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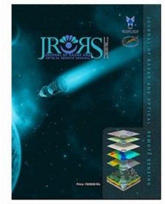

Assessment and Prioritization of Railway Network Accessibility to National Mines for Optimal Freight Transport in GIS

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ABSTRACT

Objective: one of the most effective ways to optimize freight transport from mines to processing plants or for export is through railway transportation. Since the majority of freight transport relies on railways, this study aims to assess the expansion of the railway network for mine-related freight, identify critical areas for future network development to achieve optimal national coverage, and prioritize line development based on two criteria: mineral importance and distance from mines.

Methods: To assess the accessibility of the railway network to mines, the entire territory of Iran was divided into hexagonal tessellations of 2,000 km² each using GIS. The frequency and density of mines within each unit were then calculated. The results show that 49 cells, covering a total of 98,000 km², contain more than six mines. The centroid of each cell was identified, and the distance from each centroid to the nearest railway station was measured.

Results: Among these, the centroids of 11 cells are located more than 50 km from railway stations, and for nine cells, this distance exceeds 100 km. Given the importance of transporting minerals via rail and its contribution to sustainable environmental development, these areas should be considered in future railway network expansion. **Conclusion:** Furthermore, the prioritization of future line development, using the Analytical Hierarchy Process (AHP), revealed that Gerdab, Saqeh, and Ezterari 16 are ranked as the top three priorities near mines.

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Introduction

The development of railway transportation networks undoubtedly plays a fundamental role in infrastructure, balanced, and sustainable development, and holds a high priority. Its significant contribution to the national gross domestic product (GDP) and its prerequisite role in the development of economic sectors, trade, and industry are undeniable (Sabet et al., 2017). Railway transport generally exhibits higher efficiency compared to road transportation, as trains can carry large and heavy loads effectively. Utilizing rail transport can help reduce road traffic. Moreover, rail transport typically results in lower air pollution and fuel consumption compared to road transport, as trains use lighter fuels. Furthermore, railways tend to be safer than road transport, due to the presence of more advanced security systems on rail lines. Therefore, rail transport is recognized as a sustainable, efficient, and effective mode of transportation, offering clear advantages over road transport (Kazemian et al, 2015). The relative benefits of rail transport over road transport for bulk freight and passenger movement, particularly over long distances, include higher speed, significant energy savings, exceptional safety, reduced environmental impact due to lower fossil fuel consumption, higher capacity, and lower transportation costs (Danesh Alaghehband, 2002) for both freight and passengers(Kaymanesh et al., 2016).

Currently, Iran has extensive plans for developing and improving its railway system, which include:

1. Construction of new lines
2. Infrastructure development
3. Modernization
4. International collaboration
5. Speed enhancement: Initiatives are being considered to increase train speeds, improve travel times, and enhance overall railway efficiency (Law of the Seventh Five-Year Development Plan of the Islamic Republic of Iran, 2024-2028).

Although the railway network has experienced considerable development in recent years, covering most populated centers and even mines, there remains a need for optimized coverage. Given the above reasons, the role and significance of railway development in the country are evident. For the optimal future expansion of the railway network, the priorities are populated areas and concentrated mining regions. Therefore, this study aims to examine and assess mine density and railway network accessibility to mines for their optimal coverage using a GIS environment. GIS is a powerful tool that enables the use of programs, algorithms, and information visualization within its environment (Bolouri & Vafaeinejad, 2015; Bolouri et al., 2020). In general, GIS activities utilize an integrated suite of computer software applied to geographic data, which are used for visualization and management of location-based information, spatial relationship analysis, and modeling of spatial processes (Wade & Sommer, 2006).

Materials and Methods

Mineral Coverage Assessment

Iran is among the world's most mineral-rich countries. With 68 types of minerals in 2014, Iran ranked among the top 15 mineral-rich countries (Rahimdel & Noferesti, 2020). The most essential minerals in Iran include coal, metallic minerals, sand and gravel, chemical minerals, and salt. Other major, largely undeveloped reserves include zinc (the largest in the world), copper (ninth globally in 2011), iron (twelfth globally in 2013, according to U.S. Geological Survey reports), uranium (tenth globally), and lead (eleventh globally). Despite having approximately 1% of the world's population, Iran possesses over 7% of the world's total mineral reserves.(Darvishdoost et al., 2022; Frederiksen, 2019; Kinnunen & Kaksonen, 2019).

In 2022, Iran was the world's second-largest producer of direct reduced iron (DRI), gypsum, and strontium (jointly with Spain), accounting for 25.8%, 10.6% (estimated), and 32.3% (estimated) of global production, respectively. Iran ranked fourth in feldspar (7.1%, estimated), sixth in iron ore (iron content) and kaolin (3.0% and 3.9%, respectively), seventh in barite (excluding U.S. production), bentonite, and molybdenum (2.8%, 3.7%, and 1.4%, estimated), and eighth in cement production (1.5%, estimated). In 2022, Iran possessed the world's largest barite and feldspar reserves, the eighth-largest fluorspar reserves, and the eighth-largest iron ore reserves (iron content). Iran's real GDP increased by 3.8% in 2022. Table 1 presents the production volumes of some of Iran's most important minerals in 2022 (Salehi Hikouei, 2025).

