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Assessment of primary healthcare accessibility and inequality in north-eastern Kazakhstan

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Abstract

Out of the many aspects of health care, the concept of physical accessibility is a priority that not only encompasses availability of health care resources, but also requires that they are easily accessible for all. To assess this factor as expressed in terms of the number of available physicians in the north-eastern part of Kazakhstan, we used the enhanced two-step float catchment area in a geographic information system approach. The Gini index and the Lorentz curve were used to evaluate the economic inequality within this region. Based on the data obtained, we developed models to increase the availability of health care considering allocation of additional primary health care resources. A low to zero index was found to be typical for most rural settlements, which currently make up less than 15% of the total population. We also identified a correlation between the index of accessibility and that of inequality, which indicates that areas with high accessibility show a more equitable distribution of resources. The developed location/allocation models of additional primary health care resources can be useful in implementing government initiatives to improve the availability of primary health care in rural areas.

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Introduction

Equity in access to primary health care is one of the most important requirements in a country. Primary health care (PHC) was defined as the cornerstone of 'health for all', the slogan coined at the historical conference organized by the World Health Organization (WHO) in Alma-Ata, Kazakhstan (Robertson and Davies, 1978). This idea has been further developed in the United Nations (UN) resolution (UN, 2013) and defined as universal health coverage (UHC) urging governments to provide affordable, high quality health services to everyone. It is based on the provision of comprehensive PHC services with extensive geographical coverage that includes remote and rural areas at the same level as towns and cities. The UHC concept assumes that everyone has access to medical services (Evans *et al*., 2013) which, according to Penchansky and Thomas (1981), exists as five domains: i) *availability*: supply of services and resources; ii) *accessibility*: travel time and cost; iii) *accommodation*: characteristics of supply (time table, appointment systems, *etc*.); iv) *affordability*: financial aspects of health services; and v) *acceptability*: personal, social and cultural characteristics, both of medical providers and of patients.

WHO uses a similar classification but aggregates the two first domains into one: physical accessibility of healthcare (UN, 2013).

The ratio approach, the physician/population ratio for example, is simple and widely used to measure regional availability assisting decision makers in identifying areas of health care shortage or oversaturation. Nevertheless, regional availability ratios have drawbacks, such as ignoring the variety of health care resources among sub-areas and the possibility of moving patients across sub-area boundaries as well as the utilization levels of patients living at different distances from health care facilities. In contrast, distance-based methods measure the average distance from different sub-areas to physicians, including considering the distance between physicians. However, this method overlooks the association of the number of health workers and population sizes and has difficulties comparing the needs of different sub-areas (Khan, 1992).

The use of geographical information systems (GIS) to measure physical accessibility to PHC facilities has been described by the WHO Regional Office for the Americas (PAHO) (Black *et al*., 2004) and various GIS approaches based on factors, such as the Jarman Index (1983), the Townsend Index (1988), facility capacity, travel impedance and travel time, have been utilized to measure spatial accessibility and physical access in healthcare (Kiani *et al*., 2017; Hoseini *et al*., 2018). In 2003, Luo-W and Wang (2003) proposed the two-step float catchment area (2SFCA) method, which lends itself particularly well to assess physical PHC accessibility. The data source for the 2SFCA method consists of census files based on census tracts, blocks and road networks for travel-time estimation together with master files on existing physicians by area (McGrail, 2012). This method produces several improvements, *e.g*., it eliminates the disadvantage associated with the lack of potential differences in availability index within the catchment areas.

An enhanced two-step float catchment area (E2SFCA) method containing distance decay functions to differentiate the availability index and Gaussian weights has been developed Luo-W and Qi (2009). Another improvement is the use of different catchment sizes for both urban and rural areas (McGrail and Humphreys, 2009). This considers that people in urban areas have smaller catchment areas than in rural areas and that rural people are willing to travel greater distances if not satisfied with the services within their own base catchment area (Luo and Whippo, 2012).

