Analysis of Spatial Accessibility and Capacity of Multi-Level Healthcare Facilities in The Greater Irbid Municipality, Jordan

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Abstract
Measuring the spatial accessibility and capacity of healthcare facilities is an important task to improve the quality of health services and reduce the pressure on them. This research assesses the current spatial accessibility and capacity of two-level of healthcare facilities (comprehensive healthcare centers and hospitals) in the Greater Irbid Municipality using the enhanced two-step floating catchment area (E2SFCA) method. To do this, Network analysis techniques including original-destination matrix (OD), service area, and location-allocation were employed for determining the travel time from residents' points towards every healthcare facility, the service coverage and capacity within travel time zones, and the number of served areas by every healthcare facility. Then, optimum locations for new healthcare facilities that improve the accessibility and capacity rates were determined. The results show that while all areas in the study area are located within a 30-minute drive from the hospital's locations, 18 out of 23 areas are within 15 minutes drive towards the comprehensive health centers. This means that 28.80% of the population needs more than 15 minutes of driving time to access the second level of healthcare services. In addition, the annual average of the actual patient-doctor ratio ranges from 1338 to 2900 patients per doctor in the hospitals, and 2676 to 8524 patients per doctor in the comprehensive healthcare centers, and thus, the health services are inadequate in the study area. Furthermore, the suggested new healthcare facilities in terms of the numbers and optimum location would improve the spatial accessibility and the capacity ratio.

1. Introduction

Improving healthcare services is of great importance to enhance the quality of life and social welfare in every society. The recent developments in health geography in terms of geospatial techniques allowed the planner and decision-maker to determine the best location of healthcare facilities and measure their spatial accessibility within allowable time and distance costs. This is because access to healthcare is a measure of the availability and affordability of the services (Kleinman and Makuc, 1983). From the perspective of social equity, everyone should have the opportunity to access such services equally. However, it is a challenge to achieve such equity due to various obstacles such as socio-economic, the financial status of the population, and geographical factors (Aday and Andersen, 1974 and Luo and Qi, 2009). Access to healthcare facilities varies across spatial dimensions because it is influenced by where the health facilities locate (supply) and where people reside (demand) and neither the distribution of the health facilities nor the population is perfectly matched.

Various approaches have been developed to assess the accessibility to healthcare services. These approaches can be categorized into provider-population ratios (Rekha et al., 2017), proximity to the nearest healthcare service (Wang, 2003), gravity model (Joseph and Kuby, 2011), and the floating catchment area method and its modifications (Luo and Qi, 2009, Zhuolin, 2016 and Luo and Whippo, 2012). The provider-demand ratio that can be a ratio between the number of health staff or beds to patients is the simplest method but the ground of this approach is non-spatial and thus no considerations are given to the distances between the demand and the supply. The proximity to the nearest healthcare service is also called the impudence to the nearest health provider is based on

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the travel cost from the population center (location of residents) to the nearest health facility.

The cost of the travel can be referred to as a distance in kilometers or meters or travel time in munites. Although this approach is suitable in rural areas, it is not effective in large urban areas (metropolises) where many alternatives exist (Fyer et al., 1999). The gravity method is based on the interaction between the potential population point and all health facilities within acceptable boundary distances.

The floating catchment area (FCA) method and its modification two-step floating catchment area (2SFCA) has emerged to overcome the shortcoming of the abovementioned spatial accessibility approaches. This method was first proposed by (Radke and Mu, 2018) and since then, it was intensively used to evaluate the accessibility measures to public healthcare services. The basic principle of this method is based on considering the capacity of healthcare services, potential demand, travel costs (distance/time), and the coverage of service area within a defined time frame (Mao et al., 2020). Since the 2SFCA method considers all of the population locations have equal distance impedance within the catchment and all locations located outside the catchment area have no access at all, another modification namely enhanced two-step floating catchment area (E2SFCA) was developed by Luo and Qi (2009). The E2SFCA considers multiple distance decay weights within the catchment area. The E2SFCA is thus more likely analogs to the gravity model.

Like other countries, the Jordanian government attempts to improve the health sector, but it still faces challenges due to different factors such as rapid population growth and unfair spatial distribution of health facilities particularly in rural areas which in turn lead to a decline in the quality of health services. Thus, improving the quality of health services and their accessibility is one of the main goals that the Jordanian government seeks to achieve. This study assesses the spatial accessibility and capacity of the current healthcare facilities using the enhanced two-step floating catchment area (E2SFCA) method. In addition, the distance/travel time between the demand (residents' location) and supply (healthcare facilities location) was computed by the original-destination (OD) matrix. The coverage of each healthcare facility was then determined. The study was also employed a location-allocation technique for selecting an optimum location for new healthcare facilities that improve the accessibility and capacity rates. Ultimately, this research will contribute to providing a database for planners and decision-makers to improve the current quality of health services in the study area.