Table 1. Gross production of some of the most important minerals in Iran in ۲۰۲۲

Minerals	*Amount mined in ۲۰۲۲*
Bauxite	571680 Tons
Aluminum	225942 Tons
Copper	54000000 Tons
Gold	7000 Kilograms

Iron	78326 Tons
Lead	100000 Tons
Magnesium	77000 Tons
Zinc	300000 Tons
Barite	300000 Tons
Feldspar	2800000 Tons
Gypsum	16000 Thousand tons
Coal	150 Thousand tons
Salt	2700 Tons

Given the existence of abundant and rich mineral resources in Iran and the necessity for optimal transportation of minerals to processing plants, as well as their proper distribution, the development of transportation lines becomes highly significant. In recent years, Iran's railway system has experienced considerable development; however, less attention has been paid to the transportation of minerals from mines in the expansion of rail lines. Most studies conducted in Iran on railway network development have focused on environmental monitoring of railway projects (Environmental Assessment Guidelines for Rail Transport Projects, 2007; Nasiri Badri et al., 2015; Sotoudeh et al., 2007; Papi et al., 2022; Fotohi, 2006). Some research has also addressed railway route planning using GIS (Panchal & Debbarma, 2017; Sahaf et al., 2014). In 2024, Anjum et al. investigated the improvement of accessibility to public transport systems through GIS-based modeling of feeder routes to metro stations (Anjum et al., 2024). Nonetheless, the accessibility of railway lines for mineral freight with an emphasis on sustainable environmental development, as well as the prioritization of future line development based on two criteria—distance and mineral significance—has not yet been systematically assessed. Since the railway network is now extensively distributed across the country, this study considers the entire country as the study area.

Statistics indicate that in 2021 (1400 Iranian calendar), sand and gravel mines constituted the largest number of mines in Iran. The distribution of mines by type and province indicates substantial diversity in both type and quantity, each of which plays a significant role in various economic and industrial sectors. After sand and gravel, decorative stones rank second in terms of mine count

(Iran statistical center, 2025).

Figure 1 illustrates the spatial distribution of Iranian mines.

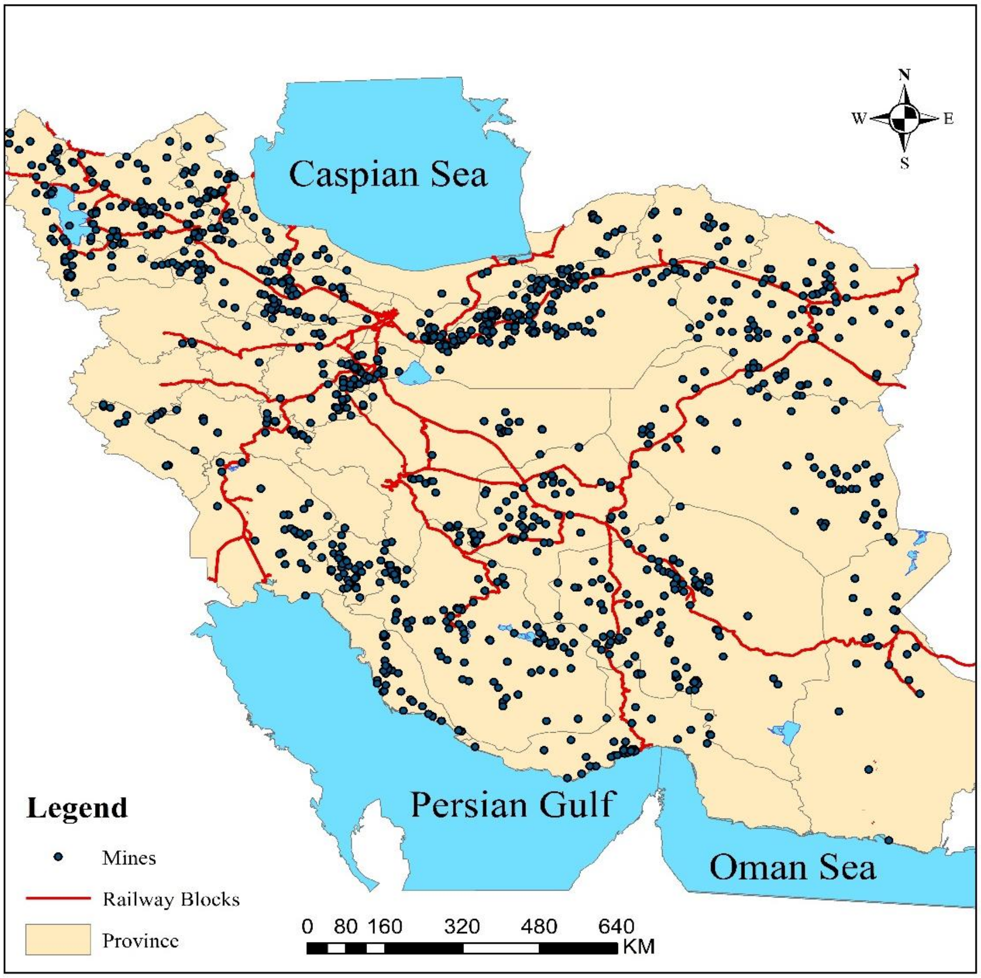

Figure 1. Distribution of Iranian mines

As illustrated in Figure 1, mines are scattered across most regions of the country, and it is certainly not feasible to expand railway lines to all of these locations. Although the railway network already covers some of the highly concentrated mining areas, many regions with dense mineral resources remain without rail access. Optimizing the expansion of rail infrastructure for freight transport could generate significant benefits for both mine owners and the railway system. Figure 2 depicts the diversity of mineral resources in Iran.

