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Mapping Of Potential Areas of Groundwater Zones in the Najaf-Karbala Alluvial Fan Using Remote Sensing and GIS Technology

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Abstract

Geospatial tools like remote sensing and GIS are vital for evaluating, monitoring, and preserving groundwater resources, especially in changing climates. Finding areas where groundwater recharge is most likely is crucial for protecting and managing its quality. In arid regions, groundwater is extracted extensively due to its importance for various uses. This study aims to identify and categorize productive areas for groundwater in Al Najaf – Karbala fan using remote sensing and GIS. The AHP method employed the weight for each factor used to determine the map potential zones, incorporating seven factors: geomorphology, lithology, aspect, drainage density, lineaments density, land cover, and slope. Each factor was ranked and categorized based on its hydrogeology impact on groundwater availability. The results revealed five productivity zones: very low, low, moderate, high, and very high, covering 5%, 10%, 15%, 30%, and 40% of the study area, respectively. Western and southwestern study areas have low potential, while eastern and middle areas have moderate potential. The center and northeastern regions boast the highest potential.

Keywords: Geographic Information System (GIS), Remote Sensing (RS), Al Najaf-Karbala Fan, Alluvial, Groundwater potential zone.

رسم خرائط المناطق المحتملة للمياه الجوفية باستخدام نظم المعلومات الجغرافية والاستشعار عن بعد في المروحة الغرينية للنجف – كربلاء

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الخلاصة

أصبحت الأدوات الجغرافية المكانية مثل الاستشعار عن بعد ونظم المعلومات الجغرافية الآن حيوية لتقييم موارد المياه الجوفية ومراقبتها والحفاظ عليها، خاصة مع تغير المناخ. يعد العثور على المناطق التي من المرجح أن يتم فيها إعادة تغذية المياه الجوفية أمرًا بالغ الأهمية لحماية جودتها وإدارتها. وفي المناطق الجافة، تعتبر المياه الجوفية ضرورية لمختلف الاستخدامات، مما يؤدي إلى استخراجها بشكل مكثف. تهدف هذه الدراسة إلى تحديد وتصنيف المناطق المنتجة للمياه الجوفية في مروحة النجف – كربلا باستخدام الاستشعار عن بعد ونظم المعلومات الجغرافية. تم استخدام طريقة AHP لاعطاء اوزان للمعاملات التي تم استخامها لرسم خريطة للمناطق المحتملة، والتي تتضمن سبعة عوامل مثل الجيومورفولوجيا، وعلم الصخور، الاتجاه، وكثافة التصريف، وكثافة التراكيب الخطية، والغطاء الأرضي، والانحدار؛ تم تصنيف كل عامل بناءً على

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تأثيره الهيدروجيولوجي على توافر المياه الجوفية. وكشف النتائج عن خمس مناطق تغذية للمياه الجوفية: منخفضة جدًا، ومنخفضة، ومعتدلة، وعالية، وعالية جدًا، وتغطي 5%، 10%، 15%، 30%، 40% من المساحة المروحة على التوالي. تمتاز المناطق الغربية والجنوبية الغربية من منطقة الدراسة بإمكانيات منخفضة من مصادر التغذية، بينما تمتاز المناطق الغربية والوسطى بإمكانيات متوسطة من مصادر التغذية و تمتاز مناطق الوسط والشمال الشرقي بأعلى الإمكانات التغذية بحيث لاتحتاج الى تغذية صناعية.

1. Introduction

Groundwater is an indispensable natural resource for potable water in some urban and rural areas [1, 2]. It plays a critical role in sustaining human life and the health of aquatic and terrestrial ecosystems. Climate change, alterations in precipitation patterns, and a diminishing trend in snowfall and river flow [2] are exacerbating water scarcity and intensifying the reliance on groundwater resources. The availability and accessibility of groundwater, coupled with its exceptional natural quality, make it an increasingly important source of water supply for domestic use worldwide [3].

An alluvial fan is a deposit formed by a fast-flowing stream or river over a flat plain. This occurs when the water velocity decreases, causing sediment to be deposited. Alluvial fans are common in arid or semi-arid. Groundwater constitutes 97% of the readily accessible liquid freshwater on Earth, serving as a primary source for drinking and other domestic purposes [4]. However, mismanagement and overexploitation of groundwater resources may have led to water shortages and contamination [5,6]. Consequently, the overexploitation of groundwater, particularly in developing countries, is becoming a major concern [3] [7]. This resource must be used economically due to its limited nature. Evaluating and monitoring groundwater resources depend on geospatial technologies like remote sensing and GIS [8] [9]. Satellite data and geospatial techniques can be harnessed to quantify reliable baseline information about factors (geology, land use, land cover, drainage, and lineaments) that govern and influence the occurrence and movement of groundwater [10] [11] [12]. However, these factors have not often been studied holistically due to data constraints and a lack of integrated tools. Remote sensing and geographic information systems are indispensable tools for investigating hydrogeological data and developing virtual models of multifaceted features [13, 14, and 15].

Geographic Information Systems (GIS) have proven to be a valuable tool for assessing groundwater potential. GIS analysis can be used to identify areas where water is likely to infiltrate the ground and replenish groundwater resources. AHP (Analytic Hierarchy Process) is a multi-criteria decision-making method that can evaluate the relative importance of factors affecting groundwater potential [13]. Remote sensing is another valuable tool for groundwater studies. Satellite imagery is widely used to identify land cover, soil type, and other factors that affect groundwater recharge. Remote sensing data is also be used to monitor changes in groundwater levels over time. Using GIS and remote sensing has helped improve our understanding of groundwater resources and develop more effective strategies for managing these resources [15]. Groundwater constitutes the primary water supply for diverse applications. Mapping groundwater recharge zones (GWRZs) has become a critical tool for methodical water resource development and planning [16]. The analytical hierarchy process (AHP) has become the most extensively utilized method for identifying GWRP zones and environmental management. By employing this approach, experts can discern the relative significance of thematic layers in GWRP analysis [17]. The delineation of groundwater potential areas has utilized a variety of datasets, including maps (geological, lithology, geomorphology, and soil), a digital elevation model (DEM), and Landsat 8 satellite imagery. It has been studied by many authors, such as [18], mentioned that the area covered by the two cliffs is built by the Dibdibba Formation, representing a giant alluvial fan, [19] studied the geomorphological characteristics of Al Najaf – Karbala alluvial fan, and [20] study the origin of Tar Al-Sayed and Tar Al-Najaf, Karbala-Najaf Vicinity, Central Iraq.

This study aims to delineate the groundwater potential recharge zone of the study region, ensuring the most efficient and sustainable development and management of groundwater resources.

2. Location of study area

The study area encompasses a specific geographical area, spanning approximately from north latitude N32°04'00" to N31°05'00" and east longitude E44°30'00" to E43°20'00". Najaf and Karbala are cities in Iraq, both with historical and religious significance. They are located in the Tigris-Euphrates river basin, an area that has developed various landforms due to the action of rivers and their tributaries. The southern edge of Al-Razzaza Lake delineates its northern border. To the northeast, it is bordered by the western regions of Karbala City. The Najaf Sea defines the southern side, while Najaf City forms the southeastern boundary. The Western Desert delineates the western border, and the Mesopotamian zone forms the eastern boundary [21] (Figure 1).