2. Materials and Methods

2.1 Study Area and Data

Greater Irbid Municipality is in the north of the Hashemite Kingdom of Jordan and extends between 35.43° to 35.60° E and 32.23° to 32.41° N, with an area of 356,84 km^2 (Greater Irbid Municipality, 2018) and it belongs to the Irbid governorate. Figure 1 shows the Hashemite Kingdom of Jordan and the study area.

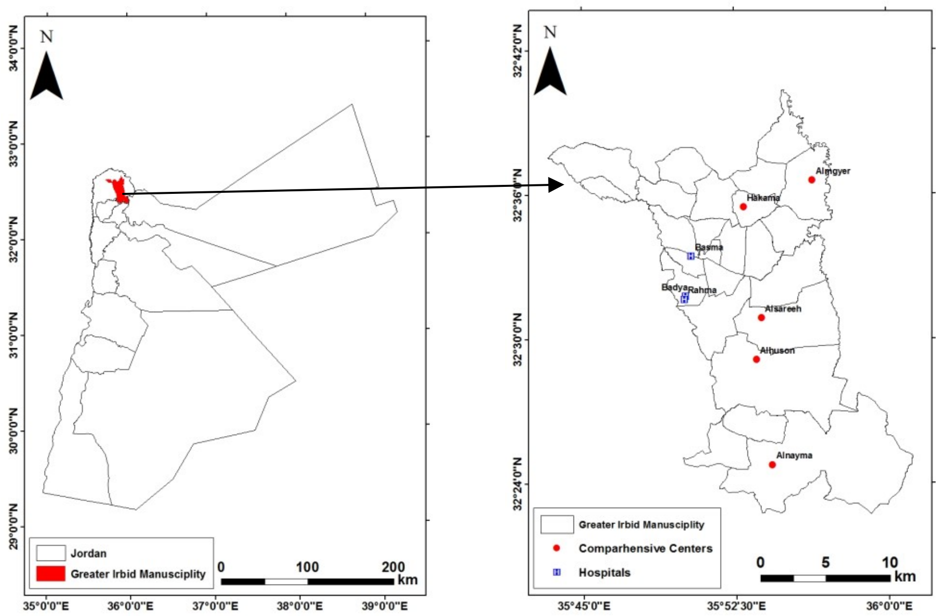

Figure1: Greater Irbid Municipality

Recently, the study area has experienced rapid population and urban growth due to several reasons including the high rate of natural increase of population (around 2.4% annually) migrations from surrounding villages and countryside, and refugees from the surrounding countries (e.g., Syria and Iraq). According to the department of statistics, the estimated population of the Greater Irbid Municipality in 2018 reached 907,675 (Department of General Statistics, 2018). As a result, the increase of population growth causes huge pressure on many public services including public healthcare facilities. As shown in Figure 2 which shows the population density in the study area, the Greater Irbid municipality is divided into 23 administrative areas, and the general population density is around 2544 people/km²).

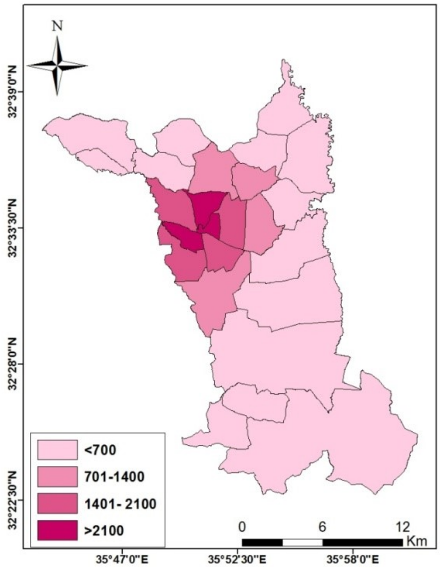

Figure 2: Population density in the study area

While the highest population density (around 1401 to 2100 people/km²) occurs in Alrawda, Alnaser, Albarha, Arabia, Almanara, Alnuzha, Alhashmih, Bayt Ras, and Aydoun, the lowest density (less than 700 people/km²) is in Fuara, Hwar, KafrJayez, Maro, Alhuosn, and Alnayma.

In Jordan as well as the study area, public healthcare services can be divided into three levels:

- Level one represents the hospitals where all healthcare services are provided. There are three public hospitals in the study area, these are Princess Basma hospital, Princess Rahma hospital, and Princess Badya hospital.
- Level two represents the comprehensive healthcare centers: these centers provide almost all medication and treatments except surgical operations. These centers are Hakama, Almgyer, Alhuson, Alnayma, and Alsareeh
- Level three represents the primary healthcare centers: they are available in almost every area where the population is more than 3000. These primary centers provide primary healthcare services such as laboratory testing, care for minor symptoms, treatment for common illnesses (cold and flu), and treatment of injuries (e.g., minor cuts or burns)

This study assesses the location of public hospitals and comprehensive health centers in the Greater Irbid municipality and measures their accessibility and capacity rates. Population data for the Greater Irbid municipality were obtained from the Department of Statistics report (2018) while the number of healthcare staff (doctors, nurses, and pharmacists) and patients in both hospitals and comprehensive healthcare centers were obtained from the Jordanian ministry of health. The center of each area was determined using the mean center tool within the ArcGIS environment. These data were used to evaluate the capacity rate of each healthcare facility. The number of health staff (doctors, nurses, and pharmacists) and patients in the hospitals and comprehensive healthcare centers are depicted in Tables 1 and 2 respectively.