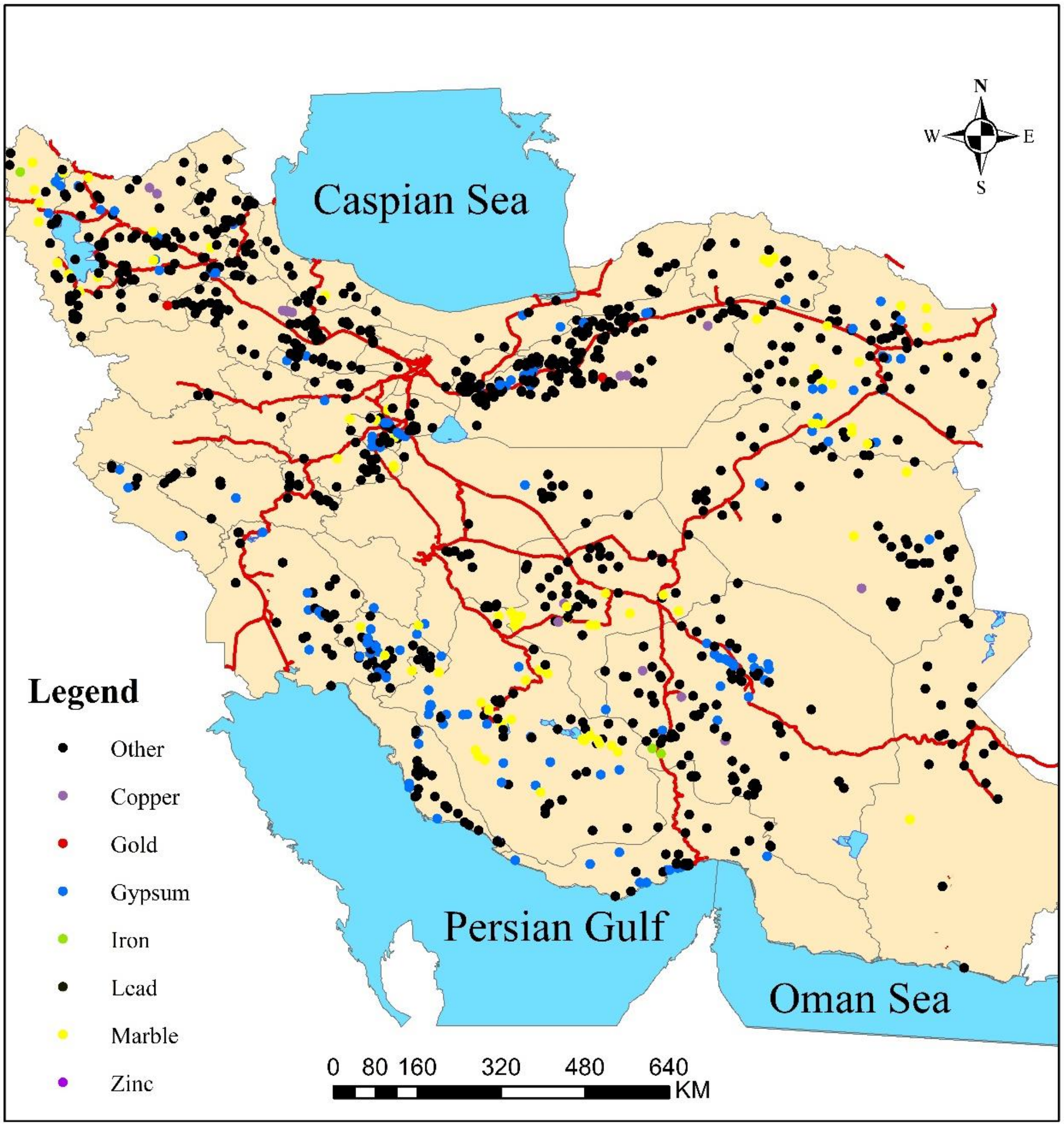

Figure 2. Diversity of mines in Iran

"Figure 3 presents the statistical distribution of the number of mines in Iran in 2021."

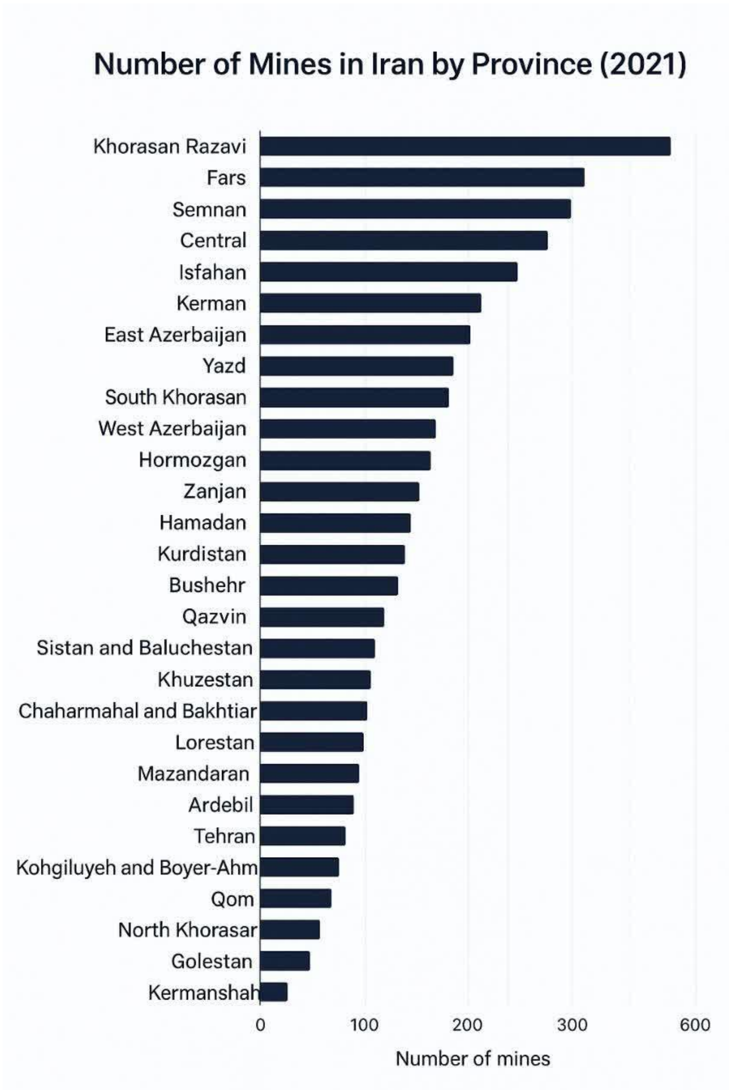

Figure 3. Number of mines in Iran by province

As shown in Figure 3, the number of mines in Iran is considerably high, with Razavi Khorasan Province ranking first, hosting 650 mines (Iran Statistical Center, 2025). Some provinces with the largest number of mines are well covered by railways, while in contrast, despite the presence of valuable mineral resources in several provinces, railway infrastructure has not been adequately developed. As illustrated in Figure 2, the provinces of Ardabil, Kohgiluyeh and Boyer-Ahmad, North Khorasan, Ilam, Bushehr, and Chaharmahal and Bakhtiari either lack railway access altogether or contain only a small portion of the railway network, with limited or no development around mining sites. The present study has therefore been conducted to identify areas with high concentrations of mines and to contribute to the improvement of future railway expansion.Figure 4 presents the statistics on the number of mines by category (Iran statistical center, 2025). As the data indicate, the abundance of valuable mineral resources in Iran highlights the necessity of their proper utilization.

