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An Analysis of the Logistics Hub Location in Isfahan Province Using the Logistics Network Cost Minimization Approach in GIS Environment

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Abstract

One of the important tools to increase supply chain productivity and reduce logistics costs is to establish logistics hubs. Since there is no logistics hub in the central region of Iran, this study was conducted to identify a suitable area for a logistics hub in Isfahan province. In this line, criteria influencing the location of the logistics centers in terms of certain limiters (geological and environmental factors) and cost influencer (measurable factors with quantitative values (compensation criteria)) criteria were identified, and then, the process of locating was implemented in two separate phases. In the first phase, geographical boundaries associated with limiters criteria were excluded from the study scope to identify the potential site options for a logistics hub within the province. In the second phase, the mathematical modeling approach was used to model the total cost of the logistics network. Next, the cost of establishing a logistics hub was calculated in possible sites in terms of cost influencer criteria and using geographic data layers. The findings revealed that the optimum location is in the central part of the province, where all the economic activities are concentrated. Still, rail and road infrastructures and industries are the most influencers in the optimum location.

Highlights

- In this paper, we have investigated the impacts of two types of criteria: certain limiters ones and cost influencer ones.
- The province is divided into 4510 separate blocks of 25 Km^2.
- To identify the possible sites for the logistics hub, the boundaries associated with certain limiters criteria are excluded from the study scope.
- The cost of establishing a logistics hub is calculated in possible sites in terms of cost influencer criteria and using geographic data layers.
- The most optimal (least expensive) area is located in the central part of the province.

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1. Introduction

Improving and promoting logistics efficiency has been proposed as one of the major goals of development in recent years (Xu & Wang, 2017; Lan et al., 2017; Hayaloglu, 2015; Sakamoto, 2012). The World Bank's surveys in 2007, 2010, and 2012 have indicated that among the countries with a similar income per capita, those with better logistics performance have shown increases in the gross domestic product (GDP) and trade by 1.0 and 2.0 %, respectively.

A solution developed since the 1960s, first in the United States and then in Europe, was establishing the logistics centers to enhance the supply chain productivity and reduce the logistics costs, to take a certain place in the supply chain management quickly (Uyanik et al., 2018; Ballis & Mavrotas, 2007). Albeit, there is still no consensus on the concept of logistics hubs in the literature, a logistics hub is broadly referred to the integrated centers where the activities related to collection, storage, transportation, and distribution of the goods from different bases to other destinations are performed (Liu, et al., 2012; Jorgensen, 2007; Barry, 2013). In other words, the centers can lead to reduced total logistics costs (transportation, warehousing, control, and shipment) through creating the focus points, economies of scale, and providing highly specialized services, and thereby creating a competitive advantage for related industries (Fernandes & Rodrigues, 2009; Ding, 2013; Gao & Dong, 2012; Lium et al., 2009; Yang & Meng, 2016; Barry, 2013).

In 2016, Iran - despite its huge potential to become a regional logistics hub - ranked the 96th based on its performance on the logistics performance index (LPI) across 160 countries and the 132th on the enabling trade index (ETI) across 136 countries (The World Bank, 2016). Iran already possesses suitable conditions in terms of the logistics infrastructure separately, but the country's operation has been weak as the general logistics system. Some major reasons are the lack of efficient infrastructure to link various logistics components and to utilize such infrastructures. The Achilles̉ heel of Iran's logistics is creating and developing the different infrastructures (such as logistics centers and multi-modal transportation terminals), which can tie all the separate logistics infrastructures and establish an uninterrupted flow in the country's domestic and foreign trade (Research Center of the Islamic Consultative Assembly of Iran, 2017).

Isfahan province is among the main economic pillars of Iran. Located in the central site of Iranian plateau with an area of approximately 107,019 square km (equivalent to 6.25% of the total area of the country) and a population of approximately 5.5 million (equal to 6.4% of the total population of the country), neighboring nine provinces (Markazi, Qom ,and Semnan provinces to the north, Fars and Kohgiluyeh and Buyer-Ahmad provinces to the south, Yazd and Southern Khorasan provinces to the east, and Lorestan and Chaharmahal and Bakhtiari provinces to the west) (Fig. 1), tying the country's two principal north-south and east-west transport corridors, having railroad access to the Persian Gulf and Oman Sea areas and having gained the country's first rank in transportation of goods (shares of 12.56 percent for cargo types moved from Isfahan as the origin, and 10.13% percent for goods moved to Isfahan as the destination); Isfahan has been suggested as an optimal logistics hub location candidate (Deputy Minister of Transportation of the Ministry of Roads and Urban Development of the Islamic Republic of Iran, 2018).

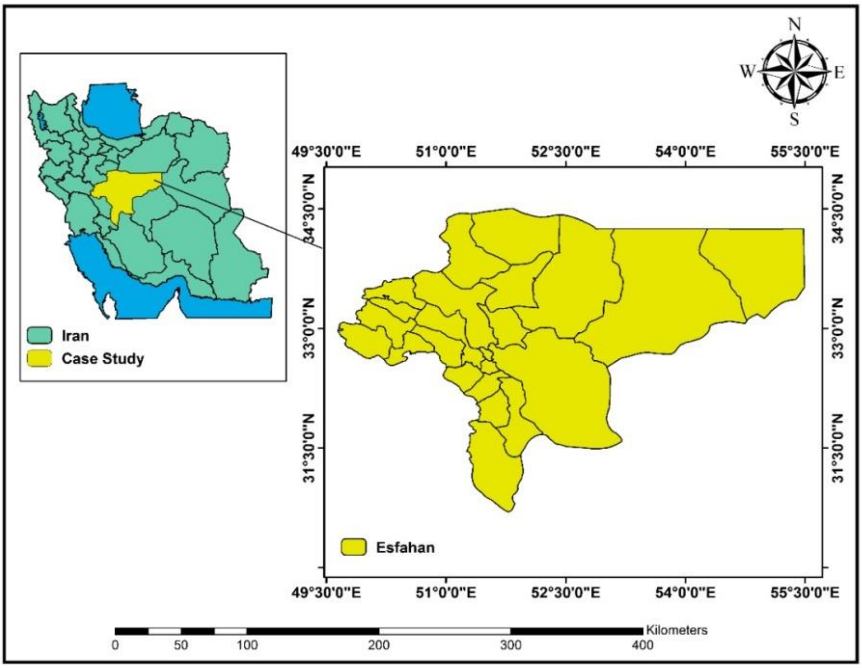

Figure 1. The geographical location of Isfahan province within Iran
***Source**: Research findings*

Since the logistics centers, like most service centers, require selection of the best location and a decision on the proper location holds a significant role for great future achievements, this study was carried out to identify and describe the criteria influencing the process of selecting the logistics hub location to find an optimal site in Isfahan province for construction of the logistics hub aimed at minimizing the costs of the logistics network.

The paper is organized as follows. Section 2 presents existing literature on the location of the logistics centers. Section 3 presents the data sources, limiter and cost influencer criteria, mathematical modeling, and solution method. Identification of the potential site options for construction of the logistics hub and spatial analysis of the production and consumption load flows are discussed in Section 4. Finally, Section 5 presents our conclusions.