3. Methodology

In this section, we present a brief explanation of the 2SFCA and E2SFCA that are used to measure the accessibility of health care services. This method will be relied upon to measure the ease of access to healthcare services in the Greater Irbid Municipality.

3.1 Online Map APIs

In this research, travel time, service area, original-distention matrix (OD), and location-allocation were computed via online Network Analysis within the ArcGIS Pro environment. This is to perform a more accurate travel time than the hypothetical speed which is calculated using ArcGIS desktop. Another reason for using the online travel time is that the speed is adjusted automatically to suit road conditions and thus it reflects real-time traffic situations. In this research, the APIs were used during the weekdays at 12:00 pm because this time is the normal situation of the traffic and thus it was chosen to avoid the unusual conditions of the traffic in different periods. ArcGIS Online was used to perform travel time from the area center (the location where people reside) towards the healthcare facilities (hospitals and comprehensive healthcare centers).

Table 1: The number of health staff (doctors, nurses, and pharmacists) and patients in the hospitals

Hospital	Doctor	Nurse	Pharmacists	Patient
Basma	126	395	47	365470
Badya	16	66	17	34640
Rahma	33	191	17	44156

Source: hospital statistics (numbers are five years averages (2016-2020)

Table 2: The number of health staff (doctors, nurses, pharmacists) and patients in the comprehensive healthcare centers

Comprehensive Healthcare center	Doctor	Nurse	Pharmacist	Patients
Hakama	11	11	2	29432
Almgyer	4	10	2	28649
Alhuson	12	15	4	42599
Alnayma	6	9	2	49349
Alsareeh	8	12	2	68192

3.2 Two-step Floating Catchment Area (2SFCA)

In this research, the 2SFCA method was used to measure the accessibility to the healthcare facilities in the study area. This method consists of two consecutive steps; the first step is to determine the supply (capacity) to demand (population) ratio (R_j) within the catchment area. While the capacity of a healthcare facility (S_j) can be the number of health staff (doctors, nurses) or the number of beds, the demand can be the weighted population (e.g., the number or density of population). This step can be computed as (Ni et al., 2019):

$$R_j = \frac{S_j}{\sum_{t_{kj} \in t_0} P_k}$$

Equation 1

where P_k is the population at area k, t_0 is the distance threshold from each healthcare facility location j.

In the second step, the accessibility of each population location (k) to a healthcare facility (j), (A_k^j) and can be calculated as a sum of the supply to demand ratio R_j (computed in the first step) for all healthcare facilities falling within the travel time from each population (k) (Rekha et al., 2017).

$$A_i = \sum_{j \in (t_{ij} \le t_0)} R_j = \sum_{j \in (t_{ij} \le t_0)} \frac{S_j}{\sum_{k \in (t_{kj} \le t_0)} P_k}$$

Equation 2

3.3 Enhanced Two-Step Floating Catchment Area (E2SFCA)

Although the 2SFCA method provides accessibility information between the supply and demand, the accessibility is considered equal among all locations within the catchment boundary and thus, locations outside the catchment boundary are unreachable at all. To overcome this drawback, (Luo and Qi, 2009) proposed an enhanced two-step Floating Catchment Area (E2SFCA) that provides a wight for distance to the healthcare services. Therefore, even if the healthcare facility location is within the catchment area but it is further away from the population location, there is a lower chance that this particular healthcare facility is chosen by the population (Kanuganti et al., 2016, Bryant and Delamater, 2019 and Kc et al., 2020). Unlike the 2SFCA which gives a similar accessibility value within the catchment area, the E2SFCA method provides more weight to the distance between the population (demand) location and the healthcare facility (provider). Thus several zones with different weights are given the distances to penalize further distances. The area within the critical distance is gradually penalized by distance. In general, Gaussian, inverse power, or Exponential functions are usually used for distance decay functions (Kwan, 2010). Two steps of E2SFCA are expressed as below:

$$R_j = \frac{S_j}{\sum_{k \in (t_k \le T_r)} P_k W_r}$$

Equation 3

$$A_i = \sum_{j \in (t_{ij} \le T_r)} R_j W_r$$

Equation 4

4. Results and Discussion

4.1 Health Service Coverage Area

The enhanced two-step floating catchment area (E2SFCA) method has been employed for calculating the spatial accessibility to the multi-level healthcare facilities based on the speed of the vehicle on different road levels. Based on online map APIs, the road levels and the travel time toward health facilities were estimated. As a result, The catchment of the demand point (population in each area) and the comprehensive centers are defined as an area within 15 minutes drive, whereas a 30 minutes drive catchment area is defined for the hospitals. The 15 and 30 minutes travel times to the comprehensive healthcare centers and hospitals were used because they are the standard distance used in Jordan for accessing those levels of healthcare facilities (Jordanian Ministry of Health, 2018). Figures 3 and 4 illustrate service area coverage within three travel time intervals toward the comprehensive healthcare centers and hospitals respectively. The coverage of the service area has been divided into time intervals as 5, 10 and 15 minutes drive from the location of the population area toward the comprehensive centers and 5, 10,15, and 30 minutes drive from the location of the population area to the hospitals.