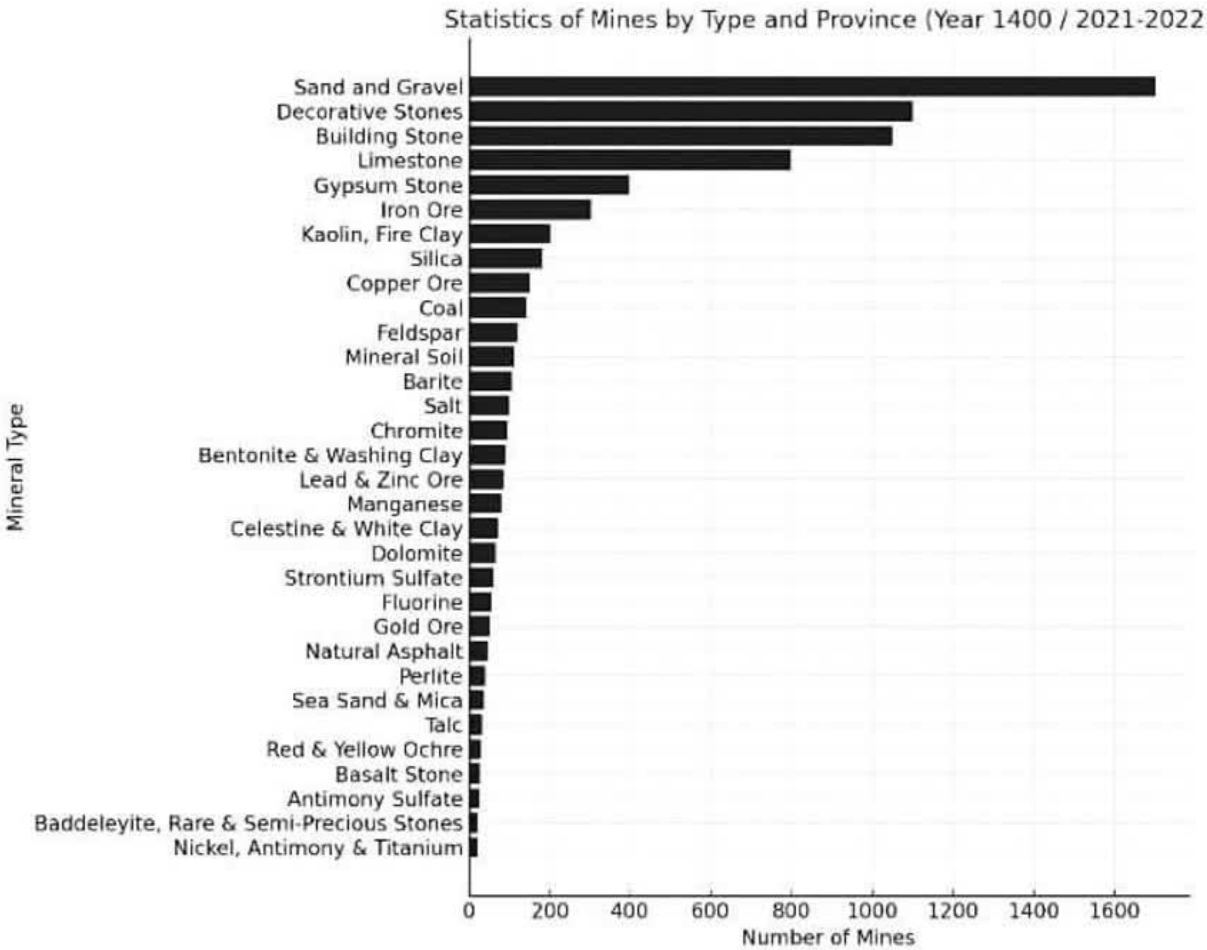

Figure 4. Statistics on the number of mines by mineral type

Figure 5 illustrates the production volume of selected mineral resources (Iran statistical center, 2025).