Both 2SFCA and E2SFCA have proved useful to measure healthcare accessibility (Langford *et al*., 2019; Hashtarkhani *et al*., 2020; Kiani *et al*., 2021) As well as for evaluating allocation of potential centres for vaccination against coronavirus disease 2019 (COVID-19) (Mohammadi *et al*., 2021). GIS tools for assessing accessibility can solve location/allocation problems and help administrators decide where to locate healthcare facilities to improve access (Luo-J *et al*., 2017; Özceylan *et al.*, 2017). The importance of UHC for the development of PHC in rural areas (Government of Kazakhstan, 2021) requires an understanding of the current physical accessibility of PHC facilities. GIS not only makes it possible to evaluate PHC accessibility, but also to propose ways to improve the situation. The aim of our study was to assess the physical accessibility and inequality with respect to PHC in East Kazakhstan and its Pavlodar Region and based on this assessment, develop models for the location of additional PHC resources.

Materials and methods

This was a descriptive study based on secondary data using the E2SFCA method with the continuous distance decay functions instead of discrete functions in GIS (Figure 1).

Study area and data

The study was carried out in East Kazakhstan (15 districts and 4 city administrations) and its Pavlodar Region (10 districts and 3 city administrations) with a total area of 407,981 km^2 (Figure 2). It was based on the 2009 population data (Population Census of Kazakhstan, 2010). The total population of both regions was 2,139,100 people: 742,500 in Pavlodar and 1,396,600 t0 in East Kazakhstan.

The number of primary care physicians and their geolocations in the PHC organization were requested from the register of the Ministry of Healthcare. The total number of PHC physicians was 1559 (552 in 80 PHC facilities in Pavlodar and 1007 in 226 PHC facilities in East Kazakhstan). Open Street Maps (OSM) (https://www.openstreetmap.org) and geofabrik (http://download.geofabrik.de/asia/kazakhstan.html) were used for settlements and boundary geodata and the connecting road network. In cities, we used PHC street addresses, while the settlement locations were used for the villages (Figure 3). According to the order of the Ministry of Health (MoH) of the Republic of Kazakhstan of 25 November 2020 (No. KPCM-205/2020), registered with the Ministry of Justice of the Republic of Kazakhstan on November 26 of 2020 (No. 21679), all clinics, such medical specialists, polyclinics, city polyclinics and private PHC polyclinics in each district should be situated in the same building. However, the rural centres contain only PHC physicians (MoH, 2020).

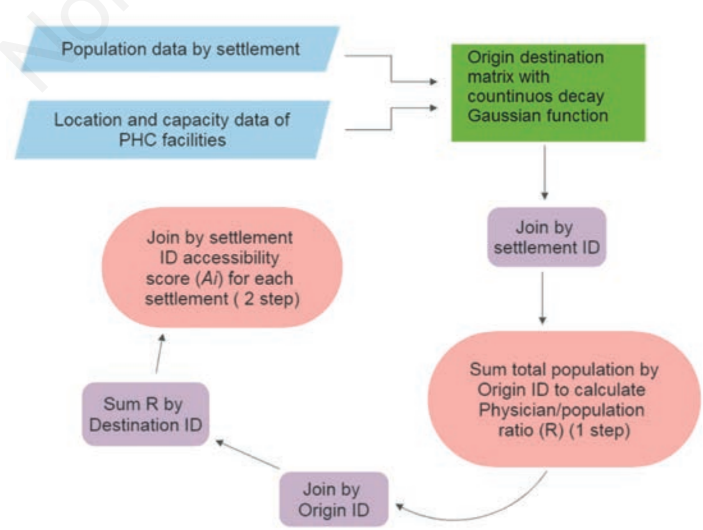

Figure 1. Flowchart of E2SFCA method.