From Figure 3, one can notice that 20 out of the 23 administrative areas need 15 minutes driving time toward the comprehensive healthcare centers, and the number of served areas within 5, 10, and 15 minutes drives are 2, 10, and 20 respectively. Thus, 3 areas require more than 15 minutes drives to get the second level of health services. For the hospital cases, however, the number of the served area within 5, 15, and 30 minutes drive are 2, 9, and 23 respectively. This means that there is no area located beyond a 30-minute drive from the hospital's locations (Figure 4). Tables 3 shows the percentage of the population who access the second-level of health services within the three driving time cutoffs. It is clear that the percentage of the population who get health services within 5, 10, and 15 minutes drive towards the health centers locations is 9.22 %, 35.42%, and 71.20 % respectively. Therefore, 28.80% of the population needs more than 15 minutes to reach the closest healthcare center. Table 4 depicts the percentage of the population who access the first-level of health services within 5, 15, and 30 minutes drive. While 100% of the population can reach health services within 30 minutes drive, 19.53% and 72.59 % can reach health services within a 5 and 15 minutes drive respectively.

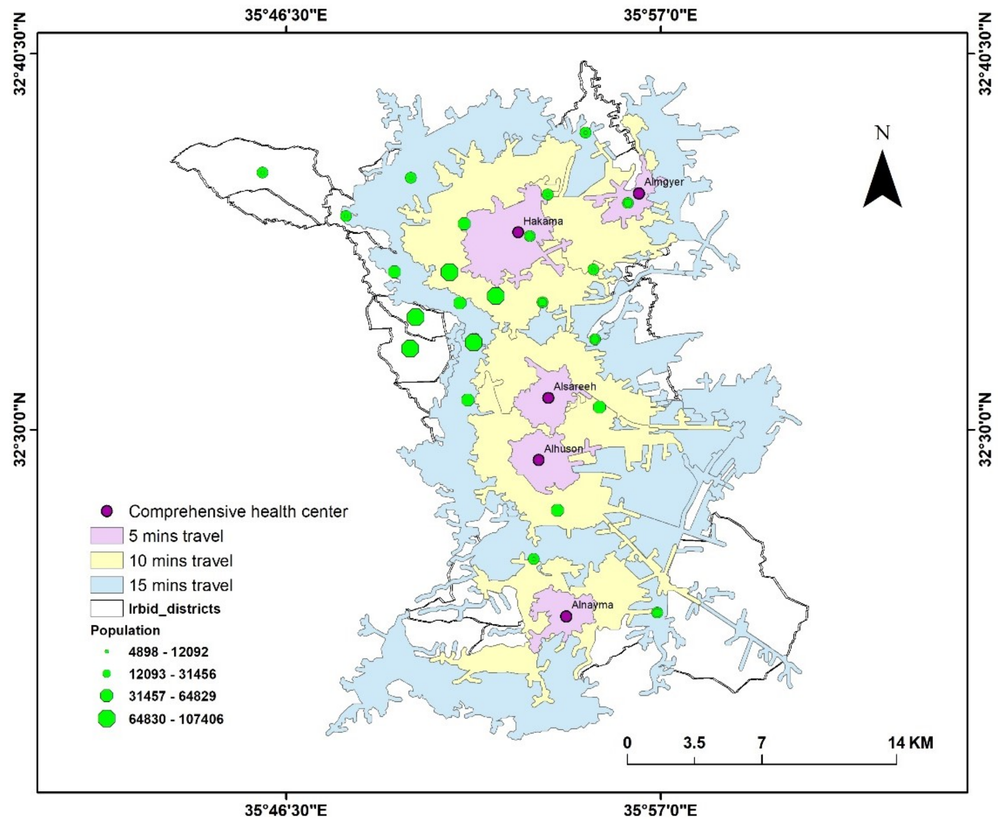

Figure 3: Service area coverage within three-time intervals toward the comprehensive healthcare centers

