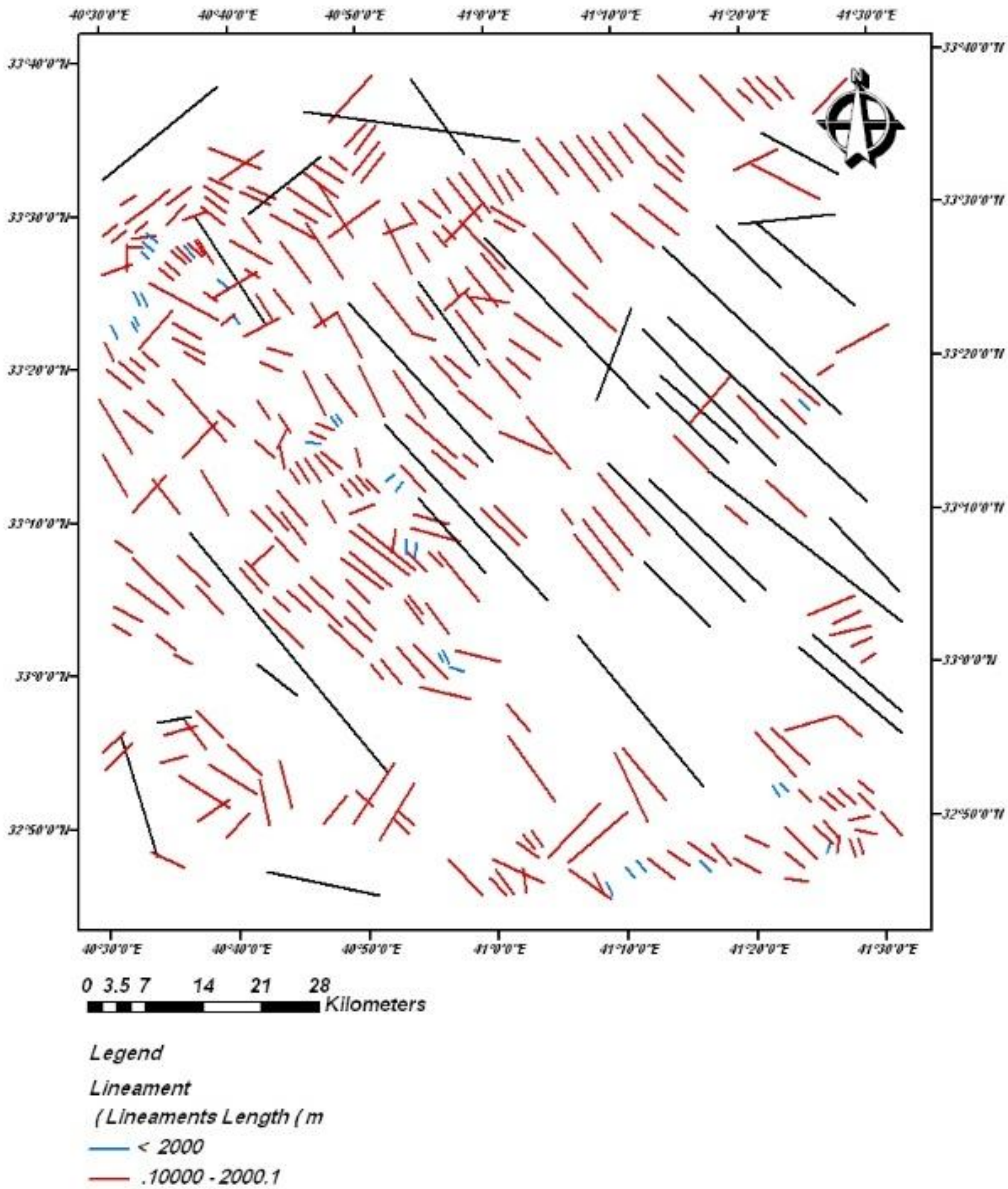

Fig. 8. Classification of linear structures within the study area.