2. Literature Review

There are two categories of theories regarding the location of firms and activities; the first deals with locating based on minimization of the costs, and the other tends to locate according to the market condition and structure[1]. Cost-based models include Weber's model with the centrality of transportation costs (inputs and products) (North, 1955); Von Thunen's model of agricultural land use according to the locations of activities from the market (O'Kelly & Bryan, 1996; Fujita et al., 1999); Christaller and Losch's central-place theory focusing on the criteria, such as spatial demand, market penetration area about transportation costs and distance (Fujita et al., 1999; Christaller & Baskin, 1966); the minimum distance sum model where the optimum point has the smallest sum of its distances to other points; the model of the number of direct connections based on which the optimum point has the greatest direct connections to other points; Leonard's model analyzing the tendency of the industries to approximate the consumer market/ raw material sources in terms of values and weights of the products and raw materials, and transportation costs. For proximity-based models, the elements of population and market size are usually considered in determining the advantage of different industries and enterprises.

Previous studies on the location of the logistics centers have indicated that multi-criteria decision-making methods, clustering approaches, economic analyses, and simulation and mathematical optimization methods have been used. Among these, multi-criteria decision-making and mathematical optimization methods are common for locating logistics centers.

Multi-criteria decision-making methods, which are often based on field research and expert opinion, are based on multiple criteria supported by quantitative and qualitative data. Some include the process of locating the establishment of multimodal logistics centers using Single-Valued Neutrosophic (SVNN) Multi-Attributive Border Approximation Area Comparison (MABAC) Model (Pamučar & Božanić, 2019), determining the location of a logistics hub using ELECTRE method in the western Black Sea (Uysal & Yavuz, 2014), specifying the location of the logistics centers in Laos using Analytic Hierarchy Process (AHP) technique (Regmi & Hanaoka, 2012), locating the logistics centers using fuzzy TOPSIS technique (Li et al., 2011), locating the air transport logistics centers using AHP-QFD conceptual model and zero-one goal programming (Tu et al., 2010), locating the global logistics hub using fuzzy AHP technique and SWOT matrix (Lee et al., 2009), locating the logistics centers using fuzzy AHP and two-phase ELECTRE techniques (Ghoseiri & Lessan, 2008).

In the mathematical optimization method, the transportation network is usually considered as a graph consisting of nodes of origin, destination and hub,

[1] In these models, those sites will have an advantage as they are closer to the market under monopolistic conditions, and incur lower costs under competitive conditions. Two well-known models are the product life cycle model and the Hotelling's model.

arms connecting hubs to origins and destinations, and arms connecting hubs to each other. These models optimize various objective functions (often related to economic or financial issues), the most common of which is cost minimization (transportation or total costs). Some include the process of locating the logistics hubs in the Beijing-Tianjin-Hebei region of China through minimizing the transportation costs and using the genetic algorithm (Xin et al., 2019); determining the location of the green logistics parks by minimizing the transportation and environmental costs using the heuristic algorithm (Xu et al., 2018); specifying the location of the logistics centers in Russia using the shortest path method, by maximizing the market share and minimizing the necessary facilities and equipment via the spatial analysis (Kiparisov, 2016); locating an air cargo hub through minimizing the total costs by the mixed-integer linear programming (MILP) method (Oktal & Ozger, 2013); locating the logistics centers through minimizing the transportation costs using the spatial analysis (Gao & Dong, 2012); determining the location of a hub by minimizing the transportation costs via the shortest path approach (Ambrosino & Sciomachen, 2012); specifying the location of the urban logistics hubs through minimizing the transportation costs and maximizing the market share using the genetic algorithm (Skrinjar et al., 2012); locating the logistics centers through minimizing the transportation costs by the center of gravity technique (Liu et al., 2012); locating the logistics centers by minimizing the total costs and using the particle swarm optimization algorithm (Zhi et al., 2010); locating the logistics centers under uncertainty by minimizing the total costs using the stochastic optimization and robust optimization methods (Wang & He, 2009); determining the location of a logistics hub by minimizing the transportation cost using the spatial analysis and the MILP method (Rahimi et al., 2008); and locating the logistics centers through minimizing the total costs by the fuzzy algorithm (Klapita & Sˇvecova´, 2006).

In the present article, one of the most common methods of location in geography has been used, which is widely discussed in urban and regional economics. The advantages and innovations of this article are as follows: 1) one of the most important and main advantages of this study is that almost all the criteria influencing the location of logistics centers have been identified (while only a limited number of these criteria have been used in national and international articles, and no study has used all these criteria in details); 2) One of the main advantages of this study, which is in fact the distinguishing feature of using this method of location in urban and regional economics and geography, is that in geography, for the final integration of data layers, since different criteria do not have the same weight and importance in locating the desired phenomenon (finding a suitable zone for logistics hub establishment here), using qualitative methods such as AHP, the weight of each criterion (data layers) is determined. But in the present paper, based on the location theories presented in the urban and regional economics, a summary of which is provided in the literature review section, the weight of the layers (cost influencer criteria) has been calculated based on the cost quantity related to that criterion (in the form of a mathematical model presented in the article) and finally the weighted data layers have been combined in order to determine the zone with the lowest cost by GIS; 3) Another advantage of the method used in the article is that in this method, all units related to each criterion (for example, all industrial units located in Isfahan Province) are included in the analysis by preparing related data layers and therefore it is possible to measure the economic impact (in this article, cost) of all units related to each criterion; for issues such as logistics centers, which are highly dependent on the geographical location of the manufacturing, consumer and intermediary sectors.

3. Materials & Methods

In this paper, one of the most common methods of location in geography has been used, which is widely discussed in urban and regional economics. In this method, by reviewing the existing experimental literature in the field of successful logistics hubs in the world, the criteria influencing the location of the logistics centers in terms of certain limiters (geological and environmental factors) and cost influencer (measurable factors with quantitative values (compensation criteria)) criteria have been identified. Next, the process of locating is implemented during two stages. In the first phase, to identify the possible sites for the logistics hub within the province, geographical data layers associated with certain limiters criteria (which depicts the spatial distribution of each criterion in the province) are gathered and the respective boundaries are excluded from the study scope. The province is divided into 4510 separate blocks of 25 Km^2 to unify the mapping units under study concerning the used 1: 2500000 scale map of analytical maps.[2] For the second stage, in order to prepare data layers related to cost influencer criteria, first based on the cost-minimization location theories presented in the previous section and according to the general framework of the logistics activities, a mathematical model has been developed including all cost influencer criteria and then accordingly, the cost of establishing logistics centers in each of 1440 blocks (5 * 5 km) located in the possible sites of Isfahan Province was calculated separately according to cost influencer criteria. More precisely, in order to prepare the data layers related to the cost influencer criteria according to the mathematical model specified in Section 4.2, road and rail distances for different origins and destinations of different profiles as well as data layers related to spatial distribution of different production and consumption profiles in the province have been calculated and prepared using GIS. Since different cost influencer criteria do not have the same weight and importance in locating logistics centers, based on the proposed mathematical model, the weight of each criterion (data layer) has been determined based on the cost quantity related to that criterion. Due to many

[2] Through such division, lands of study fields will be equal in terms of the area and dimension, also scale of these areas will not affect the results of analysis.

analysis and computing units (1440 blocks) algebraic and matrix calculations were performed by C^{++} programming software. Finally, in order to identify the appropriate zone for the establishment of logistics hub in Isfahan Province, the weighted data layers (compensation criteria) obtained from GIS were combined. Some best options having the minimum cost are introduced as a logistic hub. The research conceptual model is shown in Figure 2.