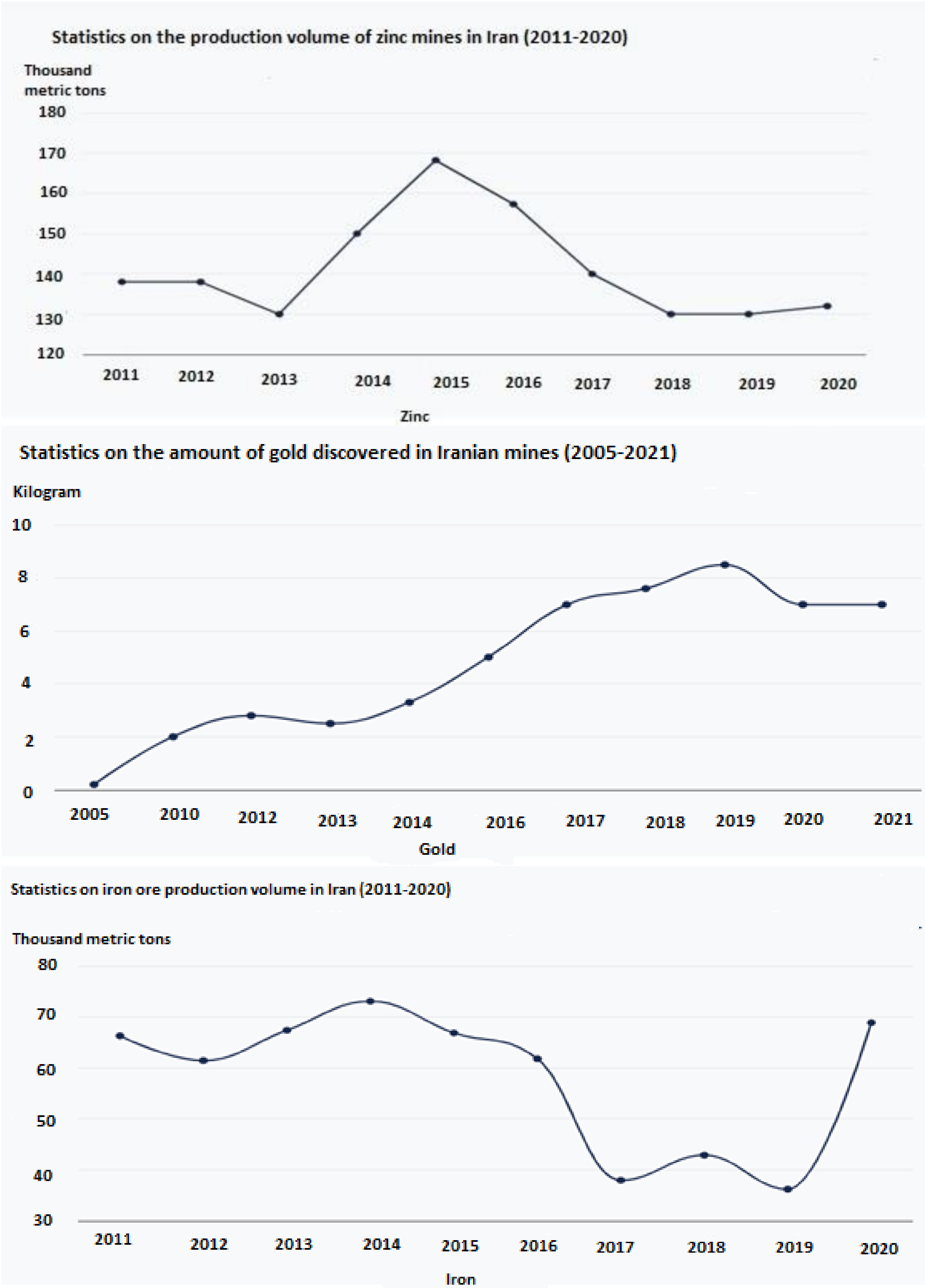

Figure 5. Production volume of some minerals

Million tons of iron by 2020, while global iron production in that year amounted to about three trillion metric tons. Additionally, by 2020, Iran produced around 132,000 metric tons of zinc through its mines, compared with global zinc production of about 12.5 million tons. These statistics clearly highlight the richness of Iran's mineral resources, which further emphasizes the necessity of their optimal utilization and the expansion of railway lines and capacity with an environmentally sustainable development approach.***Research Methodology***

To evaluate the accessibility of Iran's railway network to the country's existing mines, GIS and its valuable analytical tools were employed. It should be noted that all data, including railway lines, provinces, and mines, were obtained from OpenStreetMap (OSM) and supplemented where necessary. First, to examine mine density per unit area, the entire area of Iran was tessellated into hexagons of approximately 25 kilometers per side, each with an area of 2,000 square kilometers. Since the data used in this study are vector-based, all analyses were carried out in vector format. A proximity analysis was then performed to determine the distance of each mine to its corresponding tessellation cell. Subsequently, frequency analysis was applied to calculate mine density within each cell. For cells containing more than six mines, the cell centers were identified. Finally, the Euclidean distance between each railway station and the center of each cell was calculated. In this way, cells located farther from the railway network were identified to guide stakeholders in planning future railway expansions for optimal freight transportation. Based on two criteria—distance) The closer the distance, the greater the preference(and the importance of the mineral resource), according to national guidelines for rail freight transportation. The Analytical Hierarchy Process (AHP) was employed. For the two criteria, weighted equally at 0.5 according to business experts in the railway industry, priorities were assigned for future railway development.

Results

Evaluation of Railway Network Accessibility to National Mines: Analysis of Mine Frequency

To examine mine frequency per unit area, the entire territory of Iran, covering 1,648,195 square kilometers, was divided into tessellation cells of 2,000 square kilometers each. The use of such tessellation facilitates the calculation of mine frequency or density per unit area in vector data. The analysis revealed that defining larger or smaller cell sizes could not adequately represent mine density at the national scale. Subsequently, each mine was assigned to its corresponding tessellation cell, and the frequency of mines within each cell was calculated. Figure 6 illustrates the distribution of mine frequency (or density) across the tessellation cells.