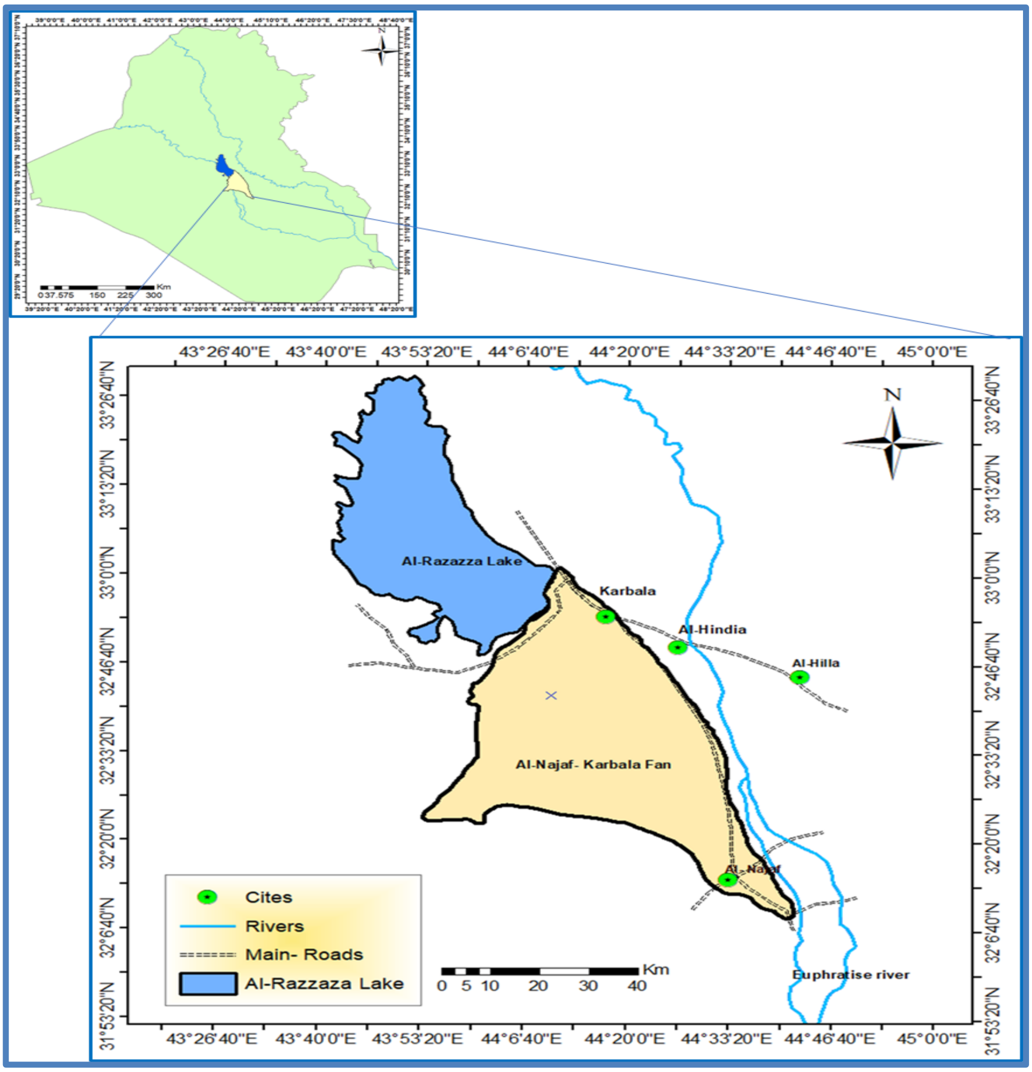


Figure 1: location of study area [22].

3. Material and methods

A variety of parametric datasets were used to construct the groundwater potential recharge map for the Al Najaf-Karbala fan, including several auxiliary data sources, including maps and programs, and a Digital Elevation Model (DEM) with a 15-meter resolution Landsat 8 with coordinate UTM. WGS 1984 38N. A scale-appropriate geological map of Iraq provided the geological information [21, 23]. Furthermore, the study extended to include remote sensing data that included lineaments, drainage density, slope gradient, and slope aspect maps obtained from the DEM. ArcGIS 10.4.1 was used to construct the drainage density map of the Al Najaf-Karbala fan using the arc hydro tool. Using the ArcGIS Spatial Analyst module, slope maps were produced using Aster DEM data at a resolution of thirty meters. This theme was given weight and rank using AHP methods (Tables 1 and 2).

Table 1: Criteria Weight

criteria	Geomorphology	Lithology	LU	slop	aspect	drainage	lineaments	WC
Geomorphology	1	2	3	4	5	6	7	0.38
Lithology	0.5	1	1.5	2	2.5	3	3.5	0.19
LU	0.3	0.6	1	1.3	1.6	2	2.3	0.12
Slope	0.2	0.5	0.7	1	1.2	1.5	1.7	0.09
Aspect	0.2	0.4	0.6	0.8	1	1.2	1.4	0.07
Drainage density	0.1	0.3	0.5	0.6	0.8	1	1.1	0.06
Lineaments density	0.1	0.2	0.4	0.5	0.7	0.8	1	0.05

Table 2: Criteria Weight and rank by AHP methods.

Theme	Class /Feature	Layers weight	Rank	weight
Geomorphology	Plateaus	0.38	4	1.52
	Marshes		5	1.9
Lithology	Evaporate	0.19	5	0.95
	Glacier		4	0.76
LU	Irrigated farming	0.128	5	0.64
	Rough grazing		4	0.512
	Rice		1	0.128
	Date		3	0.384
	Barley		2	0.256
Slope	Very low	0.09	1	0.09
	low		2	0.18
	Medium		3	0.27
	high		4	0.36
	very high		5	0.45
Aspect	Very low	0.07	1	0.07
	low		2	0.14
	Medium		3	0.21
	high		4	0.28
	very high		5	0.35
Drainage Density	Very low	0.06	1	0.06
	low		2	0.12
	Medium		3	0.18
	high		4	0.24
	very high		5	0.3
Lineaments Density	Very low	0.05	1	0.05
	low		2	0.1
	Medium		3	0.15
	high		4	0.2
	very high		5	0.25

4. Result and discussion

4.1 Evaluating physical environmental factors controlling the groundwater occurrence

4.1.1 Geomorphology

The Euphrates River's sediment deposition is responsible for constructing the Al Najaf-Karbala alluvial fan [23]. This fan-shaped landform reaches from the embrace of the Iraqi Desert in the south to the foothills of the Zagros Mountains in the north [21]. The best areas for groundwater development and investigation are those with limestone formations and those primarily made up of marshes and plateaus (Fig 2). These regions have advantageous geomorphological characteristics that encourage groundwater entry, storage, and circulation, making them prime. Each class was assigned a weighted value, indicating its priority in influencing groundwater accumulation (Table 1, 2).