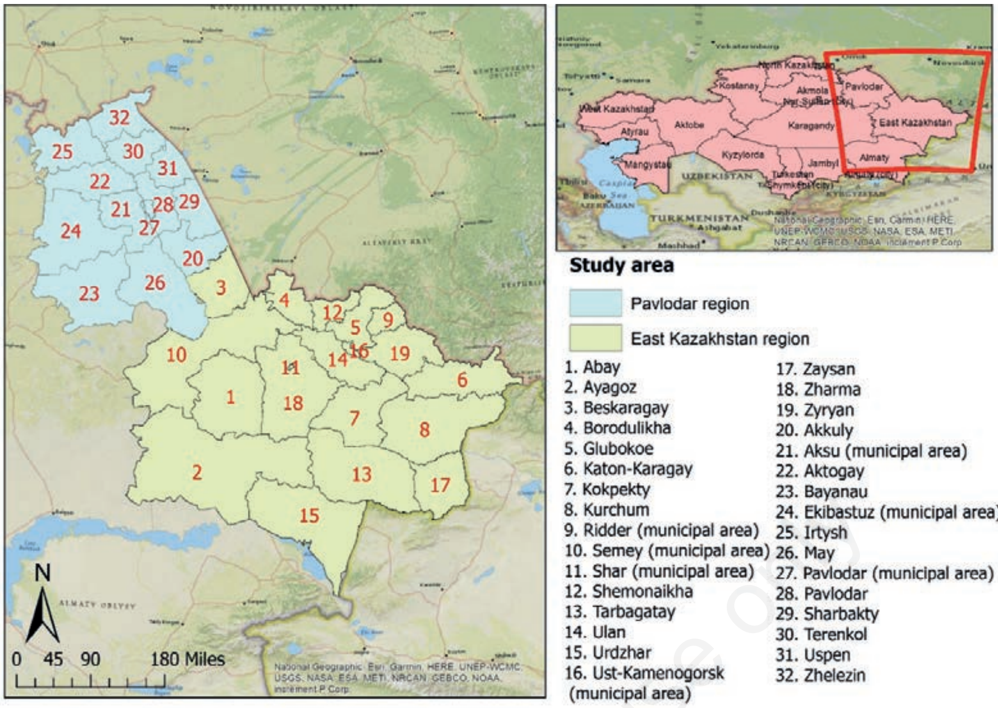

Figure 2. North-eastern part of Kazakhstan.

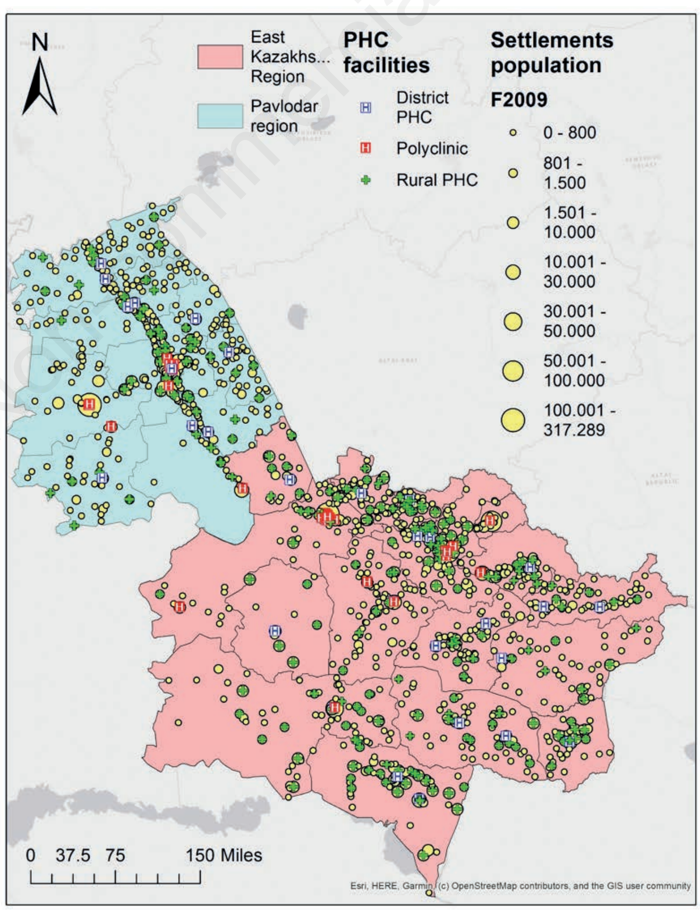

Figure 3. Primary health care (PHC) facilities network and population distribution.

Spatial statistics

The original 2SFCA method calculates supply-to-demand ratios based on 'floating' catchment areas, where the first step computes the supply-to-demand ratio within a supplier's service area, defined as a threshold travel time or distance from supplier location, while the second step calculates the supply-to-demand ratio for each demand location. The latter are usually specified travel times or distances from the centroids of the population-weighted census tract.