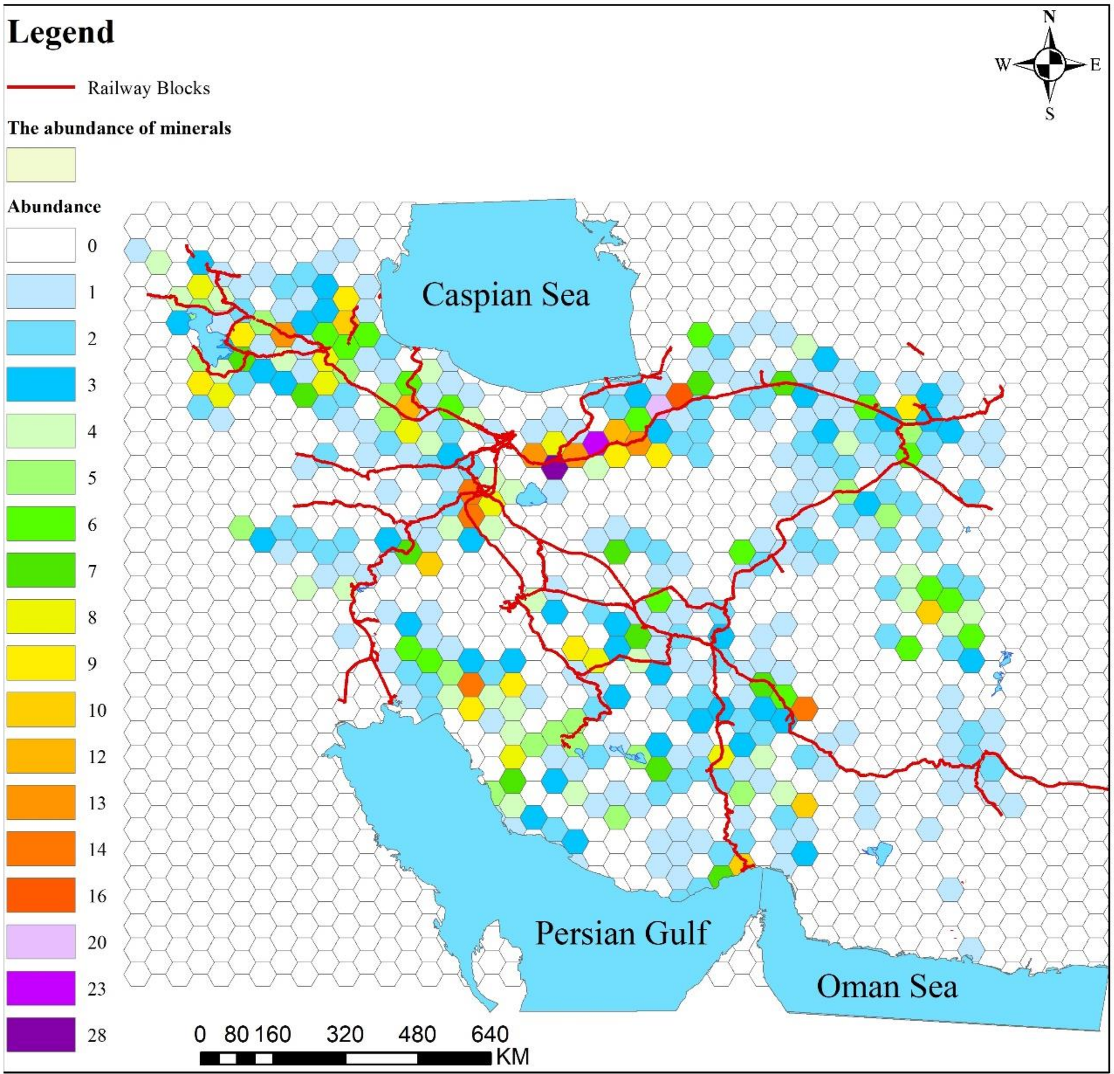

Figure 6. Abundance of mines per cell

As illustrated in Figure 6, most cells with high mine frequency are covered by railway lines; however, a considerable number of mines with significant freight revenue potential are located far from the existing rail network. The analysis shows that 390 cells contain at least one mine, meaning that approximately 780,000 square kilometers of Iran's total 1.648 million square kilometers are endowed with valuable mineral resources. Furthermore, 49 cells, covering an area of 98,000 square kilometers, contain more than six mines. In this stage, the centroid of each cell was calculated in GIS software. Considering that railway expansion is highly costly and requires extensive technical and feasibility studies, railway development may not be viable for individual mines within a cell, unless those mines are of substantial economic importance. Therefore, in this study, the focus of future railway development is limited to cells containing more than six mines. Figure 7 depicts the centroids of cells with more than six mines.

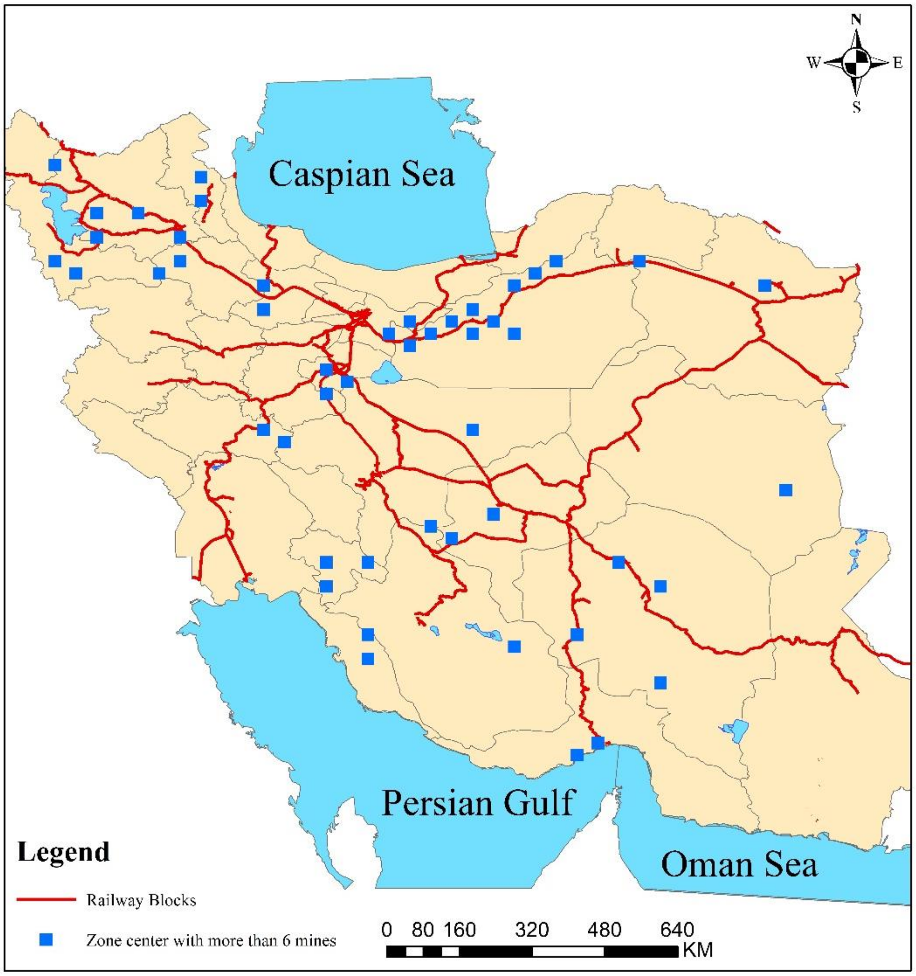

Figure 7. Cell center with more than ٦ mines

As illustrated in Figure 7, railway lines are located at considerable distances from the centroids of some cells.