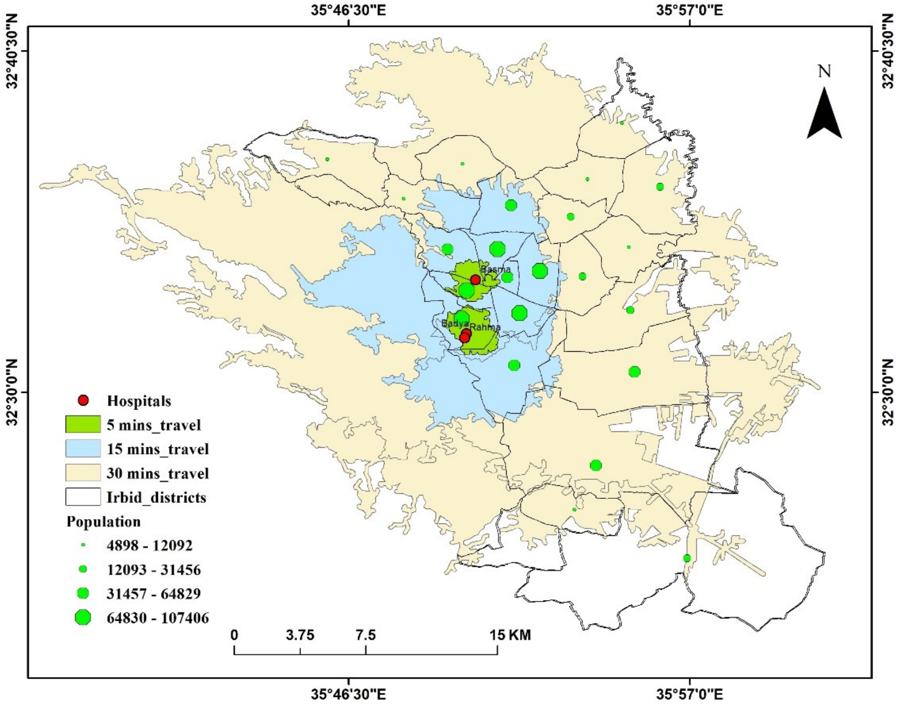

Figure 4: Service area coverage within three-time intervals toward the hospitals

Table 3: The percentage of the population who access the second-level of health services within the three driving time cutoffs

Time Interval/Minutes	Number of populations in each time zone	Populations percentage %	Cumulative percentage %
5.00	83674	9.22	9.22
10.00	237816	26.20	35.42
15.00	324808	35.78	71.20
> 15	188276	28.80	100.00

Table 4: The percentage of the population who access the first-level of health services within the three driving time cutoffs

Time Interval/Minutes	Number of populations in each time zone	Populations percentage %	Cumulative percentage %
5	173637	19.70	19.53
15	478213	52.89	72.59
30	248872	27.42	100.00

4.2 Current Spatial Accessibility and Capacity

Figure 5 shows the location-allocation analysis technique of the comprehensive healthcare centers. As can be seen, 18 out of 23 areas can reach the services provided by the comprehensive health centers within 15 minutes drive. It can also be noticed that the number of served areas varies from one healthcare center to another. This means that some healthcare centers provide services to around 10 areas (e.g., Hakama Health Center) whereas Alsareeh, Alhuson, Alnayma, and Almgyer serve 3, 2,2, and 1 areas respectively. As a result, Hakama health center may receive more patients than those of other centers. From Table 5 which shows patient-doctor ratios in the comprehensive healthcare centers, it can be seen that the population who access health services in Hakama health center is 334726 which reflects a ratio of 30430 patients per doctor.