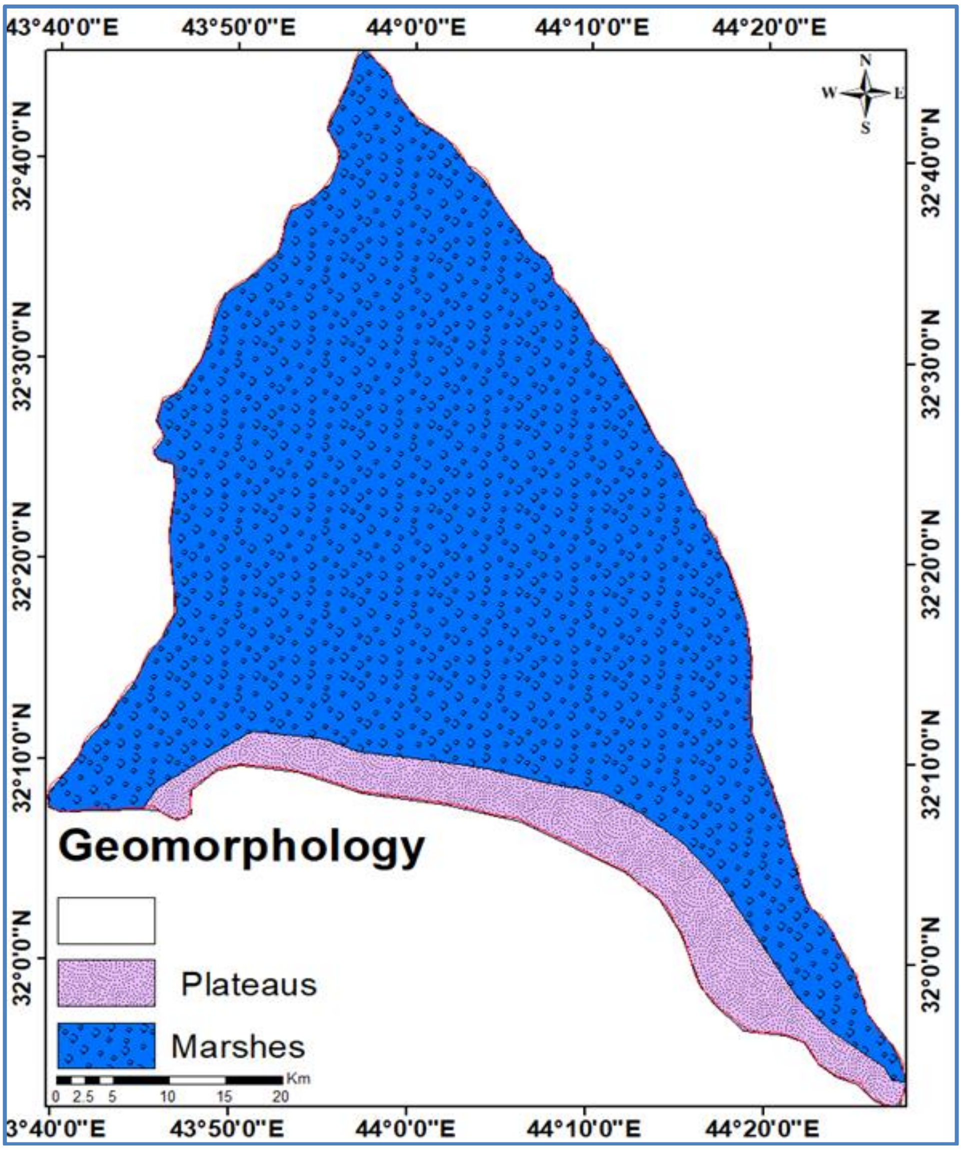


Figure 2: Part from geomorphological map of Al Najaf – Karbala alluvial fan

4.1.2 **Lithology**

The Al Najaf-Karbala alluvial fan's groundwater availability and quality are determined mainly by lithology. It affects the hydrogeological characteristics of local aquifers. The two primary lithology types are evaporate and glaciers, according to the supplied map (Fig. 3). The best places to explore and develop groundwater are those with a preponderance of glacial and evaporate deposits and those with limestone formations. A weighted value was assigned to each class, denoting its relative importance in influencing the accumulation of groundwater (Table 1, 2).

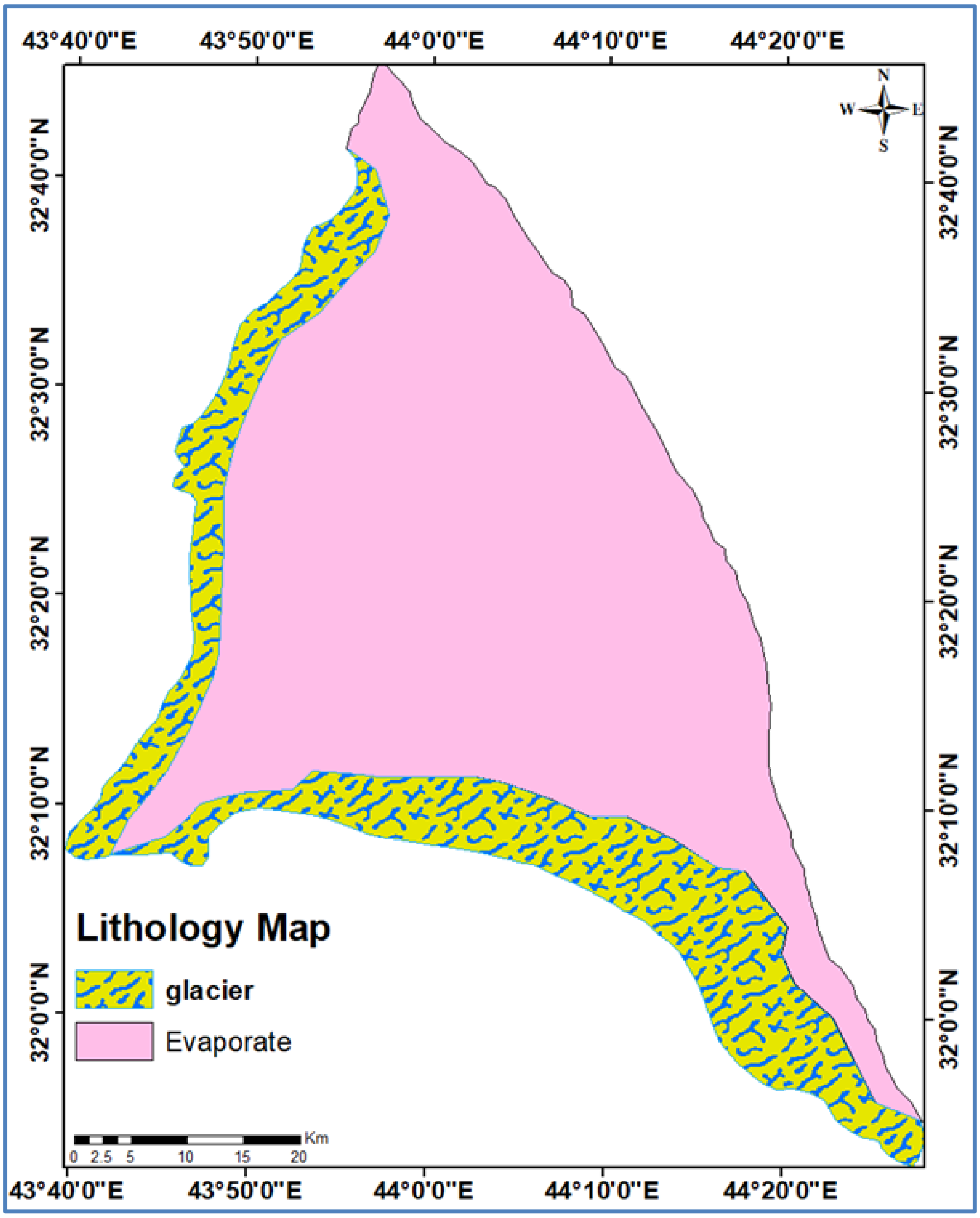


Figure 3: Lithological of Al Najaf – Karbala alluvial fan

4.1.3 Slope

One important aspect affecting the quantity and presence of groundwater is the slope; as steep slopes cause rapid runoff and reduce groundwater recharge, low-gradient slopes are better suited to hold rainfall and replenish groundwater storage [24]. A slope gradient map produced by digital elevation models showed a clear relationship between groundwater occurrence and slope angle [25] [26]. Five categories were identified to improve this classification: very low, low, moderate, high, and very high. (Fig. 4) provides illustrations for these categories. Each class was assigned a weighted value, denoting its relative importance in influencing groundwater accumulation (Table 1, 2).