Figure 8 presents the spatial distribution of railway stations.

Figure ٨. Location of railway stations

In this step, the average distance of each cell to the nearest railway station is calculated. Table 2 presents the distance from the centroid of each cell to the nearest railway station, measured in kilometers.

Table 2. Distance from the center of each cell to the nearest railway station

Mines	*Frequency of mines*	*Cell number*	*Nearest distance (kilometers)*	*Nearest railway station*
Limestone-Porcelain-Gypsum-Travertine-Salt-Sodium Sulfate	8	461	2.388	Ezterari 16
Gypsum-Limestone-Granite-Marble-Manganese-Salt	14	977	3.504	Saqeh
Perlite-Mineral Powder-Travertine-Gypsum-Carcass-Diatomite	13	1256	4.049	Tikme Dash

Limestone-China-China Crystal	7	830	5.178	Azna 1
Rock Carcass-Salt	10	222	7.536	Barko
Granite-Crack stone-Gypsum-Building-Xenolite	8	1210	7.948	Poldokhtar
Barite-Gypsum-Salt-Sodium Sulfate	13	1030	8.437	Deh Namak
Chromite-Magnesium-Salt-Feldspar	7	1184	8.636	Sankhast
Limestone-Gypsum-Marmite-Barite-Sodium Sulfate	8	930	9.781	Shourab
Limestone-Gypsum-Soil	7	607	10.172	Jalalabad
Building Stone-Salt-Crushed Stone-Diatomite	7	1206	10.768	Malekan
Iron-Barite-Coal-Limestone-Silica-Manganese	13	1081	10.895	Gerdab
Marble	8	647	13.559	Abarkouh
Travertine-Coal-Limestone-Gypsum-Carcass-Marmerite-Silica-Sodium Sulfate	20	1130	14.404	Damghan
Industrial Soil-Silica-Kaolin-Alonite	12	1118	15.388	Shirin Sou
Salt-Rock-Sodium Sulfate	13	1028	16.212	Abrdezh
Salt-Gypsum-Sodium Sulfate	28	1029	16.59	Garmsar
Gypsum-Corpse	8	1077	17.306	Simin Dasht
Dolomite-Limestone-Gypsum	23	1079	19.223	Biabanak
Travertine-Ironstone	9	1254	21.899	Azar Shahr
Limestone-Carcass-Malone-Coal	16	1179	22.404	Shahroud
Granite-Gypsum-Iron Ore-Barite-Corpse	9	1142	25.056	Mashhad
Zinc-Barite-Iron Ore-Gypsum-Carcass-Sodium Sulfate	12	1080	25.689	Miandereh 1
Gypsum-Limestone-Marble	14	561	25.717	Kerman
Limestone-Gypsum-Silica-Dolomite	8	1070	27.612	Siahbagh
Industrial Soil-Sodium Sulfate-Salt-Granite	9	1032	27.905	Miandereh 2
Iron Ore-Granite-China	9	1156	28.663	Naqdeh
Travertine-Porcelain-Granite-Copper-Marble	7	697	29.159	Ashkezar
Gypsum-Marble-Carcass-Salt	8	1348	29.989	Zal
Feldspar-Marble-Quartzite-Earth	9	646	31.62	Soghad
Gypsum-Salt	7	1180	33.276	Bastam
Gypsum	7	840	35.968	Viadok
Salt-Industrial Soil-Brasite	8	1162	37.882	Azar Pei
Manganese-Marble-Gypsum-Carcass-Barite-Travertine-Industrial Soil	14	929	41.183	Rahgerd
Granite	8	1157	42.237	Mahabad 2
Gypsum-Carcass-Iron	7	221	44.825	Shahid Rajaee Port
Iron-Gold-Silver Lead-Gravel-Granite-Sodium Sulfate	9	1034	46.672	Haft Khan
Porcelain Stoneware	10	831	47.267	Azna 2
Travertine-Perlite-Concrete-Gypsum	10	1307	64.842	Zawiye1

Travertine-Lead-Zinc-Magnesium-Porcelain-Earthenware	7	1161	79.278	Rejein
Limestone-Corpse-Marble	7	410	92.206	Gol Gohar Mine
Gypsum-Lime-Carcass	9	595	100.034	Izadkhast
Limestone-Gypsum-Carcass-Construction	8	451	101.831	Shiraz1
Porcelain Stoneware – Marble	10	369	109.116	Deh Bakri
Marble-Barite-Limestone-Gravel-Clay	9	1355	110.801	Zawiye2
Gypsum-Carcass-Construction Stone	7	403	134.146	Shiraz2
Gypsum-Carcass- Marble -Salt-Bauxite	14	593	145.515	Mahshahr2
Bauxite-Silica-Gypsum-Carcass	9	545	146.24	Mahshahr2
Industrial Soil-Magnesium	10	759	244.974	Miutek

As shown in Table 2, the shortest distance from a cell centroid is 2.3 km to the Ezterari 16 station, while the longest distance is 244.9 km to the Miutek station. Table 3 presents the statistical information on the distances from each cell to its nearest railway station.