While the original 2SFCA technique is a strictly dichotomous model, the E2SFCA adds a distance-decay parameter (W*kj*). We used the E2SFCA adoption of the study as described by Langford *et al*. (2012) with a continuous Gaussian distance-decay function (Deborah *et al*., 2018). In step 1, the physician/population ratio (*Rj*) was calculated for each catchment area by determining all settlements (*k*) for each physician's office location (*j*) within the threshold travel time (d_0):

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\leq d_0\}} P_k W_{kj}} \quad (1)$$

where P_k is the population of each location *k* (*e.g*., administrative unit) that lies within the catchment area ($d_{kj}\leq d_0$); S_j the number of PHCs at location *j*; d_{kj} the travel time between *k* and *j*; d_0 the threshold travel time and W_{kj} is a continuous Gaussian distance-decay function:

$$W_{kj} = e^{\frac{-d_{kj}^2}{\beta^2}} \quad (2)$$

where β is $\frac{d_0}{2}$; and d_{kj} the shortest network distance between population location *k* and physician location *j*.

In step 2, an accessibility index A_i^F at resident location *i* is calculated as a sum of the (*Rj*) ratios within the threshold travel time d_0 for each population location *i*:

$$A_i = \sum_{j\in\{d_{ij}\leq d_0\}} R_j W_{kj} \quad (3)$$

where d_{ij} is the travel time between *i* and *j*; and W_{kj} a continuous Gaussian distance-decay function.

ArcMap, v. 10.8.1 (ESRI, Redlands, CA, USA) was used for the GIS studies. The distances in km from each population settlement to each PHC location were calculated using 8 km as the threshold travel distanceon theroad network. This distance was chosen due to the low population density and sprawl of settlements in Kazakhstan. From the E2SFCA accessibility indices, we extracted the Lorenz curve (1905), a graphical representation of income distribution where the curve equals the straight diagonal line if the health resources are equally distributed but otherwise the curve deviates from it and the Gini coefficient, a one-dimensional metric, which is twice the area between the Lorenz curve and the equiangular line with a zero value in case of complete equity, and 1 if the resources are all in one place (Tao *et al*., 2014). This was done to investigate the disparity between the districts of the two regions using R statistical software (R Core team, 2016).

Using the Network analyst capabilities of ArcMap, we developed two location/allocation applications to increase the level of accessibility to PHCs for the populations. The first aimed exclusively at adding facilities to the existing networks, while the second was used to create a basic pool of PHC facilities from the current network (organizations within settlements with 2000 inhabitants or more) plus the allocation of new facilities. The number of new PHC facilities was calculated as the average (~30 for the region) of government initiatives (Government of Kazakhstan, 2021) and the number of PHC physicians available in each new facility was calculated as a ratio of the Health Ministry goals, *i.e*. one physician for every 1500 people (Healthcare Ministry of Kazakhstan, 2018).

We calculated the accessibility index (A_i) by the E2SFCA for both applications, which used interpolation for better visualization. We tested three interpolation methods (inverse distance weight (IDW), interpolation spline (IS) and empirical Bayesian Kriging (EBK) using cross-validation to compare the root mean square error (RMSE) of the three interpolation methods to find the best one. As seen in Table 1, IS produced the lowest number compared to IDW and EBK and was therefore applied for interpolation or our data. To obtain a correct interpolation map, the E2SFCA index outliers were replaced by the median of the measurements obtained.

Results

Figure 4 shows the results of the distribution of E2SFCA accessibility indices in East Kazakhstan. With 89% of the total population living in areas with reasonable access to health services, the A_i median was 0.0004 with 340 of the 827 settlements having an A_i above zero, but there was a substantial difference between cities and district centres. There was also large, sparsely populated areas of poor accessibility (A_i=0) that together comprised 11% of the settlements. For Pavlodar Region, the median A_i was 0.00068 with 85% of the population market share (Figure 5). Only 109 of a total of 404 settlements had an A_i above zero and the picture was the same as in East Kazakhstan with sparsely populated villages with low A_i levels; often reaching as low as zero.

Figure 6 shows histograms of the A_i distribution for the two regions. While the A_i are distributed more smoothly in Pavlodar, two outliers can be seen in East Kazakhstan indicating small suburban settlements near cities with a relatively high number of physicians. To compare the current PHC network with the applications used, these outliers were replaced by the A_i median. Figure 7 shows the average A_i distribution among the districts of East Kazakhstan and Pavlodar. Ridder Municipality, the districts Zharma and Zyryan in East Kazakstan and Ekibastuz Municipality in Pavlodar had the lowest average. In contrast, Ust-Kamenogorsk Municipality and Abay District in East Kazakhstan and the districs Bayanaul, May and Aktogay in Pavlodar had the highest average A_i.