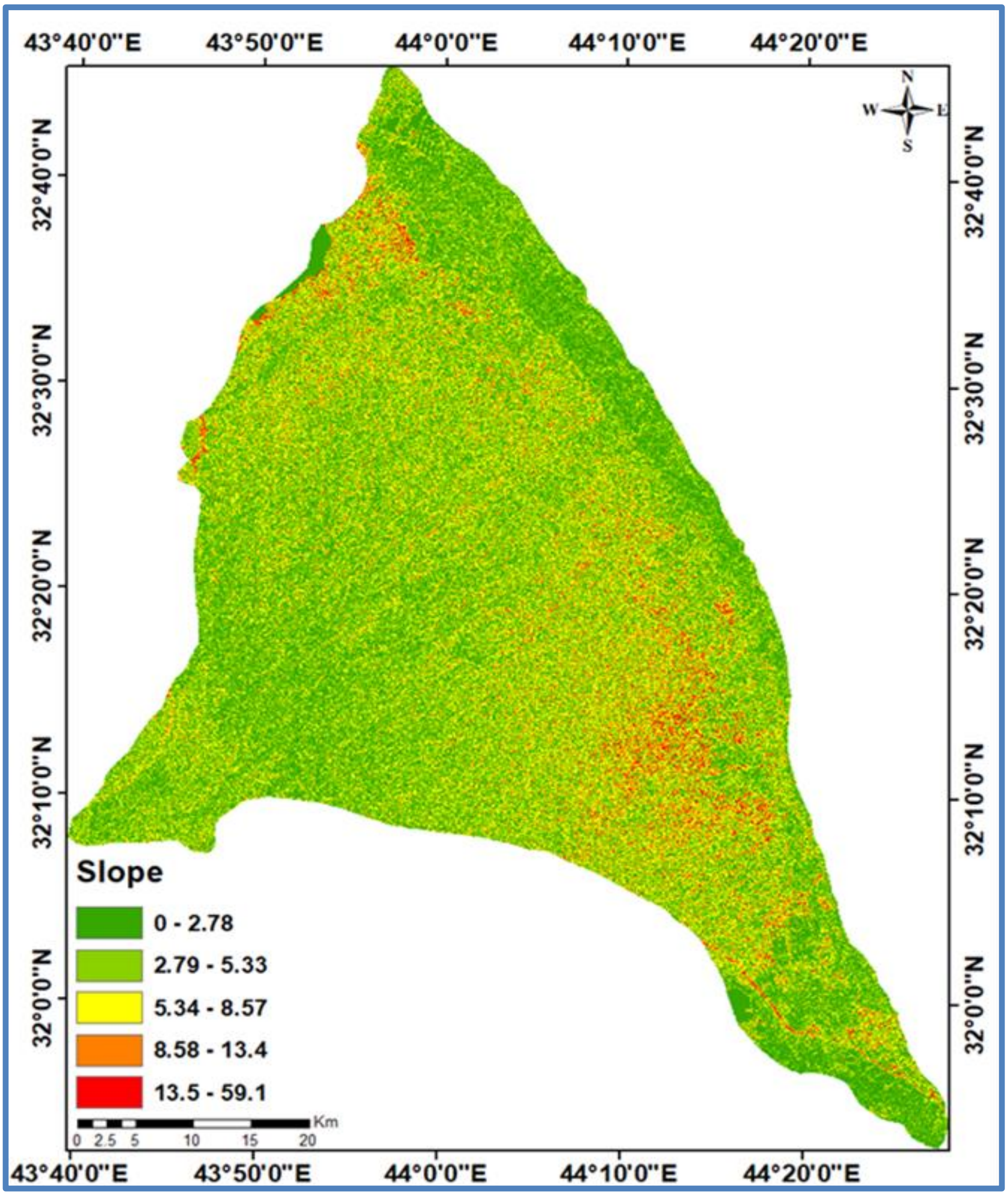


Figure 4: Slope map of Al Najaf – Karbala alluvial fan

4.1.4 Aspect

The aspect, which starts north and rotates clockwise, is the direction of the steepest slope and is expressed in degrees from 0 to 360. In essence, it tells which way the slope is inclined. The slope aspect significantly impacts semi-arid and arid regions where sunlight affects vegetation patterns [25, 26]. Five categories were identified by this study to further improve this classification: very low, low, moderate, high, and very high. (Fig. 5) provides illustrations for these categories. A weighted value is assigned to each class, denoting its relative importance in influencing the accumulation of groundwater (Table 1, 2).

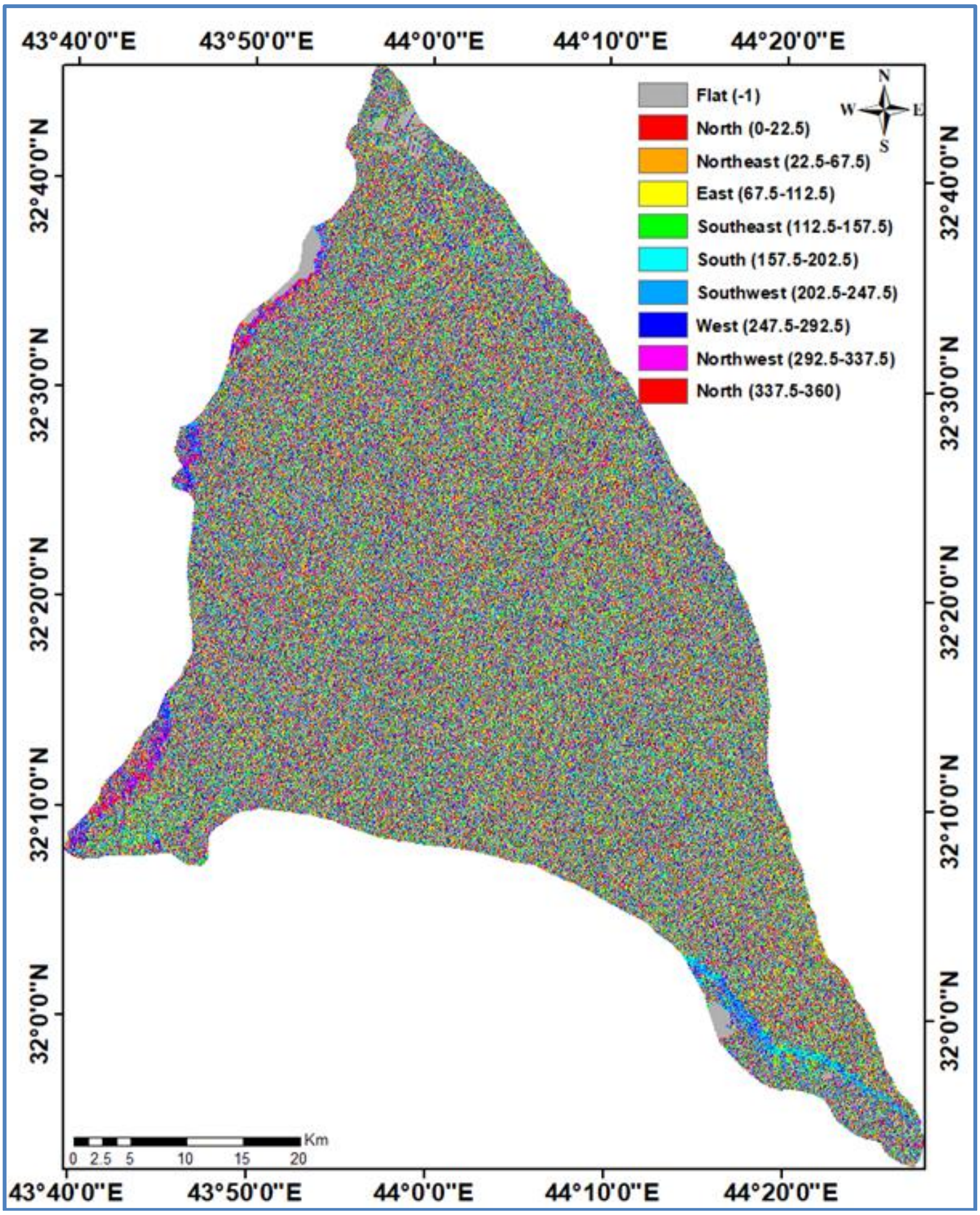


Figure 5 : Aspect map of Al Najaf – Karbala alluvial fan

4.1.5 Land Use

The LU was prepared using the Iraq land use map. Thus, the research site has been categorized into five classes: Beryl, Date, Rice, Rough Grazing, and Irrigated Farming (Fig 6). Each class was assigned a weighted value, indicating its respective priority in influencing groundwater accumulation [27] (Table 1, 2). LU information plays a crucial role in assessing the area's groundwater storage and recharge capacity. The type and nature of LU directly influence groundwater levels, with forests and cultivated land (agriculture and horticulture) offering the most favourable conditions due to their superior infiltration rates [28].