As the policies of the Ministry of Roads and Urban Development aim to increase the transferring road loads to the rail network, in mathematical modeling of logistics hub location in this study, we have considered increasing the share of rail freights forwarding in Isfahan province from 21.5 to 30% (according to the Sixth Five-Year National Development Plan). To this end, the tonnage values of load flows transferring from the road routes to the rail network are obtained separately for the industrial, mining, agronomic, and horticultural loads based on the ratio of each measure to the total weighed extra-provincial road loads (all the inputs and outputs of the province). Then, the provinces having the distance of more than 400 km[3] from Isfahan province are identified (15 provinces), and the weight of road loads transferred to the railroads is calculated by separately determining the type and cost of rail freights, considering the share of each province to the total weighed extra-provincial road loads of Isfahan province.

Table 1 shows the primary data layers used in the research process. Raw data of roadś bill of lading blocks are obtained during 2013 - 2018 for 31 commodity groups provided by the Road Maintenance & Transportation Organization of Isfahan. For simplification purposes, all 31 commodity groups are integrated in two different categories; the first consists of the four commodity groups of agronomic and horticultural, livestock, industrial and mining, and the second includes two groups of consumer goods and industrial inputs. The results will be presented based on these two categories.

[3] According to the study by McKinsey on the Indian railways, up to 400 km is economical for road transport, 400 - 700 km for rail transport and over 700 km for maritime transport. If waterway is unavailable in domestic transports, it is generally desirable to use the rail networks more than 400 km.

Table 1. Primary data layers

Data Layer	Type	Source
Environmental protected areas	Vector	Governorate of Isfahan Province
Non-hunting areas	Vector	Governorate of Isfahan Province
Heights and slopes (1)	Raster	National Organization of Geology and Mineral Exploration
Land cover restrictions (high-density pastures, forest areas, groves and shrubs, water levels and swamps)	Vector	National Organization of Geology and Mineral Exploration
Flooded and collapsed plains	Vector	National Organization of Geology and Mineral Exploration
Fault risk areas (5-km fault zone)	Vector	National Organization of Geology and Mineral Exploration
Environmental boundary of cities (2)	Vector	This study
Agronomic and horticultural lands	Vector	Agricultural Jihad Organization of Isfahan Province
Cattle and poultry breeding units	Vector	Agricultural Jihad Organization of Isfahan Province
Industrial units	Vector	Industry, Mine, and Trade Organization of Isfahan Province
Mines	Vector	Industry, Mine, and Trade Organization of Isfahan Province
Urban and rural settlements	Vector	Governorate of Isfahan Province
Freight entry/ exit points	Vector	Road Maintenance and Transportation Organization of Isfahan Province
Cold storages	Vector	Agricultural Jihad Organization of Isfahan Province
Silos	Vector	Agricultural Jihad Organization of Isfahan Province
Warehouses	Vector	Agricultural Jihad Organization of Isfahan Province
Railway network	Vector	Department of Railways of Isfahan Province
Road network (Transit routes and main roads)	Vector	Road Maintenance and Transportation Organization of Isfahan Province
Electricity network	Vector	Electricity Distribution Company of Isfahan Province
Gas supply network	Vector	Gas Distribution Company of Isfahan Province

Note (1): Areas with a slope of more than 20% are not suitable for construction of the logistics centers.
Note (2): Due to the significant pollution of the logistics centers and according to the environmental criteria and standards, establishment of the industrial and production units and activities faces the serious restrictions in Iran for building the logistics centers on a radius of 50 km from Isfahan city and 10 km from other major cities in the province.
Source: Research findings

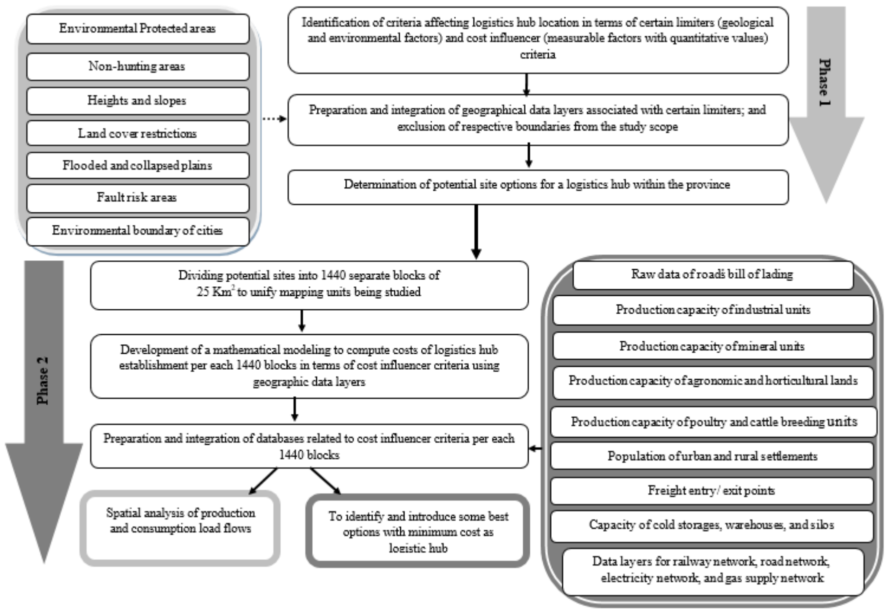

Figure 2. Research conceptual model
Source: *Research findings*

3.1 Certain Limiter Criteria

As the major factors to be considered during the process of selecting the location of the logistics centers, geological and environmental factors indicate the boundaries that have serious restrictions and prohibitions for the establishment of the logistics centers (Xu et al., 2001; Simchi-Levi et al., 2009; Zhang, 2019; Liu, et al., 2012; Pamučar & Božanić, 2019; El-Nakib, 2010; Żak & Węgliński, 2014; Awasthi et al., 2011; Rao et al., 2015; Vieira & Luna, 2016) (Fig. 3).

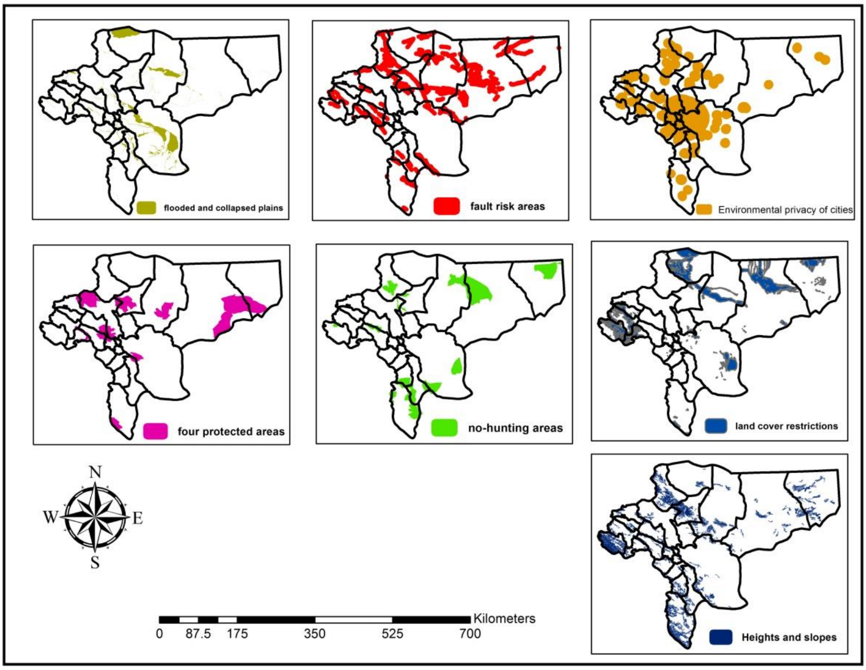

Figure 3. Data layers of geological and environmental factors
Source: *Research findings*