Table 1. Comparison of different interpolation methods.

Method	Root mean square error
Inverse distance weight (IDW)	0.000582
Interpolation spline (IS)	0.000562
Empirical Bayesian Kriging (EBK)	0.000583

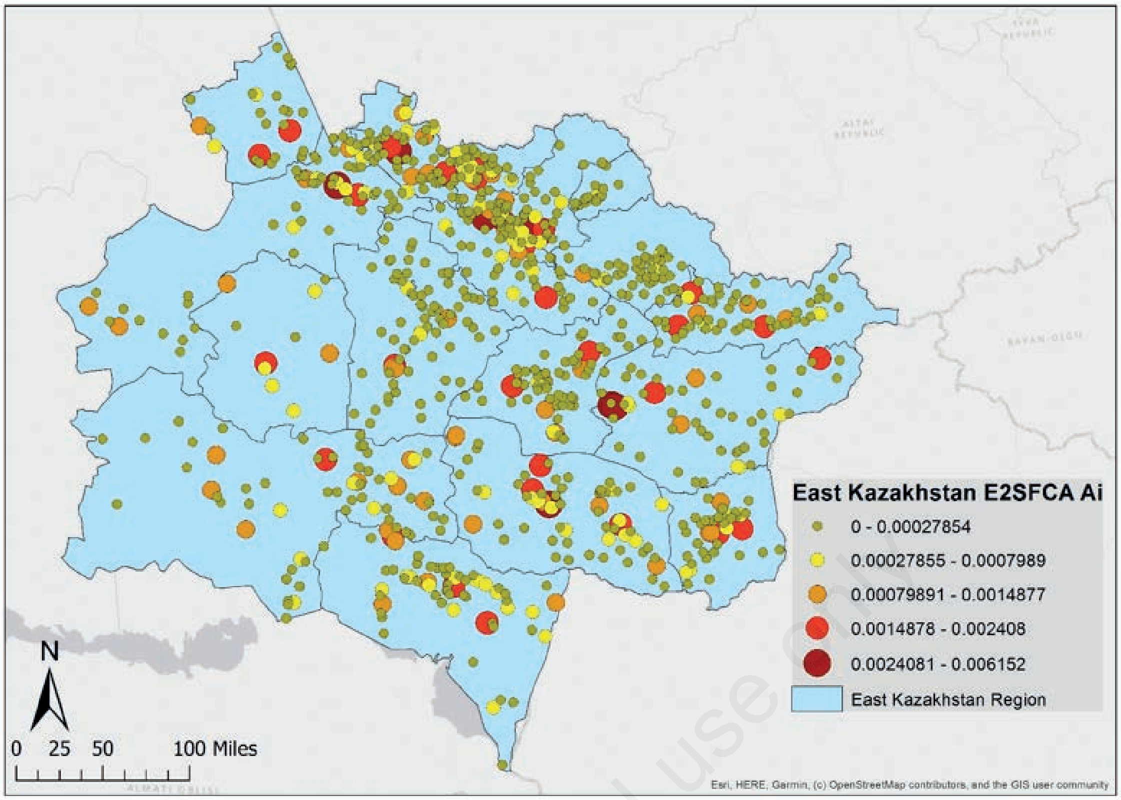

Figure 4. The E2SFCA A_i distribution in East Kazakhstan Region.