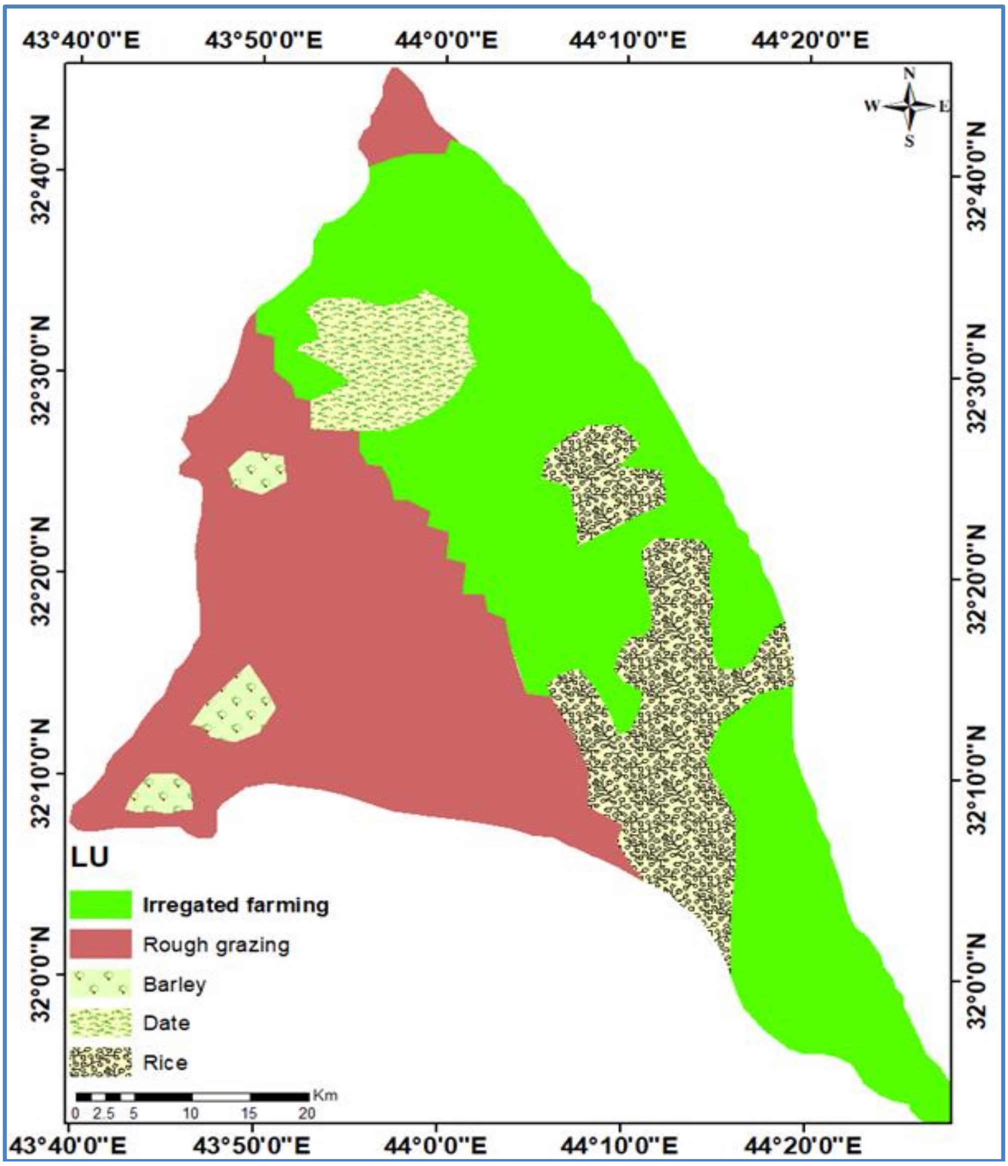


Figure 6: Land Use map of Al Najaf – Karbala alluvial fan

4.1.6 Drainage Density

Drainage-length density (Dd), a crucial indicator of groundwater potential, is calculated as the total length of lineaments within a unit area. High Dd values indicate high secondary porosity and a higher potential for groundwater storage [25]. The drainage density map (Fig 7) classifies the study area into five categories based on Dd values (very high, high, medium, low, and very low). This map provides valuable information for identifying areas with the most promising groundwater potential. Each class was assigned a weighted value, indicating its respective priority in influencing groundwater accumulation (Table 1, 2). The high drainage density area was located on the central and northeast parts of the fan, while the low drainage density area is located on the southwest part of the fan (Fig 7).

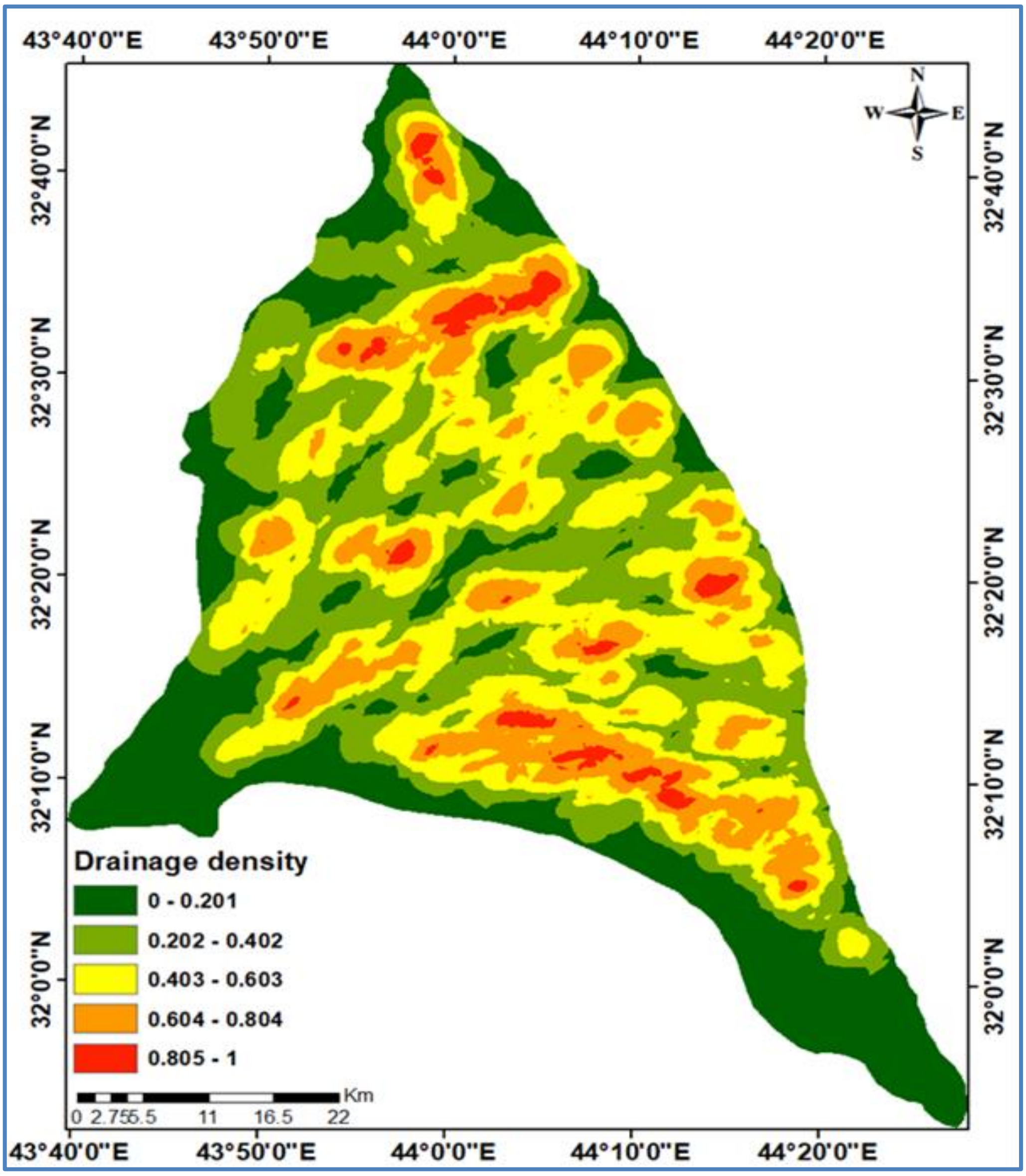


Figure 7: Drainage density map of Al Najaf – Karbala alluvial fan

5.1.7 Lineaments Density

A lineament density map was generated using a shaded relief map of the Digital Elevation Model (DEM) by using GIS, arc toolbox, Spatial analysis, hydrology, shaded relief, classified into five categories: very high, high, medium, low, and very low (Fig 8). Each class is assigned a weighted value, indicating its respective priority in influencing groundwater accumulation (Table 1, 2). Lineaments, linear or curved features on the Earth's surface such as faults, joints, and folds, play a key role in recharging groundwater in hard rock terrains. Areas closer to lineaments typically exhibit higher groundwater potential [28]. The northern and central part of the Al Najaf-Karbala alluvial fan displays the highest density of lineaments, suggesting this region possesses the greatest potential for groundwater exploration.