3.2 Cost Influencer Criteria and Mathematical Modeling

Considering the present approach for minimizing the costs of the logistics network to locate and determine an appropriate site for establishment of the logistics hub, the structure of these costs (the cost influencer criteria) are classified into three general categories:

1) Factors Influencing the Cost of Transportation (Inputs (C(1)) and Outputs (C(2))):

The production cargo should be transported from different manufacturing facilities (including industrial units, agronomic and horticultural lands, poultry and cattle breeding units, mines, and provincial freight entry points) to the logistics center, aggregated there, then sent to cargo receptors (including urban and rural settlements, industrial units as the consumers of mineral products as well as the inputs for some industrial, agronomic, horticultural, and livestock products and provincial freight exit points (forwarding outside the provinces)) and distributed there. So, the location of the logistics centers should be determined so that, the total cost of transportation network will be minimal (Xu et al., 2001; Zhang, 2019; Pamučar & Božanić, 2019; Liu et al., 2012; Rao et al., 2015; Shiau et al., 2011; Regmi & Hanaoka, 2012; Vieira & Luna, 2016).

2) Factors Influencing the Cost of Using the Existing Logistics Capabilities (the cost of trasporting different products from the logistics center to warehouses, silos and cold stores and vice versa) (C (3)):

The inclusion of these cost items for the problem of the logistics center location assumes that the establishment makes maximum use of the available logistics facilities (Xu et al., 2001; Liu et al., 2012; Zhang, 2019; Pamučar & Božanić, 2019; Rao et al., 2015; Regmi & Hanaoka, 2012).

3) Factors Influencing the Construction Cost (including fixed cost of establishment and maintenance of railways and roads; and fixed cost of establishment and maintenance of electricity and gas supply network) (C(4)):

They include the distance from the road (transit and main roads); distance from the rail network; distance from the electricity utilities; and distance from the gas networks (Zhang, 2019; Xu et al., 2001; Rao et al., 2015; Liu et al., 2012; Pamučar & Božanić, 2019).

Now, after describing the cost structure of the location model, the structure of the mathematical model of the location of the logistics hub of the province is presented. In this model, the analysis and calculation unit is the same as 5 * 5 km blocks in the province. In order to calculate the cost of establishing a logistics hub in each block, it is assumed that the logistics hub is located in the center of that block and the cost of establishing a logistics hub in each of 1440 blocks located within the possible sites of the province according to the above cost structure is calculated using the mathematical model presented below. The best option for establishing a logistics hub is the block with the lowest cost:[4]

$$MinZ_i = C_i(1) + C_i(2) + C_i(3) + C_i(4) \tag{1}$$

$$C_i(1) = c_{AG}\sum_{j=1}^{a} d_{ij}AG_j + c_{CO}\sum_{j=1}^{o} d_{ij}CO_j + c_{AG}\sum_{k=1}^{l} d_{ik}AGO_k + c_{CO}\sum_{k=1}^{l} d_{ik}COO_k + c_{MI}\sum_{k=1}^{l} d_{ik}MIO_k + \tag{1-1}$$

$$+ c_{IN}\sum_{k=1}^{l} d_{ik}INO_k + c_{IN}\sum_{j=1}^{n} d_{ij}IN_j + c_{MI}\sum_{j=1}^{m} d_{ij}MI_j + c_{INR}\sum_{r=1}^{t} INRI_r d_{ir} + c_{MIR}\sum_{r=1}^{t} MIRI_r d_{ir} + c_{AGR}\sum_{r=1}^{t} AGRI_r d_{ir}$$

$$C_i(2) = c_{AG}\sum_{j=1}^{m} d_{ij}AGC_j + c_{CO}\sum_{j=1}^{n} d_{ij}COC_j + c_{IN}\sum_{j=1}^{q} d_{ij}INC_j + c_{AG}\sum_{j=1}^{v} d_{ij}AGF_j + c_{CO}\sum_{j=1}^{y} d_{ij}COF_j + \tag{2-1}$$

$$+ c_{IM}\sum_{j=1}^{u} d_{ij}INF_j + c_{MI}\sum_{k=1}^{l} d_{ik}OMI_k + c_{IN}\sum_{k=1}^{l} d_{ik}OIN_k + c_{AG}\sum_{k=1}^{l} d_{ik}OAG_k + c_{CO}\sum_{k=1}^{l} d_{ik}OCO_k +$$

$$+ c_{INR}\sum_{r=1}^{t} INRO_r d_{ir} + c_{MIR}\sum_{r=1}^{t} MIRO_r d_{ir} + c_{AGR}\sum_{r=1}^{t} AGRO_r d_{ir}$$

$$C_i(3) = c_{GO}\sum_{g=1}^{r} d_{ig}R_g + c_{AG}\sum_{h=1}^{s} d_{ih}S_h + c\sum_{p=1}^{w} d_{ip}W_p \tag{3-1}$$

$$C_i(4) = c_{RO}d_{iro} + c_{RA}d_{ira} + c_E d_{ie} + c_G d_{igas} \tag{4-1}$$

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[4] The used counters, parameters, and variables are defined in the appendix.

4. Results & Discussion

4.1 Identification of the Potential Site Options for Construction of the Logistics Hub

Fig. 4 (right) shows the geographical boundaries associated with each certain limiter criteria, while Fig. 4 (left) shows the potential and non-potential site options possible for construction of the logistics hub within the Isfahan province. Potential sites are marked in yellow and non-potential options are marked in gray.

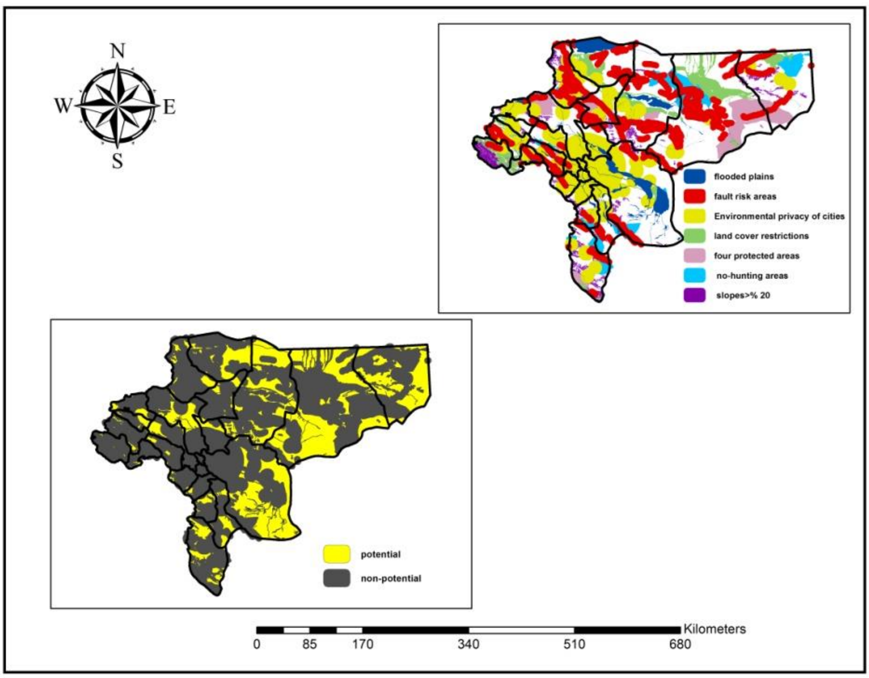

Figure 4. Potential and non-potential site options in Isfahan province for the establishment of the logistics hub
Source: *Research findings*