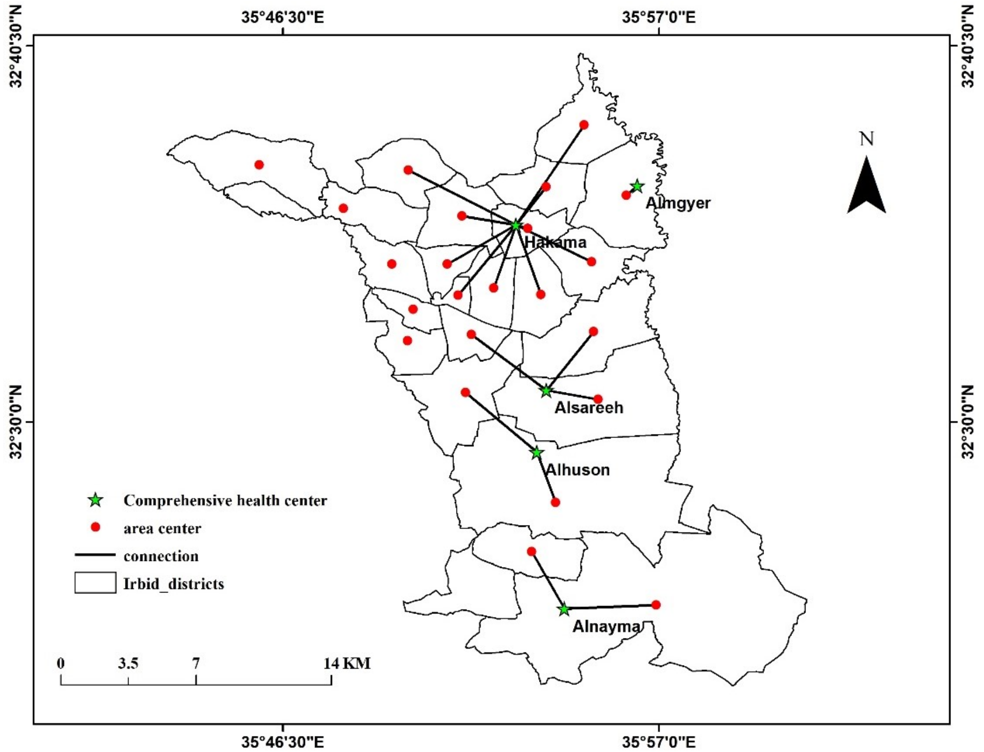

Figure 5: The location-allocation analysis technique of the comprehensive healthcare centers

Table 5: Patient-doctor ratios in the comprehensive healthcare centers

health center	Number of the population within 15 minutes drive	population to doctor ratio	Actual* Patients	The actual ratio of patients to doctor	Number of served areas
Hakama	334726	30430	29432	2676	10
Almgyer	17872	4468	28649	7163	1
Alhuson	102932	8578	42599	3550	2
Alnayma	40994	6833	49349	8225	2
Alsareeh	158820	19853	68192	8524	3

**The average of actual annual patients in the last 5 years according to the health service statistics*

Table 6: Areas with populations that are not within 15 minutes drive from the closest healthcare center

Areas not within 15 minutes drive	Population
Alrabia	64055
Fuara	6953
Albarha	64055
Hwar	7686
Almanara	84603
Total	227352

However, according to the statistics provided by Hakama health center, the 5-year average of patients who have visited the health center from different areas was 29432 yearly, and thus the actual annual patients-doctor ratio is only 2676 patients per doctor. On the other hand, Almagyer health center provides services to only one area with an actual annual average of 28649 patients with a patient-doctor ratio is about 7163 patients per doctor. Although the number of served areas by Hakama health center is the highest among the other centers, the actual annual patient to doctor ratio is the lowest. This means that residents are not necessarily choosing the closest healthcare center.

Table 6 depicts the areas with populations that are not within 15 minutes drive from the closest healthcare center. As can be seen, five areas namely Alrabia, Fuara, Albarha, Hwar, and Almanara with a total population of 227352 do not access services within 15 minutes drive time. Based on the analysis given above, the quality of health services provided by these healthcare centers is low. This means that the location, the number, and the capacity of these health centers need to be reassessed by the health planner and decision-maker in the study area. Figure 6 shows the location-allocation analysis technique of the hospitals, while Table 7 shows the current situation of the population to doctors ratio and actual annual patients to doctors ratio in each hospital. Within 30 minutes drive to the princess Basma hospital, the number of served areas is 17 whereas the princess Badya and Rahma serve 4 and 1 areas respectively. It can also be seen that Alnayma with a total population of 31456 is not within 30 minutes drive to the closest hospital. Given that, the total number of the population who get health services in the princess Basma hospital is 625036 with an actual annual average of patients and ratio are 365470 and 2900 patients per doctor respectively. The number of the population who are served by princess Badya hospital within 30 minutes drive is 241645 and the actual annual average of patients is 34640 with a ratio of 2165 patients per doctor. The third hospital is the princess Raham hospital and the number of served population, the actual annual average of patients, and the ratio are 9538, 44156, and 1338 patients per doctor respectively.