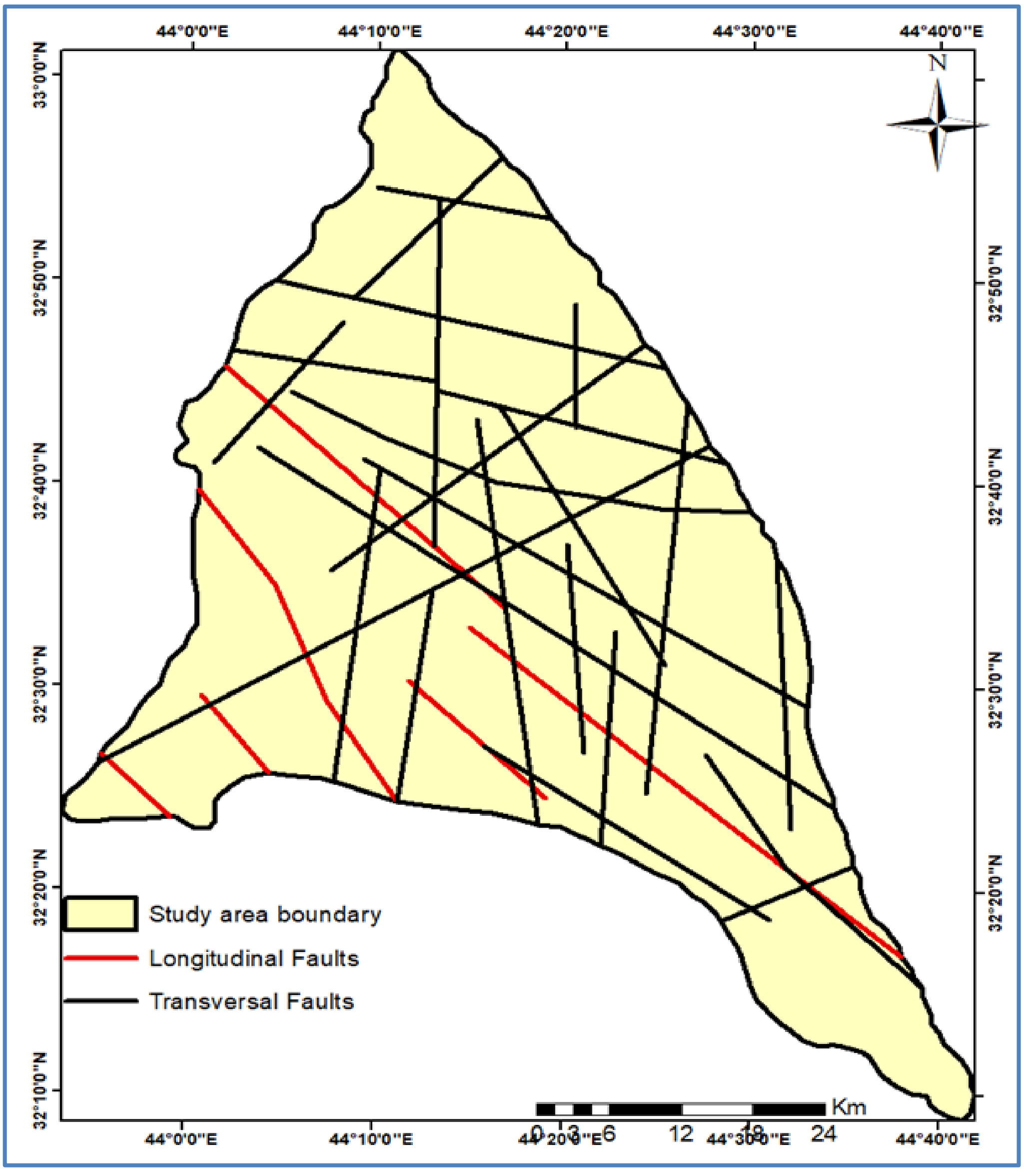


Figure 8: Lineaments map of Al Najaf –Karbala alluvial fan

4.2 Groundwater Potential Recharge (GWPR)

AHP method was employed to create a GWPR map for the Al Najaf-Karbala alluvial fan. This analysis considered six thematic layers: geomorphology, aspect, land use, lineament density, slope gradient, drainage density, and lithology. Pairwise comparisons were conducted to assign weights to each thematic layer based on their relative importance in influencing groundwater recharge potential (Table 1). The thematic layers were then reclassified according to these weights (Figure 9 a-g) .Using Equation 1:

$GWP = Wj * Xj$

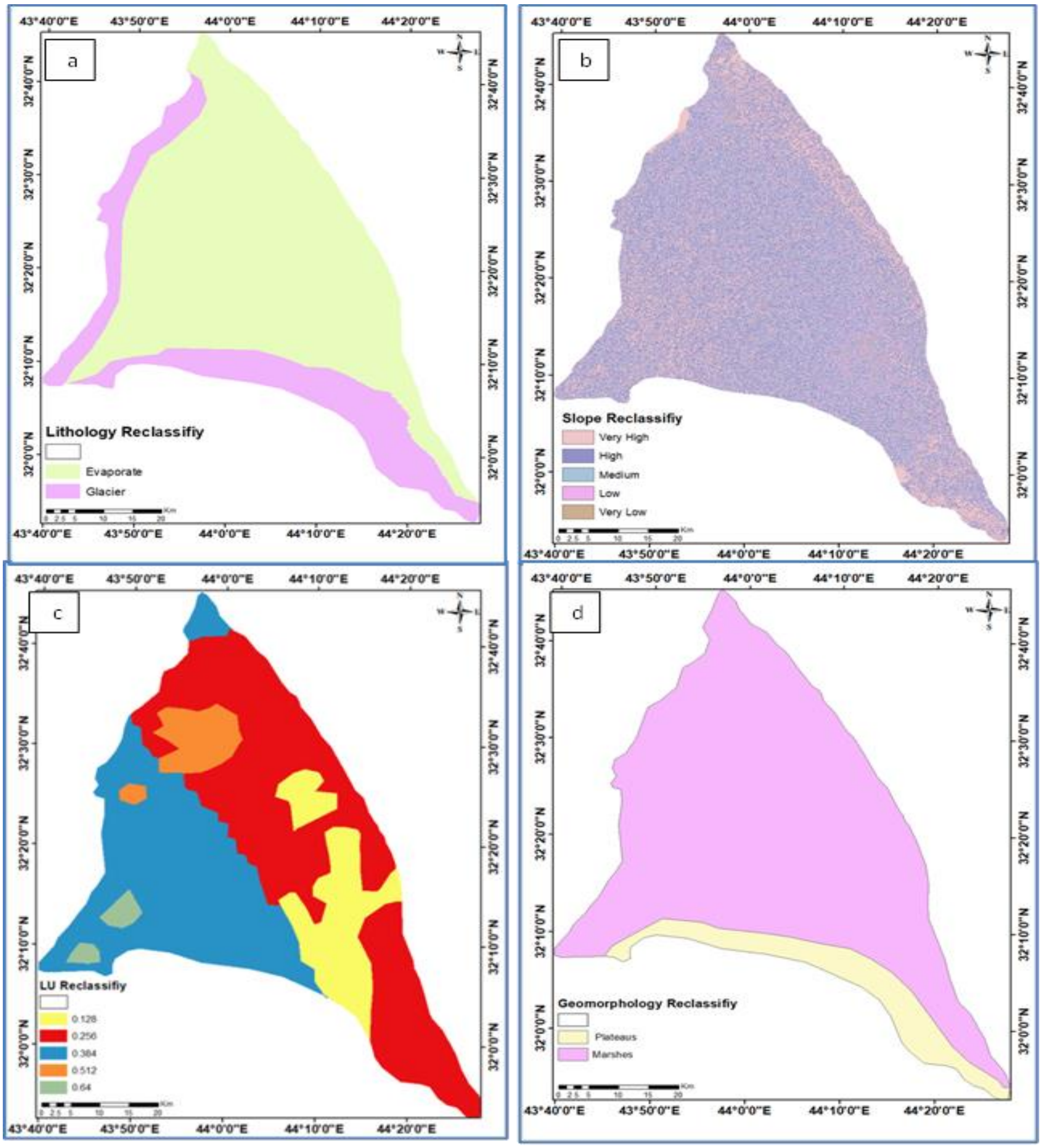
Where

GWP: groundwater potential zone.

Wj: is the normalized weight of j theme.

Xj: is the normalized weight of the j class of the theme.

The reclassified thematic layers were combined in a GIS environment to generate the final GWPR map (Figure 9a, b, c, d, e, f, and g). This map delineates three distinct zones based on GWPR values: Very High potential zone: This zone covers approximately 40% of the study area and primarily encompasses the center and northeastern regions; the High potential covers 30%. These areas are characterized by gravelly and sandy soils alongside agricultural land use, facilitating increased infiltration rates and promoting groundwater recharge. Moderate potential zone: Roughly 15% of the total area is situated in the western and middle parts of the fan. Groundwater recharge potential in this zone is moderate and may require supplemental artificial replenishment. Low potential zone: This zone covers a minimal portion (~10%) of the study area, primarily located in specific areas of the western and southwestern sectors and the Very low covers 5%. Groundwater recharge potential in this zone is the least favourable and demands active intervention to improve. The AHP-derived GWPR map provides valuable insights into the spatial distribution of groundwater recharge potential across the Al Najaf-Karbala alluvial fan. This information can be used for efficient water resource management, sustainable agricultural practices, and informed decision-making regarding groundwater exploration and development initiatives (Fig 10).