The lineaments' azimuths are also measured and plotted as rose diagrams. The lineament orientations within the research region are well mapped as seen in Fig. 9. The rose diagram shows that the linear structures are concentrated in the main direction within the studied area, which is N 40° W, while the minor directions are (N 15° W, N 50° E, and N 55° W) (Fig. 9). The groups of linear structures are approximately parallel to each other. 354 lines are discovered and digitized in the entire study area. Based on the interpretation of satellite imagery, the structures show surface evidence for possible deep faults in the basement rocks.

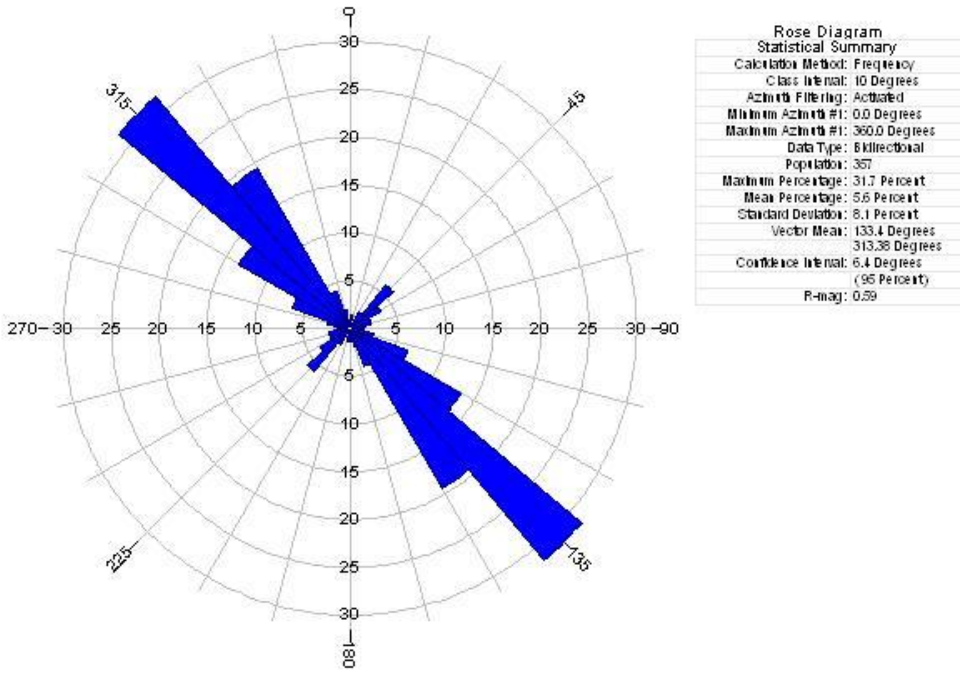

Fig. 9. Rose diagram of the linear structures within the study area.

Results and Discussion

In fractured aquifers, lineaments serve as groundwater drainage systems (Koita, 2010; Brunner et al., 2007). Because smaller lineaments may be missed during the manual extraction process, it is subjective and challenging to apply to a large region (Saepuloh et al., 2018).

Linear features like faults, fractures, and geological linkages between different lithologies can cause the water to seep into the soil and migrate through the aquifer system, perhaps using the lineaments as a path. According to Pradhan and Kim (2014), lineaments are geologic structures that symbolize underlying surface fractures. These structures have the potential to improve the definition of already existing aquifers, identify new reservoirs close to highly inhabited regions that facilitate fluid movement to the bottom, and provide information about water penetration and flow along lineaments (Benjmel et al., 2020).

It is believed that as lineament density increases, so does the quantity of water penetration; hence, lineament density may act as an indirect predictor of groundwater potential (Magesh et al., 2012). Satellite data may be used to map fractures, bedding planes, and geological boundary contacts, all of which will be correlated with these lineaments to assist the groundwater potential analysis (Jhariya et al., 2016).