4.2 Spatial Analysis of the Production and Consumption Load Flows

4.2.1 Loads of the Industrial and Mineral Products

Fig. 5 (right) presents the spatial distribution for the tonnage of industrial (production) cargo exiting from the provincial blocks (intra and extra-provincial), and Fig. 5 (left) shows the spatial distribution for the tonnage of mineral (production) cargo exiting from the provincial blocks (intra-and extra-provincial). To calculate industrial cargo tonnage exiting from the provincial blocks, industrial units located in each block are first identified under the Arc GIS environment. Their total operating capacity is calculated. Then, an industrial cargo tonnage exiting from each county about the total operating capacity of industrial units in every block is assigned to all the blocks located in the same county. Similarly, mineral units located in each block are first identified under the Arc GIS environment. Their total production capacity is calculated to obtain the mineral cargo tonnage exiting from the provincial blocks. Next, a mineral cargo tonnage exiting from each county about the total production capacity of mineral units in every block is assigned to all the blocks located in the same county.

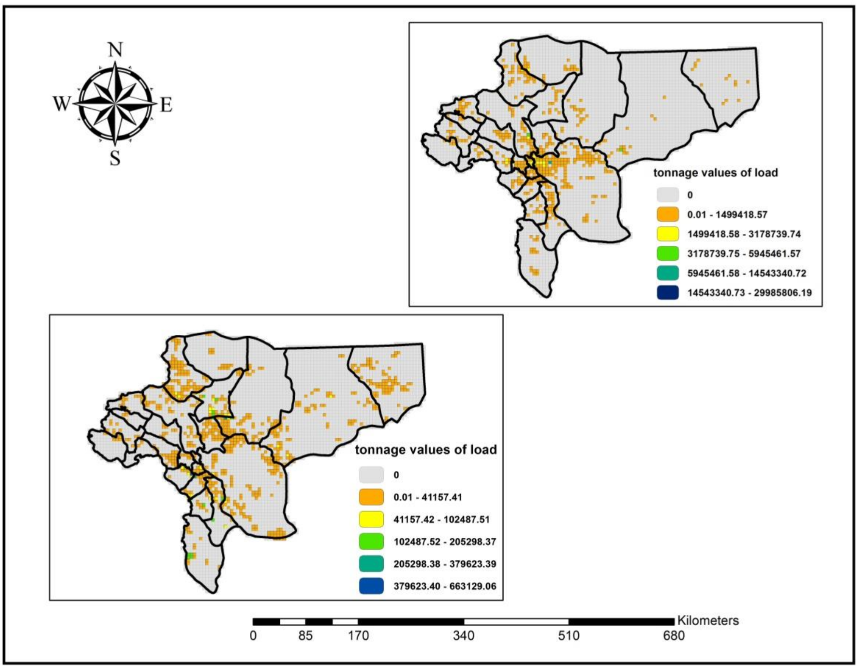

Figure 5. Spatial distribution of the exiting industrial and mineral cargo tonnage across Isfahan province
***Source:** Research findings*

Since almost all the industrial activities are located in the western half of the province (Management and Planning Organization of Isfahan Province, 2017; Governorate of Isfahan Province, 2013), the highest exiting industrial cargo tonnage belongs to the same half (Fig. 5- left). In this half, two dense regions of industrial activity can be mentioned. The first dense region is located in the north of the province and around Kashan, Aran and bidgol and continues with a small density towards Ardestan in the central region to the east of the province. The second dense region of the province, which of course is the largest and most important, is the dense central region that is located around Isfahan. Industrial density in this region also moves to the east and makes the regions around Koohpayeh a place for scattered industrial units. However, unlike the industrial sector, mines are more homogeneously scattered in the province, as shown in Fig. 5 (right).

4.2.2 Agricultural Production Load

Fig. 6 (right) presents the spatial distribution for the tonnage of agronomic and horticultural (production) cargo exiting from the provincial blocks (intra and extra-provincial) and Fig. 6 (left) shows the spatial distribution for the tonnage of livestock (production) cargo exiting from the provincial blocks (intra and extra-provincial). The total area of agronomic and horticultural lands located in each block is first computed under the Arc GIS environment to calculate the agronomic and horticultural cargo tonnage exiting from the provincial blocks and agronomic and horticultural cargo tonnage exiting from each county to the total land area of every block is assigned to all the blocks located at the same county. Similarly, poultry and cattle breeding units located in each block are first identified under the Arc GIS environment. Their total operating capacity is calculated to obtain the livestock cargo tonnage exiting from the provincial blocks. Next, a livestock cargo tonnage exiting from each county about the total operating capacity of poultry and cattle breeding units in every block is assigned to all the blocks located in the same county.

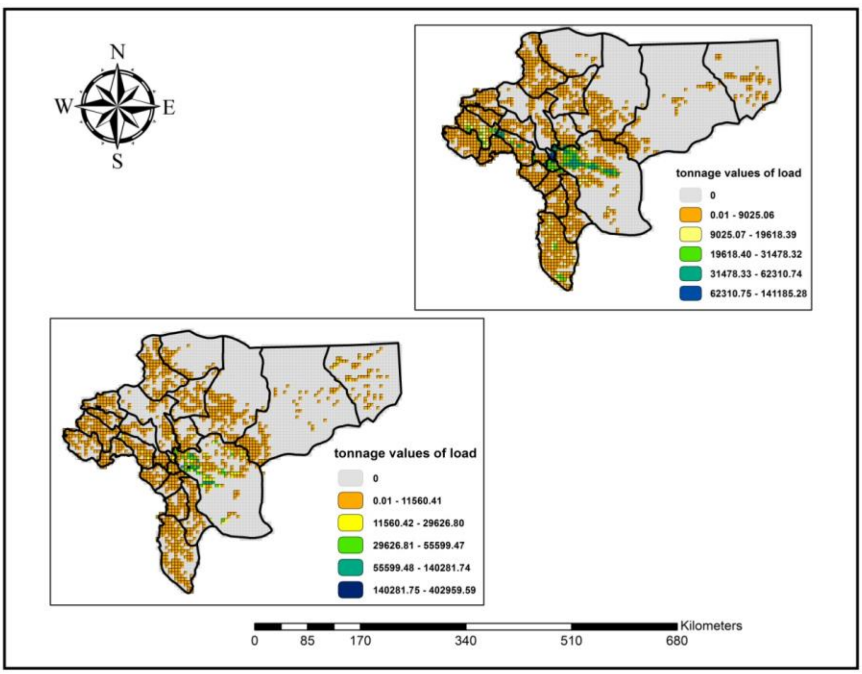

Figure 6. Spatial distribution of the exiting agricultural cargo tonnage across Isfahan province
***Source:** Research findings*

Since almost all the agricultural activities are located in the western half of the province (Management and Planning Organization of Isfahan Province, 2017; Governorate of Isfahan Province, 2013), the highest exiting agricultural (production) cargo tonnage belongs to the same half. As shown in Fig. 6, In this half, three dense regions of agricultural activity can be mentioned. First, the dense region of the west, which is located near Golpayegan, Khansar, Fereydunshahr and Daran. Due to its relatively high precipitation, this region is also the location of a limited part of the province's rainfed agriculture. The second dense region located in the center of the province is the largest dense agricultural region located around the city of Isfahan. The third region is located in the south of the province and around Semirom and south of Shahreza, which due to the desired climatic conditions, part of the rainfed agricultural lands of the province is also located in this region. Also, due to the mountainous nature of this region, its agricultural lands, unlike the dense central region, are less integrated and mainly scattered.