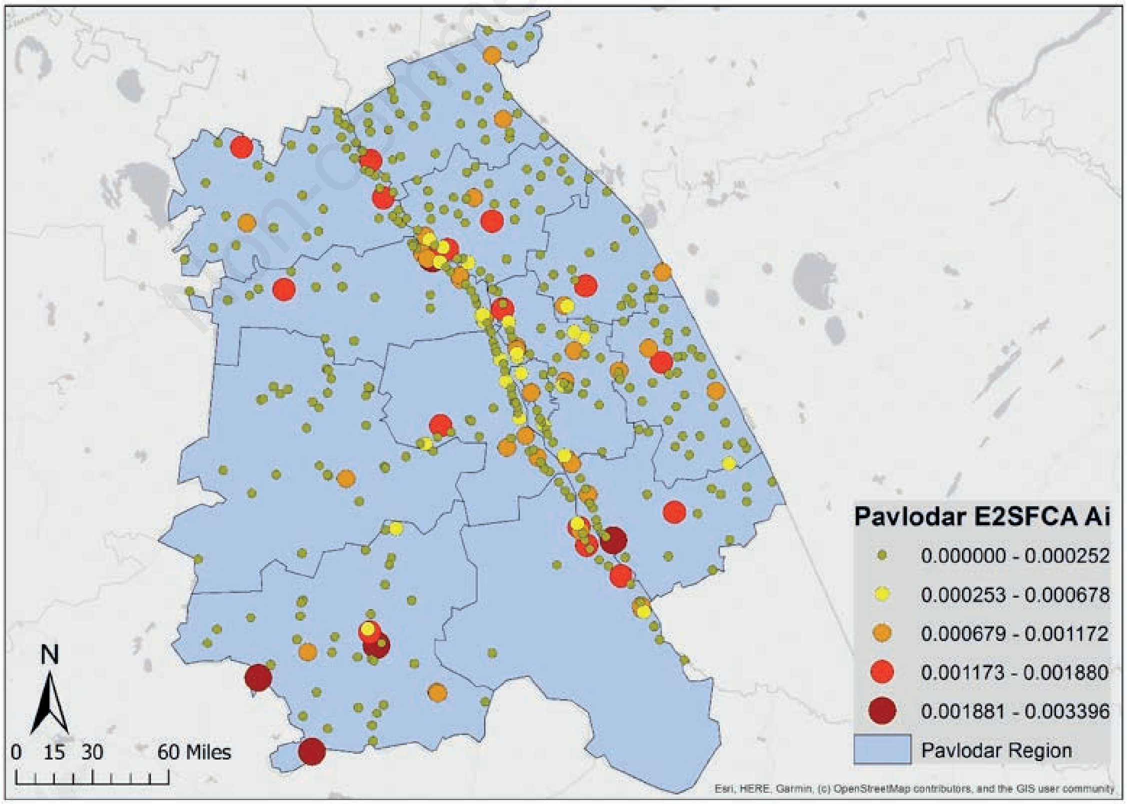

Figure 5. The A_i distribution in Pavlodar Region.

Calculating the Gini indices (Table 2), the greater disparity was seen in East Kazakhstan varying from Abay District (0.52) to Zharma District (0.93). In Pavlodar Region, the higher value was noted for Ekibastuz Municipality (0.97) and the lowest in Pavlodar District (0.69). These findings were visually confirmed by the Lorentz curves (Figures 8 and 9). In fact, the average E2SFCA A_i showed a strong negative correlation with the Gini index for East Kazakhstan districts (ρ= –0.60, P=0.008 in Spearman's correlation test), while the districts in Pavlodar had higher A_i and lower Gini indices, thus indicating better equality (ρ= –0.81, P=0.001 in Spearman's correlation test).

A comparison of the developed models with the current PHC facilities network for the regions of East Kazakhstan and Pavlodar is shown in Figures 10 and 11, respectively. Both the developed models have a better E2SFCA A_i than the current situation, which should contribute to better accessibility of PHC. This is confirmed by the data presented in Table 3.

Discussion

To the best of our knowledge, this is the first study in Kazakhstan and the Commonwealth of Independent States (CIS) assessing the physical accessibility and inequality of PHC in East Kazakhstan and Pavlodar based on the E2SFCA method. In order to reduce the inequality in the distribution of the A_i, we developed two location/allocation applications to increase the level of accessibility to PHCs for the populations, one investigating the need of adding facilities to the existing network, and another to see how this addition would work together with the current network. Both applications used were designed to solve the problem of selecting the minimum number of facilities required to capture a specific percentage of the total market share in the presence of competitors (Kuldeep *et al*., 2017).

We found that the majority of rural settlements in north-eastern Kazakhstan have a low availability of PHC services (Table 3). The

Table 2. Gini indices of the study districts.