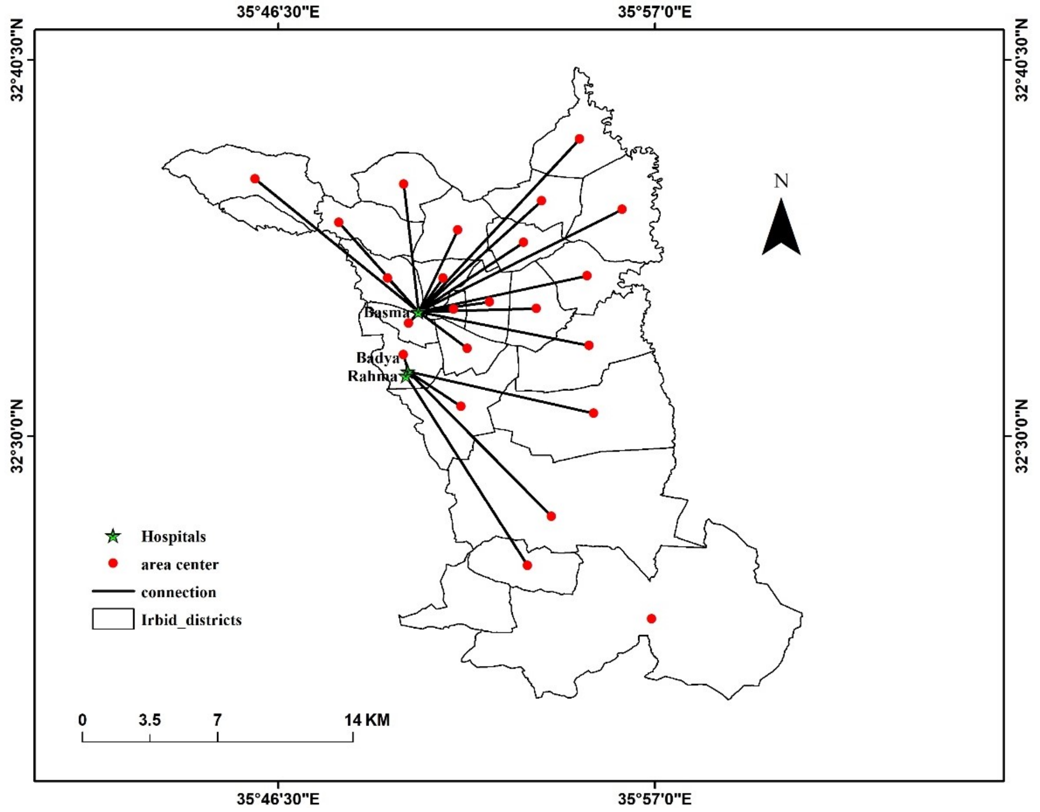

Figure 6: The location-allocation analysis technique of the hospitals

Table 7: The current situation of the population to doctors ratio and actual annual patients to doctors ratio in each hospital

Hospital	Number of the population within 30 minutes drive	population to doctor ratio	Actual* Patients	The actual ratio of patients to doctor	Number of served areas
Basma	625036	4961	365470	2900	17
Badya	241645	15103	34640	2165	4
Rahma	9538	289	44156	1338	1
n/a***	31456	-	-	-	Alnayma

The average of actual annual patients in the last 5 years according to the hospital statistics
****Area which is not within 30 minutes drive from the closest hospital*

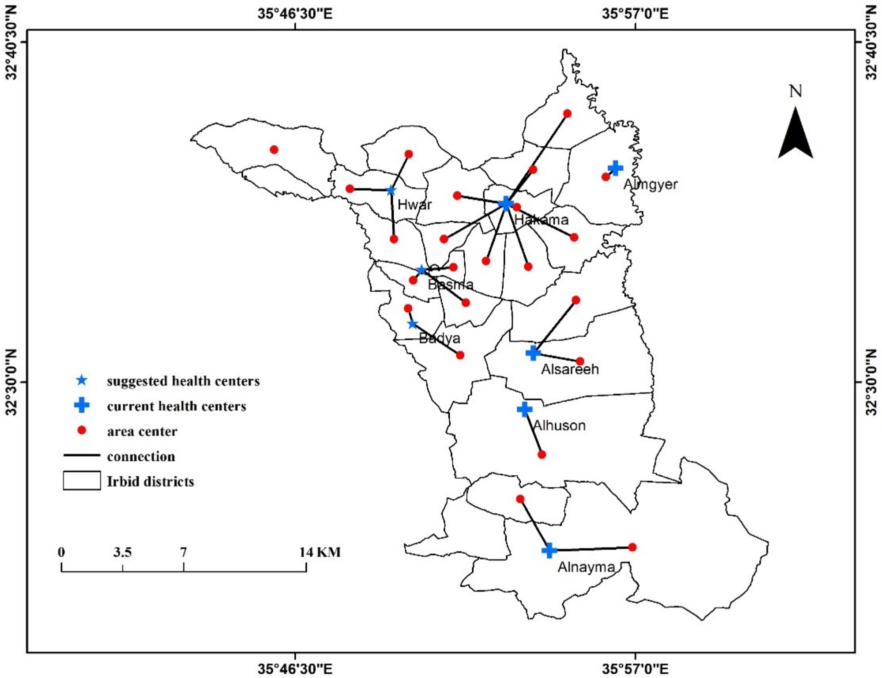

Figure 7: The current and the suggested healthcare facilities locations in the study area within 15 minutes drive toward the comprehensive healthcare centers

4.3 Optimum Locations and Numbers of New Healthcare Facilities

Since all levels of the healthcare facilities do not cover all the areas within a standard time frame (30 and 15 minutes drive to hospitals and comprehensive health centers respectively), this study provides optimum locations for new health facilities. Figure 7 demonstrates the current and the suggested healthcare facilities locations in the study area within 15 minutes drive toward the comprehensive healthcare centers. For the comprehensive health centers, three new locations are suggested to enhance the current services and also provide coverage for almost the whole study area within 15 minutes drive. As can be seen, with the new facilities and location, the pressure on the current healthcare centers can be reduced. When three health centers are suggested based on optimum locations, the number of served areas, as well as the capacity, are improved. For instance, Hakama health center normally receives patients from 10 surrounding areas, but with the new healthcare centers, two areas will be redistributed to other centers. Other areas (e.g., Alrabia, Albarha, Almanara, and Hwar) which are located more than 15 minutes drive to the closest healthcare centers can now get services within 15 minutes drive. Not only, the time to the closest healthcare center can be reduced, the ratio of patients-doctor can also be improved.