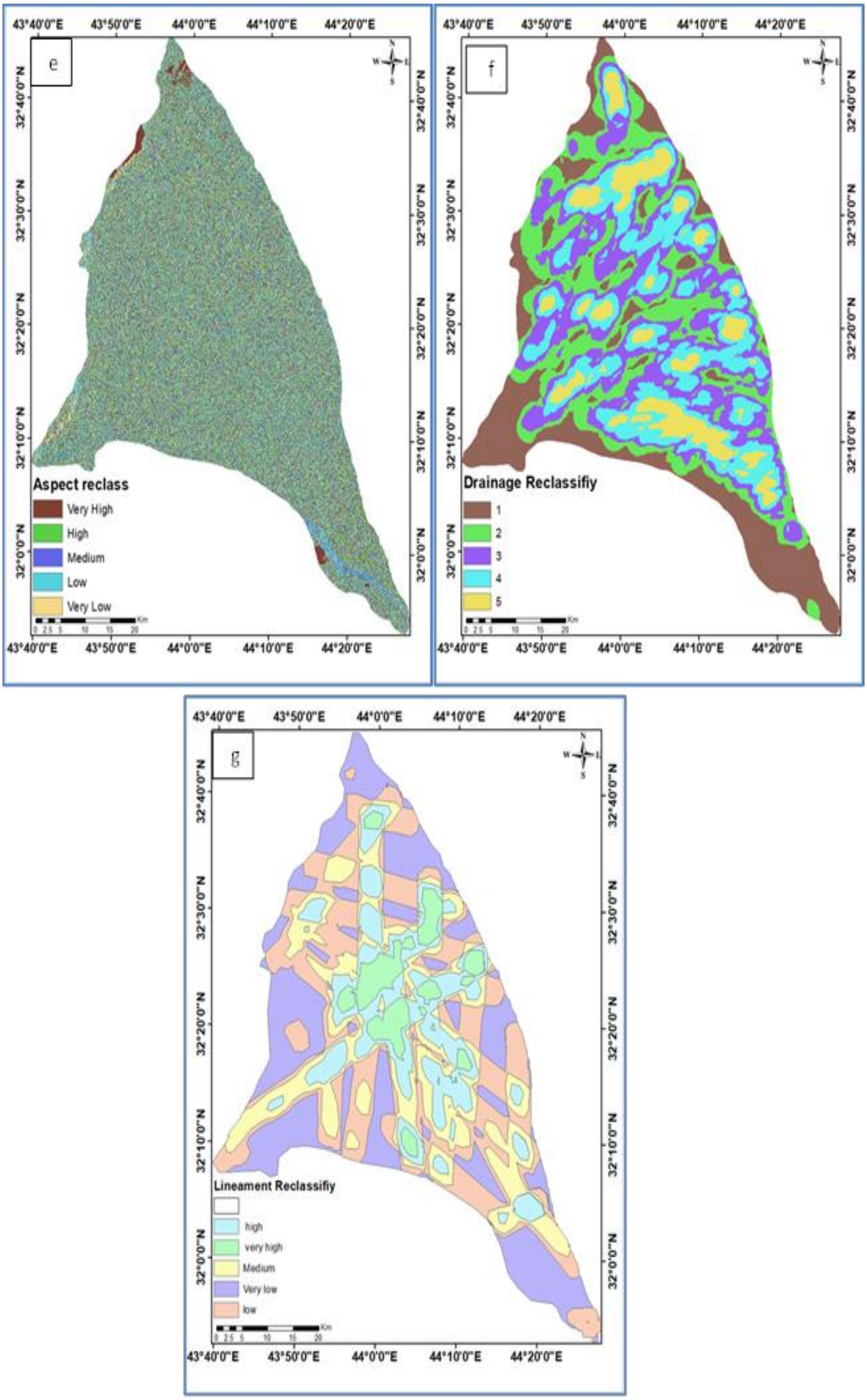


Figure 9: (a, b, c, d, e, f, and g): Reclassify (Geomorphology, Lithology, Slope, Land use, Aspect, Drainage density, and Lineaments density).

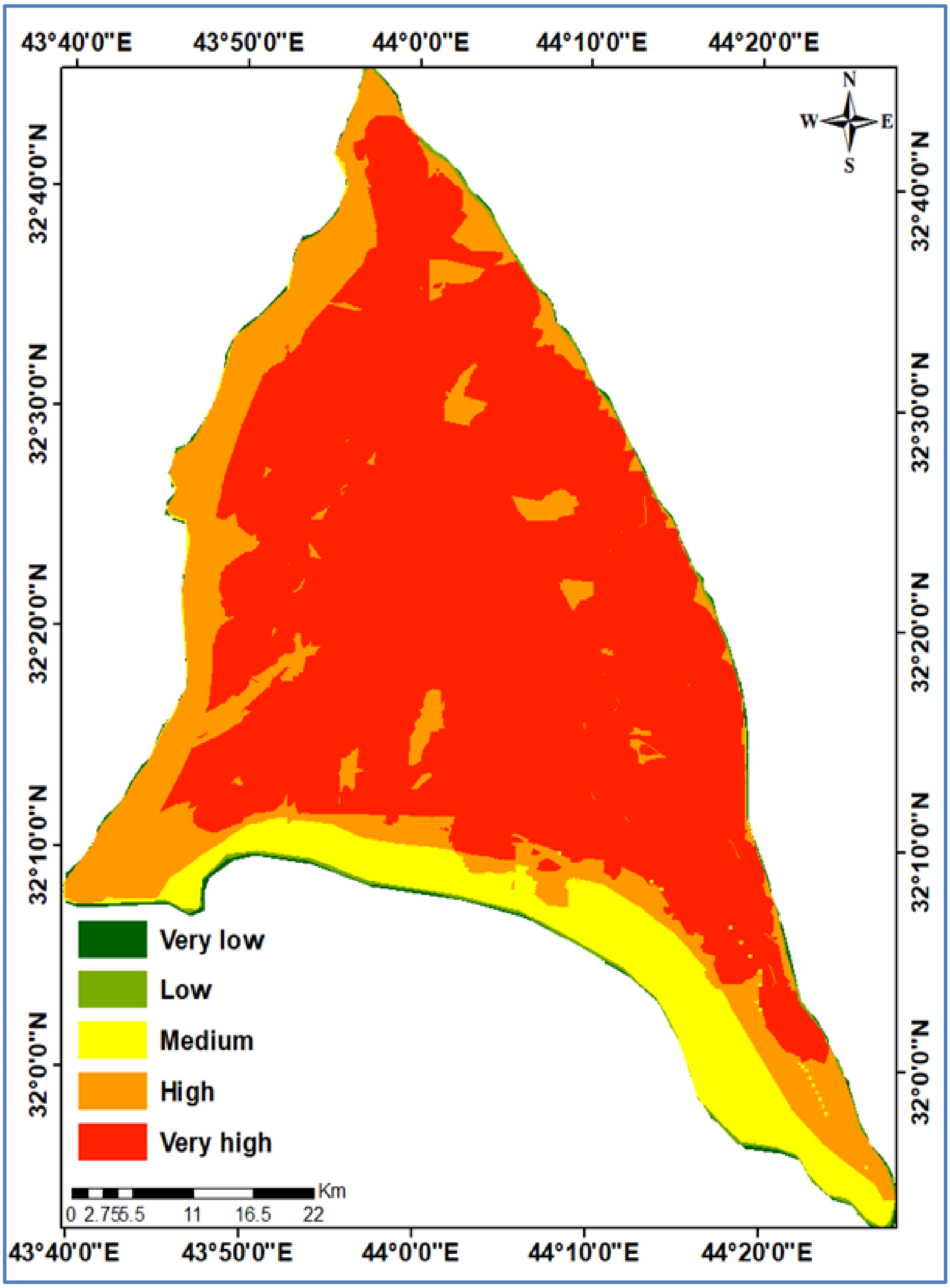


Figure 10: Groundwater potential zone (GWP)

4.2 Groundwater prospecting and validation

By taking into account some variables, including landforms, rock types, slope, land use, drainage density, and the existence of geological cracks, the regions with the greatest potential for groundwater recharge were determined. GIS was used to assess these variables and produce a groundwater potential map. According to the results, the Al Najaf - Karbala alluvial fan has seven categories for groundwater recharge potential: very high, high, moderate, low, very low, poor, and extremely poor. Downstream, on gently sloping alluvial plains, are the places most likely to experience groundwater recharge. This area's drainage concentration contributes to the replenishment of groundwater supplies. There is less opportunity for groundwater recharge from the upstream to the southwest due to the high altitude and steep slopes that hinder water from penetrating the ground. Groundwater recharge means seeping water through the ground, which is called percolation. A grid model can be used to predict groundwater recharge potential zones by quantifying small-scale changes that impact groundwater recharge, such as land use changes or earthquakes. By tracking the flow of water with isotope tracers and comparing the volume of groundwater pumped to the volume of groundwater recharge, the correctness of the model may be confirmed.