4.2.3 Industrial and Mineral Consumed/ Input Cargo

Fig. 7 (left) presents the spatial distribution for the cargo tonnage of industrial consumption (consumed by the urban and rural settlements) entering the provincial blocks (intra and extra-provincial). Fig. 7 (right) shows the spatial distribution for the cargo tonnage of industrial and mineral inputs (used by the industrial units except for the agricultural transformative and complementary industries) entering the provincial blocks (intra and extra-provincial). All the rural and urban settlements located in each block are first identified under the Arc GIS environment. Their total population is calculated to calculate the consumed industrial cargo tonnage entering the provincial blocks. Then, the consumed industrial cargo tonnage entering each county in relation to the total rural and urban settlements population for every block is assigned to all the blocks located in the same county. Similarly, industrial units (excluding agricultural transformative and complementary industries) located in each block are first identified under the Arc GIS environment. Their total operating capacity is calculated to obtain the cargo tonnage of industrial and mineral inputs entering the provincial blocks. Next, the cargo tonnage of industrial and mineral inputs entering each county about the total operating capacity of industrial units of every block is assigned to all the blocks located in the same county.

Since almost all the industrial activities are located in the western half of the province, and the establishment of rural and urban settlements is significantly higher in the western half compared to the eastern half (Management and Planning Organization of Isfahan Province, 2017; Governorate of Isfahan Province, 2013), the highest entering industrial and mineral cargo tonnage belongs to the same half, as shown in Fig. 7.

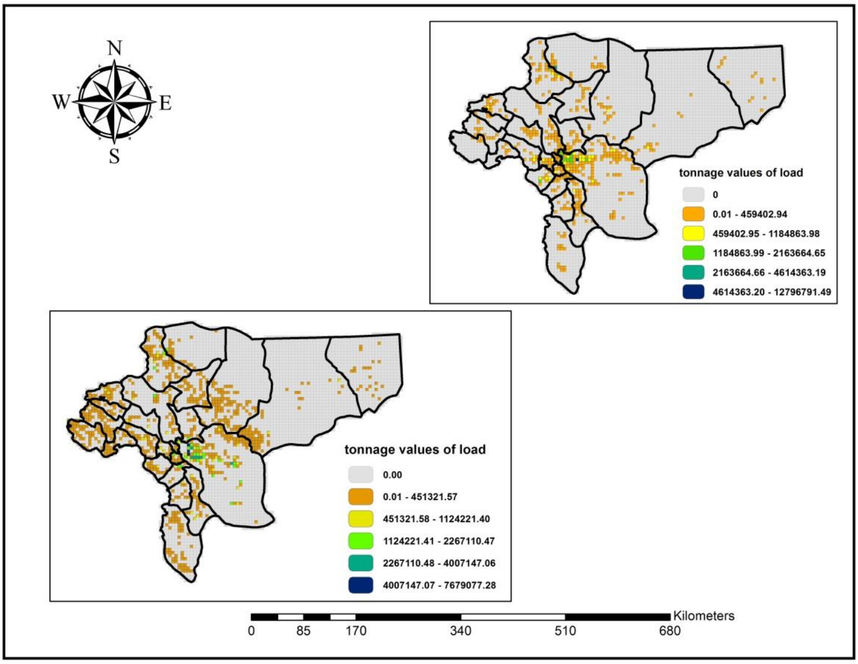

Figure 7. Spatial distribution of the entering cargo tonnage of industrial and mineral (consumed and inputs) products across Isfahan province

Source: *Research findings*

4.2.4 Agricultural Consumed/ Input Cargo

4.2.4.1 Agricultural Cargo Consumed by the Rural/Urban Settlements

Fig. 8 (right) presents the spatial distribution for the cargo tonnage of agronomic and horticultural consumption entering the provincial blocks (intra and extra-provincial) and Fig. 8 (left) shows the spatial distribution for the cargo tonnage of livestock consumption entering the provincial blocks (intra and extra-provincial). For calculating the entering cargo tonnage of agronomic, horticultural, and livestock consumption, 60% of agronomic, horticultural, and livestock cargo tonnage entering each county about the total population of urban and rural settlements of every block is respectively assigned to all the blocks located at the same county. Since almost all the population is settled in the western half of the province (Management and Planning Organization of Isfahan Province, 2017; Governorate of Isfahan Province, 2013), almost total consumption of agricultural products belongs to the same half. As shown in Fig. 8, in this half, three dense residential regions with significant spatial adaptation to the dense industrial and agricultural regions of the province can be mentioned. The first region, which of course is the largest and most important, is the central region of the province, which is located around the city of Isfahan and has a very dense residential system. The second region is located near Golpayegan, Khansar, Fereydunshahr and Daran and the third region is located in the north of the province and around Kashan and Aran and Bidgol and continues with a small density towards Ardestan in the central region to the east of the province.

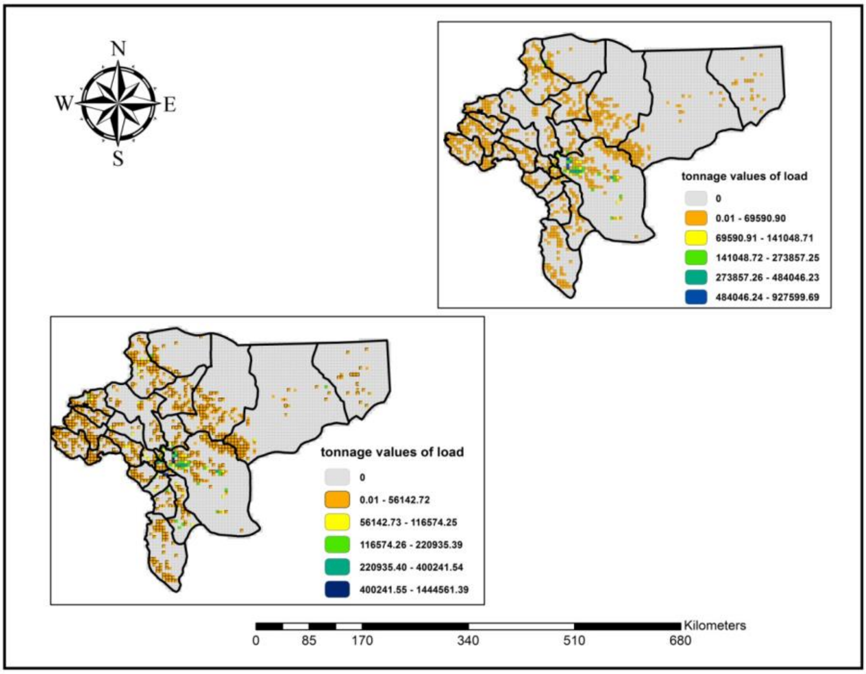

Figure 8. Spatial distribution of the entering cargo tonnage of agricultural consumption across Isfahan province
Source: *Research findings*