Table 3. Statistical information of the distances of each cell to the nearest station

Number of cells	**49**
Minimum distance (m)	2.387910183
Maximum distance (m)	244.9736878
Total distances (m)	2155.979194
Average distance (m)	43.99957539

Tables 2 and 3 indicate that the distance of the railway network from certain mines is considerable, meaning that the railway currently does not play a significant role in the transportation and optimal movement of these mineral resources. Considering the advantages of rail transport over roadways, this issue should be taken into account by stakeholders in future railway development plans. Naturally, numerous other parameters also influence the expansion of railway lines and the location of stations. Conversely, the proximity of the railway network to some other mines presents an opportunity for near-term development, which could enhance the railway's contribution to efficient freight transport and support environmentally sustainable development. The findings suggest a significant relationship between railway station development based on transit-oriented development principles and increased employment, enhanced transportation efficiency, greater social equity, and environmental sustainability (Mohtadi & Maleki, 2023).

Prioritization for Future Railway Development Using AHP

The Analytical Hierarchy Process (AHP) was used to establish priorities for the development of future railway lines. Two key criteria were considered: the length of the railway lines and the significance of the minerals being transported. Both criteria were assigned the same weight of

0.5, based on expert judgment. Furthermore, according to national guidelines for rail freight transportation, the importance of mineral transport is detailed in Table 4.

Table 4. Degree of importance of minerals

Minerals	*Degree of Importance*
Iron ore	5
Coal	4
Limestone	3
Copper	2
Other bulk cargoes	1

Furthermore, considering the high costs associated with constructing new railway lines, priority for development is given to lines with the shortest distances. Accordingly, based on Table 2, all lines are assigned values ranging from 49 to 1, from the shortest to the longest distance. After forming a pairwise comparison matrix for each criterion, the normalized values, geometric mean, and the overall priority ranking of each station are presented in Table 5.

Table 5. Priority & normalized values of the geometric mean of the two distance & importance criteria

Priority	*Normalized Values Geometric Mean (Importance Criterion)*	*Normalized Values Geometric Mean (Distance Criterion)*	*Station Name*
0.642277	1	0.284554	Gerdab
0.631286	0.351898	0.910674	Saqeh
0.562611	0.125223	1	Ezterari 16
0.545669	0.351898	0.73944	Azna1
0.494816	0.768935	0.220697	Damghan
0.474031	0.125223	0.822838	Tikmeh Dash
0.42883	0.768935	0.088724	Shahroud
0.393495	0.125223	0.661766	Barko
0.38244	0.351898	0.412981	Shorab
0.358582	0.351898	0.365265	Jalalabad
0.35777	0.125223	0.590317	Poldokhtar

0.325195	0.125223	0.525168	Deh Namak
0.313133	0.548497	0.077768	Mashhad
0.29569	0.125223	0.466156	Sankhast
0.294334	0.548497	0.04017	Naqdeh
0.280451	0.548497	0.012405	Shahid Rajaee Port
0.279708	0.548497	0.010919	Haftkhan
0.233643	0.351898	0.115388	Biabank
0.226548	0.351898	0.101198	Azarshahr
0.22391	0.125223	0.322597	Malekan
0.210025	0.351898	0.068152	Miandereh 1
0.205808	0.351898	0.059717	Kerman
0.202111	0.351898	0.052323	Siahbagh
0.187972	0.125223	0.250721	Abarkouh
0.179264	0.351898	0.006629	Golgohar Mine
0.178886	0.351898	0.005873	Izadkhast
0.178556	0.351898	0.005213	Shiraz 1
0.178018	0.351898	0.004137	Zawiye 2
0.159663	0.125223	0.194103	Shirin Sou
0.147905	0.125223	0.170588	Abardezh
0.137524	0.125223	0.149824	Garmsar
0.128369	0.125223	0.131515	Simin Dasht
0.125933	0.216662	0.035203	Ashkezar
0.085534	0.125223	0.045844	Mi&ereh2
0.078039	0.125223	0.030856	Zal
0.076138	0.125223	0.027053	Soghad
0.074474	0.125223	0.023726	Bastam
0.07302	0.125223	0.020817	Viadok
0.071748	0.125223	0.018273	Azar Pei
0.070636	0.125223	0.016049	Rahgerd
0.069664	0.125223	0.014104	Mahabad2
0.067422	0.125223	0.009621	Azna2
0.066855	0.125223	0.008486	Zawiye1
0.066359	0.125223	0.007495	Rejein
0.06493	0.125223	0.004638	Deh Bakri
0.064463	0.125223	0.003702	Shiraz2
0.064275	0.125223	0.003327	Mahshahr1
0.064115	0.125223	0.003006	Mahshahr2

0.06398	0.125223	0.002738	Miutek

Conclusion

Rail transport is considerably more economical and environmentally friendly compared to other modes of transportation. Historically, due to the low speed of trains, it was primarily used for freight movement. However, in recent years, with increased train speeds and improved passenger amenities, rail transport has gained greater popularity. This mode of transport offers numerous relative advantages over road transport. Accordingly, the present study aimed to evaluate the accessibility of Iran's railway network to the country's mines. To assess railway accessibility to mines, the centroid of each cell was first calculated, followed by the computation of its distance to the nearest railway station. Among these, the centroids of 11 cells are located more than 50 km from the nearest railway station, and nine cells are more than 100 km away. Considering the importance of transporting minerals via rail and its contribution to environmentally sustainable development, these areas should be prioritized in future railway expansion plans. The results of the priority assessment for future railway line development using AHP, based on the two criteria of distance and mineral importance, indicate that the railway lines near Gerdab (At a distance of about 11 km), Saqeh (about 3.5 km), and Ezterari 16 (about 2.5 km) stations rank first to third in development priority to mines. Also, the mines near these threeAuthor Contributions

All authors contributed equally to the conceptualization of the article and writing of the original and subsequent drafts.

Conflict of interest

The authors declare no conflict of interest.

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