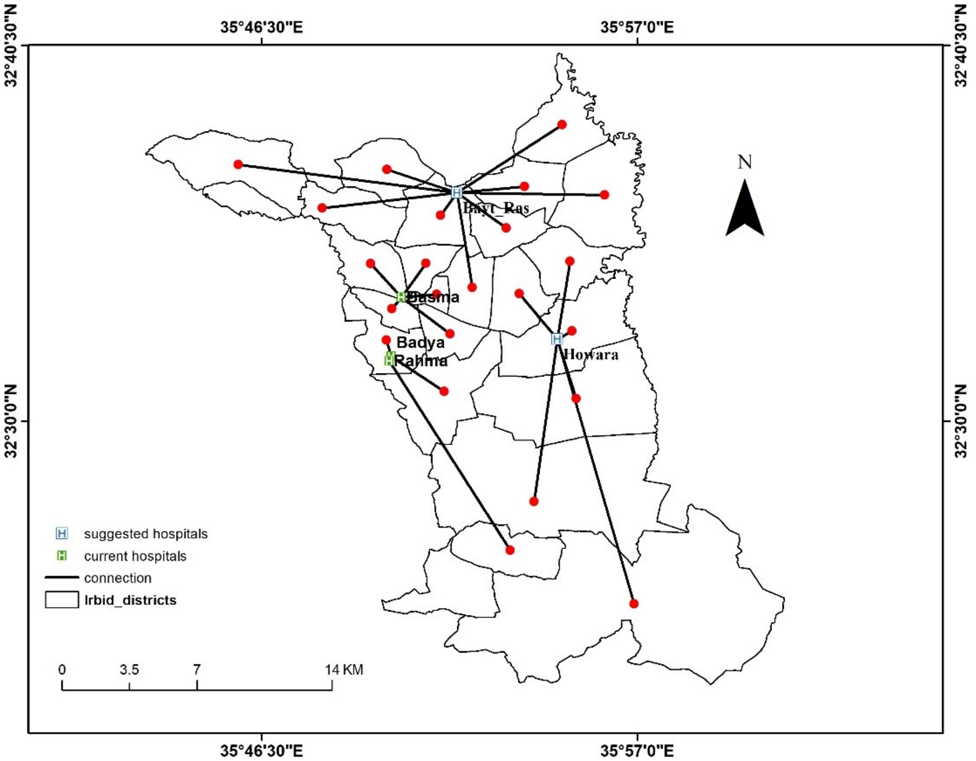

Figure 8: The current and the suggested healthcare facilities locations in the study area within 30 minutes drive toward the hospitals

For hospitals case, new locations for another two hospitals in the study area are suggested near Kufr Jayez and Howara. Figure 8 shows the current and the suggested healthcare facilities locations in the study area within 30 minutes drive toward the hospitals. As can be seen, when a new hospital is suggested near Kufr Jayez area, it will provide services to around 9 areas and this would reduce the pressure on the princess Basam hospital. The suggested hospital near Howara will also reduce the pressure on other hospitals. It can be noticed that due to the current location of the princess Rahma hospital, only 1 out of 23 administrative areas can be served. However, when new hospitals are suggested, the number of served areas by the princess Rahma hospital becomes 2 and this would reduce the pressure on other hospitals as well.

5. Conclusions

This research implemented and estimated the spatial accessibility to different levels of healthcare facilities (hospitals and comprehensive healthcare centers) in the Greater Irbid municipality using the E2SFCA method. The costs of distance and travel time to every healthcare facility were measured using the original-destination (OD) matrix, service area coverage, and location-allocation techniques. Additionally, the capacity of healthcare facilities in terms of doctor-population ratio was assessed in each time interval. Finally, optimum locations for new healthcare facilities were suggested. Although the number of healthcare facilities in the study area is adequate for providing health services, the imbalanced spatial distribution of these healthcare facilities impacts the spatial accessibility, reduces the quality of the provided health services, and increases the doctor-patient ratio. It has been found that 18 out of 23 areas can access the second level of health services within the standard driving time while the first level of health services can be accessed within 30 minutes drive by all areas. The imbalanced distribution of the healthcare facilities caused unfair service coverage and a high doctor-patient ratio. Therefore, some healthcare facilities serve 10 areas with around 334726 of population, and a ratio of 2676 patients per doctor, while other healthcare facilities serve only one area with a total population of 17872 and 7163 patients per doctor.

The suggested number and location of new healthcare facilities would improve the quality of the provided services by improving the spatial accessibility and reducing the patient-doctor ratio. Spatial accessibility to the third level of healthcare facilities (primary health centers) needs to be further evaluated at different periods and in rural areas with the E2SFCA method in future research.

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