4.2.4.2 Cargo of Agricultural Inputs Used by the Transformative and Complementary Industries

Fig. 9 (left) shows the spatial distribution for the cargo tonnage of agronomic and horticultural inputs (used by the agronomic and horticultural transformative and complementary industries) entering the provincial blocks (intra and extra-provincial), and Fig. 9 (right) shows the spatial distribution for the cargo tonnage of livestock inputs (consumed by the livestock transformative and complementary industries) entering the provincial blocks (intra-and extra-provincial). To calculate the entering cargo tonnage of agronomic and horticultural inputs, all the agronomic and horticultural transformative and complementary industries located in each block are first identified under the Arc GIS environment. Their total operating capacity is calculated. Then, 40% of agronomic and horticultural cargo tonnage entering each county about the total operating capacity of relevant industries of every block is respectively assigned to all the blocks located at the same county[5]. Similarly, all the livestock transformative and complementary industries located in each block are first identified. Their total operating capacity is calculated to obtain the cargo tonnage of livestock inputs entering the provincial blocks. Then, 40% of livestock cargo tonnage entering each county about the total operating capacity of relevant industries of every block is respectively assigned to all the blocks located at the same county.

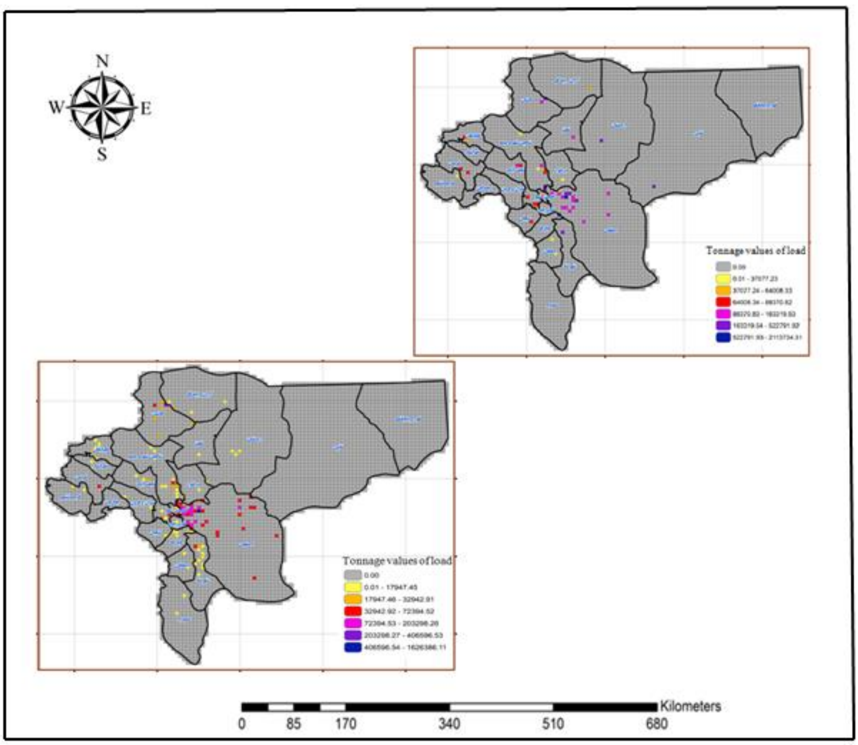

Figure 9. Spatial distribution of the entering cargo tonnage of agricultural inputs across Isfahan province
Source: *Research findings*

Since almost all the transformative and complementary industrial activities are located in the western half of the province (Management and Planning Organization of Isfahan Province, 2017; Governorate of Isfahan Province, 2013), the highest cargo tonnage of agricultural inputs belongs to the same half as shown in Fig. 9.

[5] According to the statistics published by the Agricultural Jihad Organization of Isfahan province, only about 40% of the province's agricultural products are processed annually because of the lack of transformative and complementary industries in the province.

5. Conclusions

One of the important tools to increase supply chain productivity and reduce logistics costs is to establish logistics hubs. Since there is no logistics hub in the central region of Iran, this study was conducted to identify a suitable area for a logistics hub in Isfahan province. In this line, criteria influencing the selection of locations for logistics centers (cost influencers and limiters) were identified, and then, the process of locating was implemented in two separate phases. In the first phase, geographical boundaries associated with limiters criteria were excluded from the study scope to identify the potential site options for a logistics hub within the province. At the second stage, according to the general framework of logistics activities, first the agricultural, horticultural, livestock, industrial and mineral load flows (production and consumption) in the province were *spatially* analyzed and then based on cost-minimization location theories a mathematical model was developed, the cost of establishing a logistics hub in each of 1440 blocks located within the possible sites was calculated according to cost influencers criteria, then GIS provided data layers related to each of these criteria and finally, all data layers were combined.

Fig. 10 shows the final integrated layer based on which the most optimal (least expensive) blocks for establishing a logistics hub are marked in pink. According to Fig.10, when a county takes more distance from the center of the province towards the borders, its advantages will be decreased because it will move away from the manufacturing and cargo receptor centers, which increases the costs of aggregating and distributing the loads. Moreover, since the core of major economic activities (including industrial, agronomic, horticultural, and livestock) is located in the central region of the province, especially in the city of Isfahan; it is expected that the proximity to the city of Isfahan enhances the desired options for hub establishment. This reduces tangible costs. However, intangible social costs are incurred. Therefore, providing the protection radius according to the upstream documents, especially the Isfahan land use planning document, leads to transforming the potential site options into the environmental radius environment of the Isfahan urban complex. As the major transportation routes are located in the north extending to the east, the best option offered for constructing the logistics hub is the northeast region of this environmental radius. At the same time, its advantage is reduced by extending to the east. Compared to the eastern zone of Isfahan, the northeastern zone is more efficient in having access to the western region of Isfahan through freeways, in addition to having proximity to the road and rail networks. This can lead to reduced delivery costs from the north and south to the western region of Isfahan. Blocks between the railway lines (red line) and the east Isfahan Freeway, linking to the Isfahan-Kashan Freeway, are the best options for constructing a logistics hub. Furthermore, there is no problem related to the pollution in the east of Isfahan province due to the climate of this region.

The study results showed the capability of GIS to model and help to locate logistics centers using different geological, environmental and economic criteria.

For future research, according to planning document of the country's logistics centers, the establishment of a logistics hub in addition to Isfahan Province has been suggested in 13 other regions[6], and the logistics hub in the other proposed provinces can be located using mixed integer linear programming (MILP) model or simply integer programming. Another case that can be mentioned for future research is the location of these centers using Hub and Spoke model for transportation using spatial analysis or as a multi-objective mixed integer linear programming model (MOMILP) model that the objective functions can minimize transportation and environmental costs.