According to Subba Rao (2006), lineaments are the surface manifestations of underlying geological features that indicate the permeability and porosity of the underlying rocks. The main routes for groundwater flow and storage on Earth are fractures in impermeable rocks (Preeja et al., 2011). Both on-site observations and satellite imagery are used in this work to identify the lineaments in the investigated region. Most of the fractures have NW–SE trends. A map of lineament density is made using the line density approach. The lineament density map (Fig. 10) was made after lineaments were digitized from satellite images. Then, based on Natural Breaks intervals, it is split into five classes: 0 to 2.064, 2.064 to 4.129, 4.129 to 6.194, 6.194 to 8.258, and 8.258 to 10.323 (Table 1). Groundwater development is beneficial in areas with high lineament density, except in the remaining hill environment. The research region is divided into five distinct hydrogeological potential zones, which are depicted as patches in Fig. 10. Table 1 provides a summary of the zones.

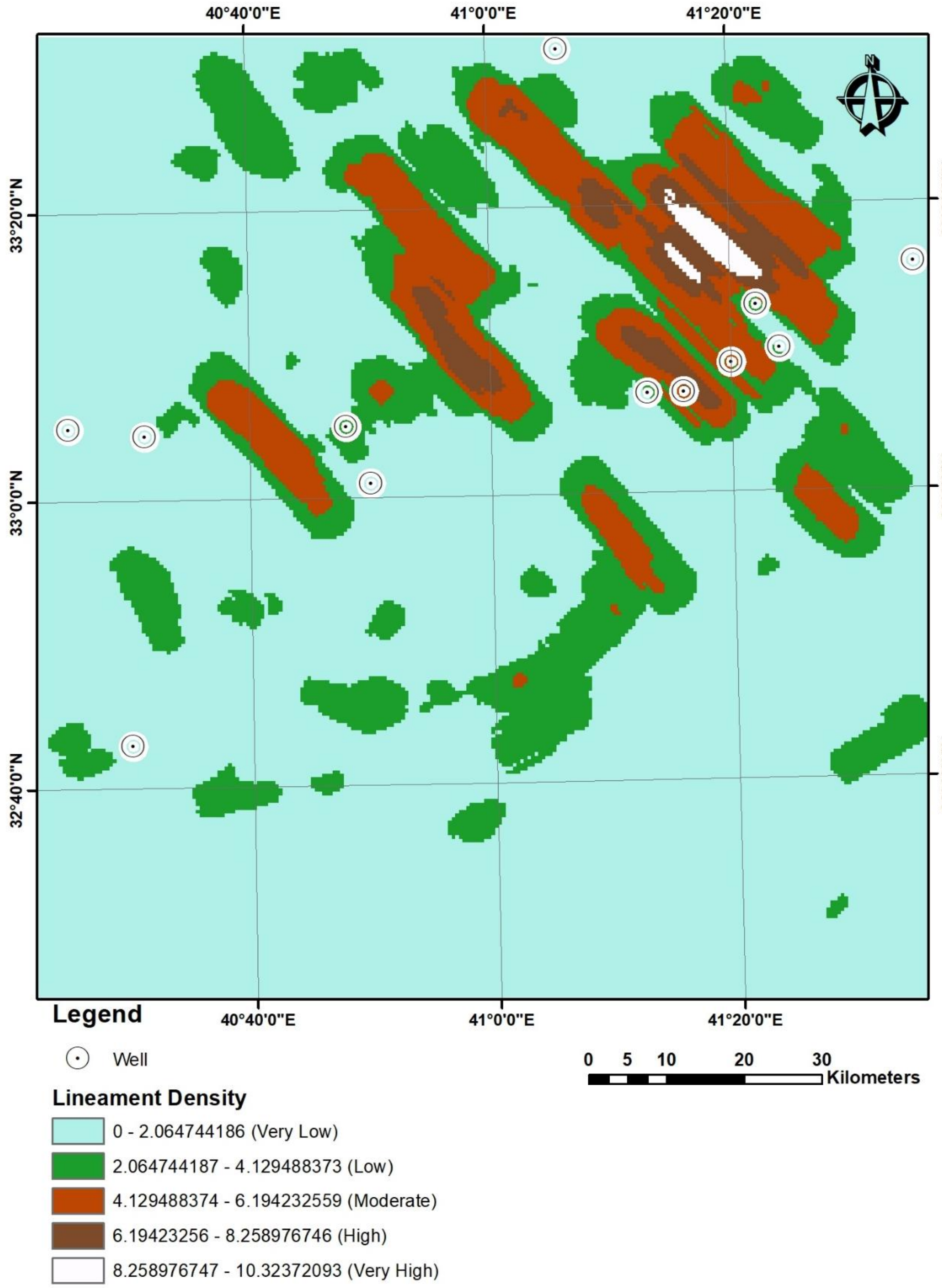

Fig. 10. Lineament density map of the studied area.

Table 1: Research areas' groundwater prospecting depending on lineament density.

Lineaments Density Range (km/km^2)	Groundwater Prospecting
0 to 2.064	Very low
2.064 to 4.129	Low
4.129 to 6.194	Moderate
6.194 to 8.258	High
8.258 to 10.323	Very high

As Fig. 10 illustrates, the lineament density is much lower in the research area's southeast and considerably higher in the study area's northern portion as compared to the other locations. In the site with low lineament density, there is a lower groundwater infiltration rate, whereas in the region with high lineament density, there is a higher groundwater infiltration rate.

A lineament frequency map indicates how many lineaments there are in a square kilometer grid region, with more lineaments indicating excellent groundwater potentiality (Naidu et al., 2015). By calculating the number of lineaments per square kilometer grid, a weighted lineament frequency map is created. Five zones, from high to poor, are used to classify the research region based on lineament frequency. Fig. 11 illustrates that a high zone in this research region denotes a modest groundwater potential.