No.	East Kazakhstan	Gini index	Pavlodar Region	Gini index
1	Abay District	0.52	Akkuly District	0.90
2	Ayagoz District	0.78	Aksu District	0.78
3	Beskaragay District	0.85	Aktogay District	0.75
4	Borodulikha District	0.83	Bayanaul District	0.86
5	Glubokoe District	0.80	Ekibastuz Municipality	0.97
6	Katon-Karagay District	0.86	Irtysh District	0.93
7	Kokpekty District	0.87	May District	0.70
8	Kurchum District	0.88	Pavlodar District	0.69
9	Ridder Municipality	0.84	Sharbakty District	0.89
10	Semey Municipality	0.80	Terenkol District	0.87
11	Shemonaikha District	0.68	Uspen District	0.85
12	Tarbagatay District	0.77	Zhelezin District	0.93
13	Ulan District	0.86		
14	Urdzhar District	0.71		
15	Ust'-Kamenogorsk Municipality	0.75		
16	Zaysan District	0.80		
17	Zharma District	0.93		
18	Zyryan District	0.86		

Table 3. Comparison between the current network and the two applications used.

	Pavlodar Region			East Kazakhstan		
	Current	Application 1	Application 2	Current*	Application 1*	Application 2*
Number of PHC facilities**	80	99101	226	251	234	
Number of physicians	552	586584	1007	1070	1057	
Market share	85%	90%90%	89%	92%	92%	
No. of settlements with A_i >0	109 of 404	136 of 404	146 of 404	340 of 827	366 of 827	360 of 827
Median of the calculated A_i	0.00068	0.00079	0.00084	0.0004	0.0006	0.0006

*Contains two settlements equated to the median E2SFCA A_i; **primary health care facilities.

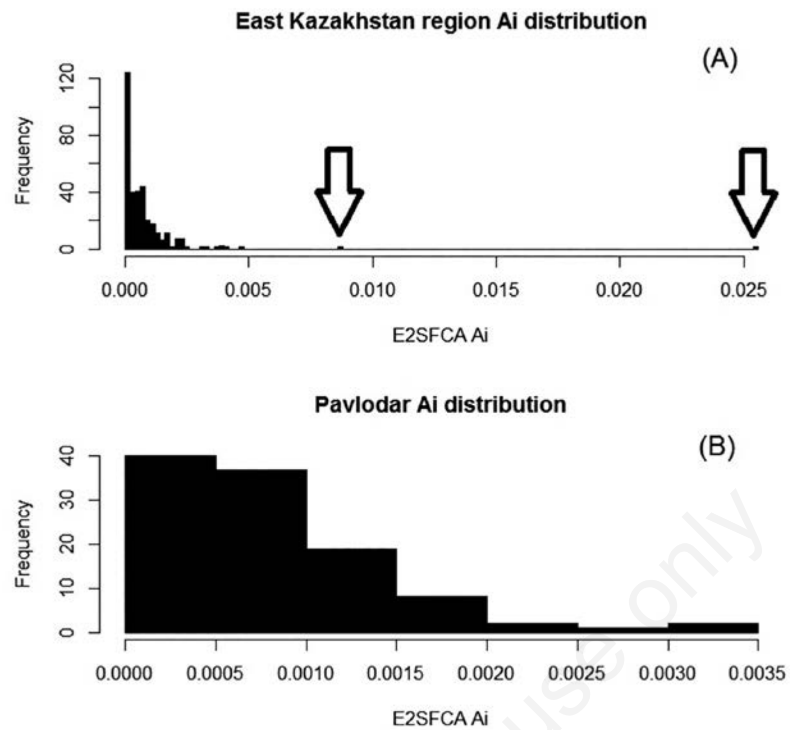

Figure 6. Histogram of A_i distribution in (A) East Kazakhstan and (B) Pavlodar regions. The arrows in plot A points indicates outliers consisting of small suburban settlements with a relatively high number of physicians.