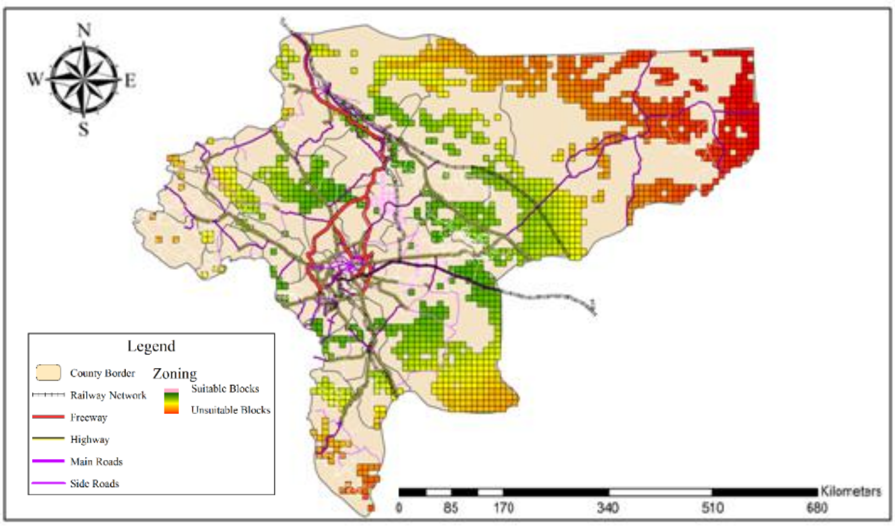

Figure 10. The optimal site for construction of the logistics hub in Isfahan province

Source: *Research findings*

Author Contributions

Supervision: B.S. Conceptualization, methodology, validation, formal analysis, resources, writing—original draft preparation, writing—review and editing: all authors.

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Conflicts of Interest

The authors declare no conflict of interest.

[6] Yazd, Mashhad, Tabriz, Amirabad port, Sirjan, Shiraz, Qom, Zahedan, Qazvin, Kermanshah, Andimeshk, Bushehr and Jask (it should be noted that the zoning used in this document is slightly different from conventional provincial zoning in the country) (Deputy Minister of Transportation of the Ministry of Roads and Urban Development of the Islamic Republic of Iran, 2018).

Data Availability Statement

The data used in the study were collected by referring to different governmental organizations.

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Appendix

Model Description

A-1. Set

$i = \{1,2,...,1440\}$: Total number of the blocks located within the province's potential site for the establishment of the hub

$j = \{1,2,.....,4510\}$: Total number of the blocks situated in the province (both potential and non-potential options)

$k = \{1,2,......,19\}$: Total number of the provincial freight entry (exit) points

$g = \{1,2,.....,63\}$: Total number of the cold storage in the province

$h = \{1,2,.....,25\}$: Total number of silos in the province

$p = \{1,2,.....,82\}$:Total number of warehouses in the province

$r = \{1,2,......,15\}$: Total number of the country's provinces with a distance of more than 400 km from the province

A-2. Parameters

c_{IN} : The average cost of a road freight unit for industrial products per ton-kilometer

c_{MI} : The average cost of a road freight unit for mineral products per ton-kilometer

c_{AG} : The average cost of a road freight unit for agronomic and horticultural products per ton-kilometer

c_{CO} : The average cost of a road freight unit for livestock products per ton-kilometer

c_{GO} : The average cost of a road freight unit for agronomic, horticultural, and livestock products per ton-kilometer

c: The average cost of a road freight unit for different industrial, mineral, agronomic, horticultural, and livestock products per ton-kilometer

c_{IM} : The average cost of a road freight unit for industrial and mineral products (industrial inputs) per ton-kilometer

c_{MIR} : The average cost of a rail freight unit for mineral products per ton-kilometer

c_{INR} : The average cost of a rail freight unit for industrial products per ton-kilometer

c_{AGR} : The average cost of a rail freight unit for agronomic and horticultural products per ton-kilometer

c_{RO}: Fixed cost of construction and maintenance of the road routes per kilometer

c_{RA}: Fixed cost of construction and maintenance of the rail networks per kilometer

c_E : Fixed cost of construction and maintenance of the electricity transmission lines per kilometer

c_G : Fixed cost of construction and maintenance of the gas transmission lines per kilometer

A-3. Variables

d_{ij}: Distance from block i to block j

d_{ik} : Distance from block i to entry (exit) point k

d_{ig} : Distance from block i to cold storage g

d_{ih} : Distance from block i to silo h

d_{ip}: Distance from block i to warehouse p

d_{iro}: Distance from block i to the nearest road route (existing or under construction)

d_{ira}: Distance from block i to the nearest railroad (existing or under construction)

d_{ir} : Distance from block i to the capital of the province r

d_{igas} : Distance from block i to gas supply network

d_{ie} : Distance from block i to the electricity network

AG_j : Cargo tonnage of agronomic and horticultural production exiting from block j

CO_j : Cargo tonnage of livestock production exiting from block j

IN_j : Cargo tonnage of industrial production exiting from block j

MI_j : Cargo tonnage of mineral production exiting from block j

AGO_k : The tonnage of agronomic and horticultural cargo entering the province from entry point k located outside

COO_k : The tonnage of livestock cargo entering the province from entry point *k* located outside of the province

INO_k : The tonnage of industrial cargo entering the province from entry point *k* located outside of the province

MIO_k : The tonnage of mineral cargo entering the province from entry point *k* located outside of the province

AGC_j : Cargo tonnage of agronomic and horticultural consumption entering the block *j*

COC_j : Cargo tonnage of livestock consumption entering the block *j*

INC_j : Cargo tonnage of industrial consumption entering the block *j*

AGF_j : Cargo tonnage of agronomic and horticultural inputs (in the agronomic and horticultural transformative and complementary industries) entering the block *j*

COF_j : Cargo tonnage of livestock inputs (in the livestock product transformative and complementary industries) entering the block *j*

INF_j : Cargo tonnage of industrial and mineral inputs (mineral and industrial products used as the production inputs by industrial units) entering the block *j*

OAG_k : The tonnage of agronomic and horticultural cargo exiting from exit point *k* located outside of the province

OCO_k : The tonnage of livestock cargo exiting from exit point *k* located outside of the province

OIN_k : The tonnage of industrial cargo exiting from exit point *k* located outside of the province

OMI_k : The tonnage of mineral cargo exiting from exit point *k* located outside of the province

$INRI_r$: The tonnage of industrial cargo entering the province *r* in the rail network (transferring from the road routes to the railroads)

$MIRI_r$: The tonnage of mineral cargo entering the province *r* in the rail network (transferring from the road routes to the railroads)

$AGRI_r$: The tonnage of agronomic and horticultural cargo entering the province *r* in the rail network (transferring from the road routes to the railroads)

$INRO_r$: The tonnage of industrial cargo exiting from the province to province *r* in the rail network (transferring from the road routes to the railroads)

$MIRO_r$: The tonnage of mineral cargo exiting from the province to province r in the rail network (transferring from the road routes to the railroads)

$AGRO_r$: The tonnage of agronomic and horticultural cargo exiting from the province to province r in the rail network (transferring from the road routes to the railroads)

R_g : The capacity of the cold storage g

S_h : The capacity of the silo h

W_p : The capacity of the silo h