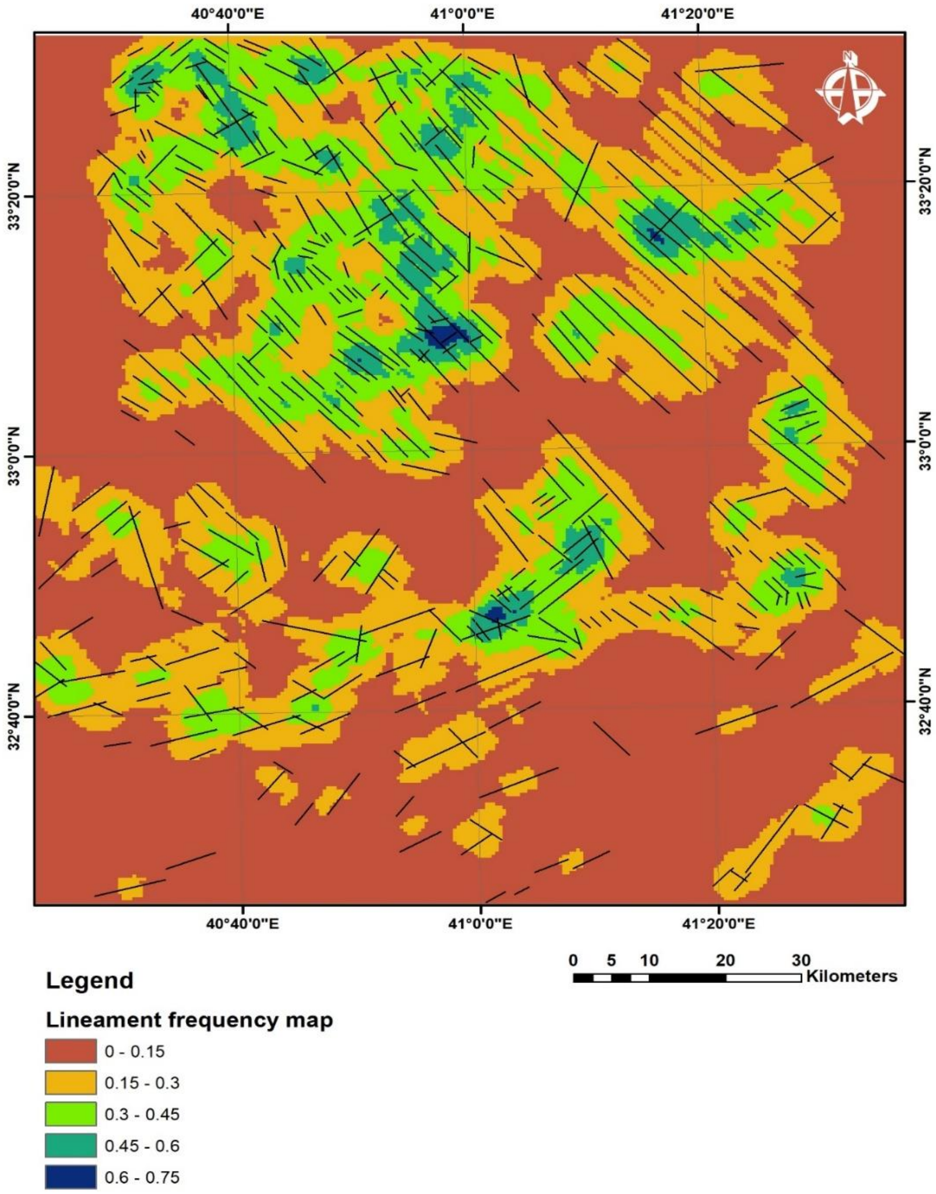

Fig. 11. Lineament Frequency map of the studied area.

According to Fig. 12, there are many lineament junction nodes in the land located in the north and south portions of the research region, but there are few or none in other places. Since groundwater originates within faults and fractures in the rocks, these previously indicated regions might offer strong groundwater potentials in terms of groundwater exploration due to their large concentration of lineament intersections.