Conclusion

A groundwater potential map for the Al Najaf-Karbala basin was produced using remote sensing and GIS technology. The outcome of this study can be used as a reference to plan artificial recharge projects in the future, assuring sustainable groundwater management and use techniques. The AHP method was used to determine each factor's weight and delineate the groundwater potential recharge zone using GIS, data from DEM, and satellite images. Thematic maps including Geomorphology, Lithology, Land use, Slope. Aspect, Drainage density, and Lineaments were used to design the GWPR map. Finally, the Zone of Very High potential includes the center and northeastern sections, making up around 40% of the study area, whereas the Zone of High Potential comprises the remaining 30%. In addition to agricultural land use, these regions are distinguished by their gravelly and sandy soils, which enable higher infiltration rates and encourage groundwater recharging. The Moderate Potential Zone in the fan's center and western regions makes up around 15% of the area. This zone has a moderate groundwater recharge capacity and would need more artificial replenishment. Low Potential Zone makes up only a small percentage (~10%) of the research area and is mostly found in the southwestern and western sectors. A Very Low Potential Zone makes up the remaining 5% and has the least potential for groundwater recharge.

References

[1] A. Fashae, N. Tijani, O. Talabi, I. Adedeji. Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach. Appl Water Sci 4(1):19–38**.** (2014)

[2] A. Lone, G. Jeelani, D. Deshpande, A. Shah. Evaluating the sensitivity of glacier to climate by using stable water isotopes and remote sensing. Environ Earth Sci 76:598. https://doi.org/10.1007/s12665-017-6937-6. (2017)

[3] K. Todd, W. Mays. Groundwater hydrology, 3rd edn. Wiley, New York, p 636. (2005)

[4] S. Foster. Groundwater assessing vulnerability and promoting protection of a threatened resource. In: Proceedings of the 8th Stockholm water symposium, Sweden, pp 79–90. (1998).

[5] G. Tsakiris. Water resources management trends, prospects and limitations. In: Proceedings of the EWRA symposium on water resources management: risks and challenges for the 21st century, 2–4 September 2004, Izmir, pp 1–6. (2004).

[6] K. Nag, P. Ghosh. Delineation of groundwater potential zone in Chhatna Block, Bankura District, West Bengal, India using remote sensing and GIS techniques. Environ Earth Sci 70(5):2115–2127. https://doi.org/10.1007/s12665-012-1713-0. (2013).

[7] D. Pinto, S. Shrestha, S. Babel, S. Ninsawat. Delineation of groundwater potential zones in the Comoro watershed, Timor Leste using GIS, remote sensing and analytic hierarchy process (AHP) technique. Appl Water Sci 7(1):503–519. https://doi.org/10.1007/s13201-015-0270-6. (2017).

[8] I. Jasmin, P. Mallikarjuna. Delineation of groundwater potential zones in Araniar River basin, Tamil Nadu, India: an integrated remote sensing and geographical information system approach. Environ Earth Sci 73(7):3833–3847. (2015).

[9] J. Mallick, K. Singh, H. Al-Wadi, M. Ahmed, A. Rahman, S. Shashtri, S. Mukherjee. Geospatial and geostatistical approach for groundwater potential zone delineation. Hydrol Process 29(3):395–418. https://doi.org/10.1002/hyp.10153. (2015).

[10] G. Bobba, P. Bukata, H. Jerome. Digitally processed satellite data as a tool in detecting potential groundwater fow systems. J Hydrol 131(1–4):25–62. https://doi.org/10.1016/0022-1694(92)90212-E. (1992)

[11] J. Meijerink, A. Schultz, T. Engman. Remote sensing in hydrology and water management. Springer, Berlin, pp 305–325. (2000).

[12] S. Magesh, N. Chandrasekar, P. Soundranayagam. Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu India: a GIS approach. Environ Earth Sci 64:373. https://doi.org/10.1007/ s12665-010-0860-4. (2011).

[13] B. Watkins, C. Lu, G. Hart, C. Daughtry. The current state of precision farming. Food Rev Int 13(2):141–162. (1997).

[14] C. Gogu, G. Carabin, V. Hallet, V. Peters, A. Dassargues. GIS based hydrogeological databases and groundwater modeling. Hydrogel J 9:555–569. https://doi.org/10.1007/s1004 0-001-0167-3. (2001).

[15] W. Gossel, M. Ebraheem, A. Wycisk. Very large scale GIS based groundwater fow model for the Nubian sandstone aquiferin Eastern Sahara (Egypt, northern Sudan and eastern Libya). Hydrogeol J 12(6):698–713. https://doi.org/10.1007/s1004 0-004-0379-4 https://doi.org/10.1007/ s12665-014-3666-y. (2004).

[16] A. Al-Abadi, A. Al-Shamma'a. Groundwater potential mapping of the major aquifer in Northeastern Missan Governorate, Southof Iraq by using analytical hierarchy process and GIS. J Environ Earth Sci 10:125–149. (2014).

[17] R. Ahmed, and H. Sajjad Analyzing factors of groundwater potential and its relation with a population in the Lower Barpani watershed, Assam, India. Natural Resources Research, p. 1 – 13. 2019.

[18] A. Ghalib. "Study the Geomorphology of Najaf Plateau." M.Sc. thesis, University of Baghdad. 1988.

[19] R. Ahemed, and M. Majed. The Alluvial fan of the plateau AL -Najaf, Karbala. Firest volume, number 212. Professor magazine. 2015.

[20] V. Sissakian, F. Mawahib, N. Al-Ansari and S. Knutsso. The Origin of Tar Al-Say'ed and Tar Al-Najaf, Karbala-Najaf Vicinity, Central Iraq. Journal of Civil Engineering and Architecture 9 (2015) 446-459 doi: 10.17265/1934-7359/2015.04.008. 2015.

[21] Z. Jassim and C. Guff. Geology of Iraq. Dolin, Prague and Moravian Museum, Brno. 341pp. 2006.

[22] A. Al-Abadi. A. Handal and Al-Ginamy., 2019. Evaluating the Dibdibba Aquifer Productivity at the Karbala–Najaf Plateau (Central Iraq) Using GIS-Based Tree Machine Learning Algorithms. Natural Resources Research (2019). https://doi.org/10.1007/s11053-019-09561-x.

[23] V. Sissakian, and S. Fouad Geological map of Iraq, Scale 1: 1000 000,. Iraqi Bull. Geol. Min., Vol.10, No.3, p. 43 – 67. 2015.

[24] B. Arkoprovo, J. Adarsa, and S. Prakash, S. Delineation of groundwater potential zones using satellite remote sensing and geographic information system techniques: A case study from Ganjam district, Orissa, India. Research Journal of Recent Sciences, Vol.1, No.9, p 59 – 66. 2012.

[25] O. Ribolzi, J. Patin, M. Bresson, O. Latsachack, and E. Mouche, O. Sengtaheuanghoung, Impact of slope gradient on soil surface features and infiltration on steep slopes in Northern Laos. Geomorphology, Vol.127, No. 1 – 2, p. 53 – 63. (2011).

[26] Suaad Albhadili, Inass Almallah, and Saher Almulla., 2023. Mapping groundwater potential recharge zones of Wadi Al-Batin alluvial fan, using Remote sensing and GIS techniques, southwestern Iraq. RAQI BULLETIN OF GEOLOGY AND MINING (IBGM). https://doi.org/10.59150/ibgm1901a07.

[27] R. Huggett, and J. Cheesman, Topography and the Environment. Prentice Hall, 247pp. (2002).

[28] T. Dar, N. Rai, and A. Bhat, Delineation of potential groundwater recharge zones using analytical hierarchy process (AHP). DOI: 10.1080/24749508.2020.1726562.(2020).