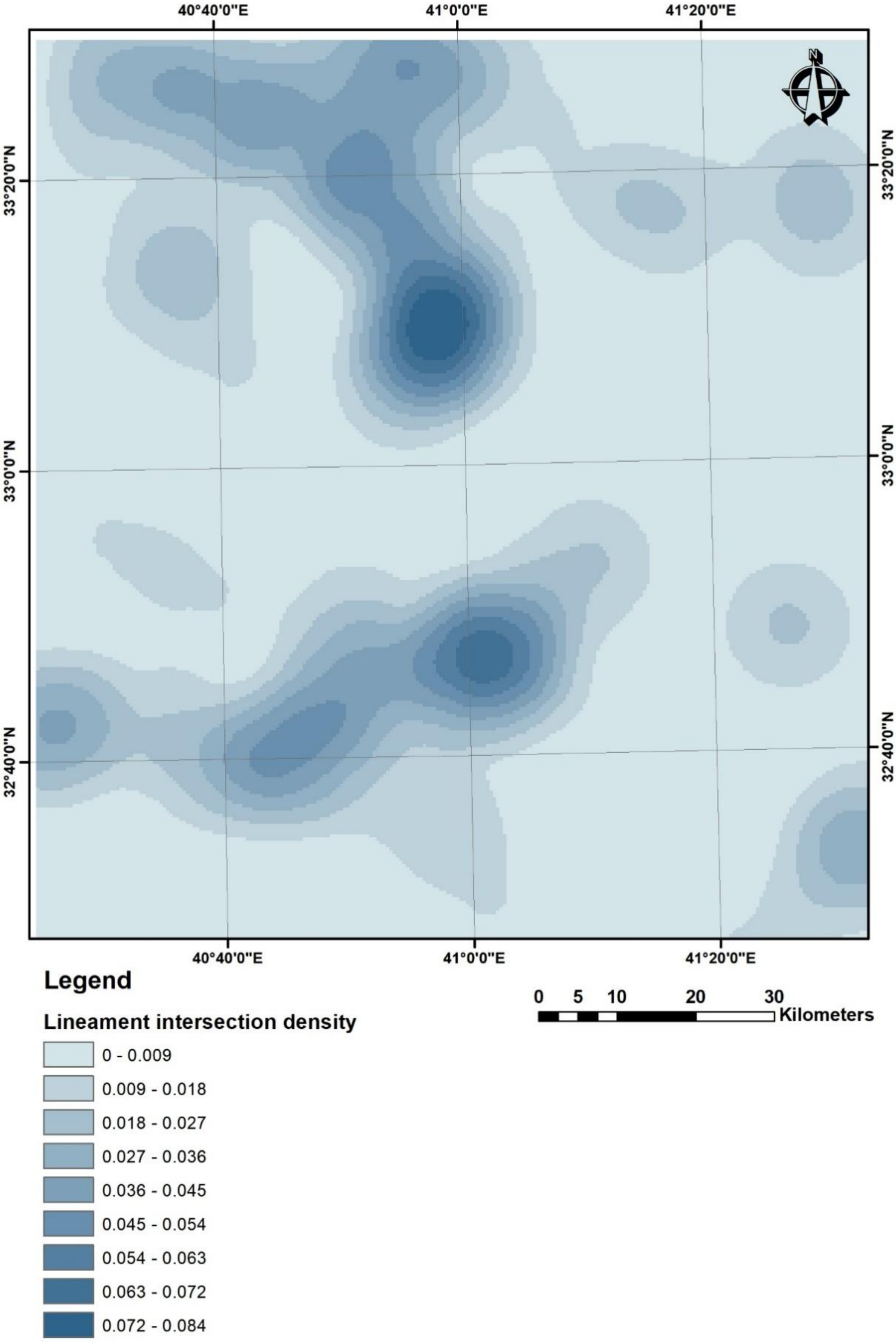

Fig. 12. The Study area's density map of lineaments intersecting.

Conclusion

Groundwater investigations on hard formations frequently necessitate data extraction from satellite imagery and GIS. Because of the lack of available data, maps of the lineaments and structural features are crucial materials for identifying locations of the groundwater recharge and discharge, flow, and development. Specifically, the lineaments related to fractures, faults, and joints are primarily responsible for groundwater occurrences in hard rocks. Moreover, the concentration and distribution of groundwater discharge locations are strongly associated with lineament distribution.

For geologic and tectonic research in desert regions like the study region, where rocks are well exposed, and field visits are challenging, remote sensing is a potent tool. Most geological formations, including faults, can be understood and analyzed through the use of satellite images. This study presents the results of lineament extraction from Landsat-7 satellite images in identifying groundwater areas in the Iraqi Western Desert. Filtering and band composite processes are applied to the final lineament extraction in the studied area. Combining several image-enhancing methods, such as color composite (CC) and filtering, proved useful and appropriate for spotting linear structures.

To effectively acquire a thorough general perspective of the tectonic stress direction in this area, the orientation analysis of the lineament findings shows that the primary orientations of the lineaments are N 40° W, with the minor directions being N 15° W, N 50° E, and N 55° W.

Groundwater wells in the investigated region are projected on a lineament density map; most of these wells matched the areas with a high density of linear structures. The research region has been divided into five groups based on lineament frequency, density, and intersect maps (Figures 10, 11, and 12); they are: very low, low, moderate, high, and very high. Groundwater potential is highest in areas in the high and very high categories. According to the study, 1351 km^2 of zones have very good, medium, and moderate groundwater potential.

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