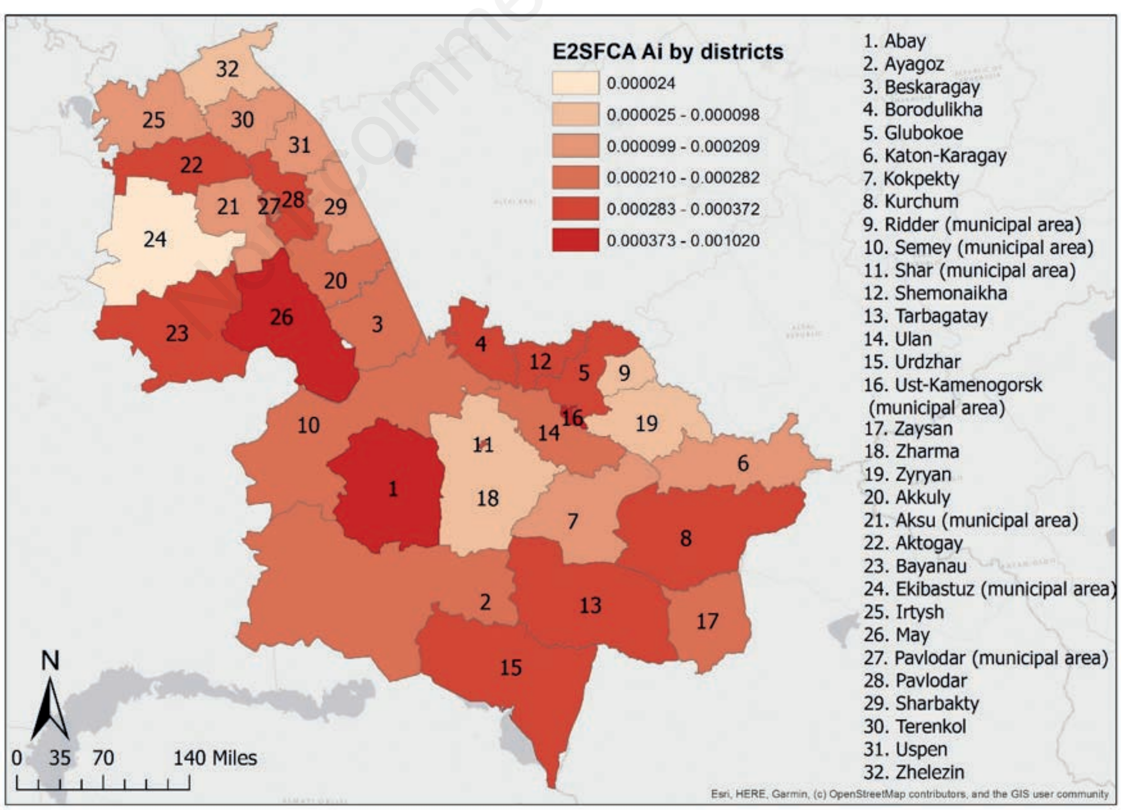

Figure 7. Distribution of A_i by districts of two regions.

rural regions of Kazakhstan have a huge territory with low population density, which leads to low availability indices in remote, sparsely populated settlements. These discrepancies have a major impact on the A_i value for the entire region. We found that low or zero indices are typical in most settlements, which, however, represent less than 15% of the total population in these regions.We used E2SFCA with a continuous decay because it is more sensitive for rural areas (Donohoe *et al*., 2016) and our finding are in accordance with results from other rural areas with similarily sparse populations (McGrail and Humphreys, 2009).

The 8 km threshold choice was decided after consulting similar international studies, in which most use travel time as part of the cost in the E2SFCA method (McGrail, 2012). British scientists found the maximum distance between a health facility and a presumptive patient to be 9.4 km with deprived areas defined as those more than 5 km away (Jordan *et al*., 2004), while an Indian study reported that the number of visits to a general practitioner sharply decreased if patients live more than 8 km away (Kanuganti *et al*., 2016). According to WHO (2019), a high proportion of populations living within 5 km of a PHC facility indicates of good coverage of health services.

Some studies find variable catchment areas for the E2SFCA method useful to account for the inclusion of residents in remote areas who must travel from far away (Luo-W and Qi, 2009; McGrail and Humphreys, 2009; Mao *et al*., 2011). In addition, authors commonly select various time zones in relation to the catchment areas in step 1, *e.g*., 5-, 10-, 15-min drive times was used in Iran to evaluate the spatial accessibility of emergency medical services and hospitals for people living with disability (Hashtarkhani *et al*., 2020; Kiani *et al*., 2021). A recent study measured the potential spatial access to COVID-19 vaccination centres using 1, 1.5 and 2 km distances for their different catchment areas (Mohammadi *et al*., 2021).

The results of application of location/allocation models, presented in Table 3 and Figures 9-10, provide evidence of the efficacy of these tools to improve the geographical accessibility of PHC.

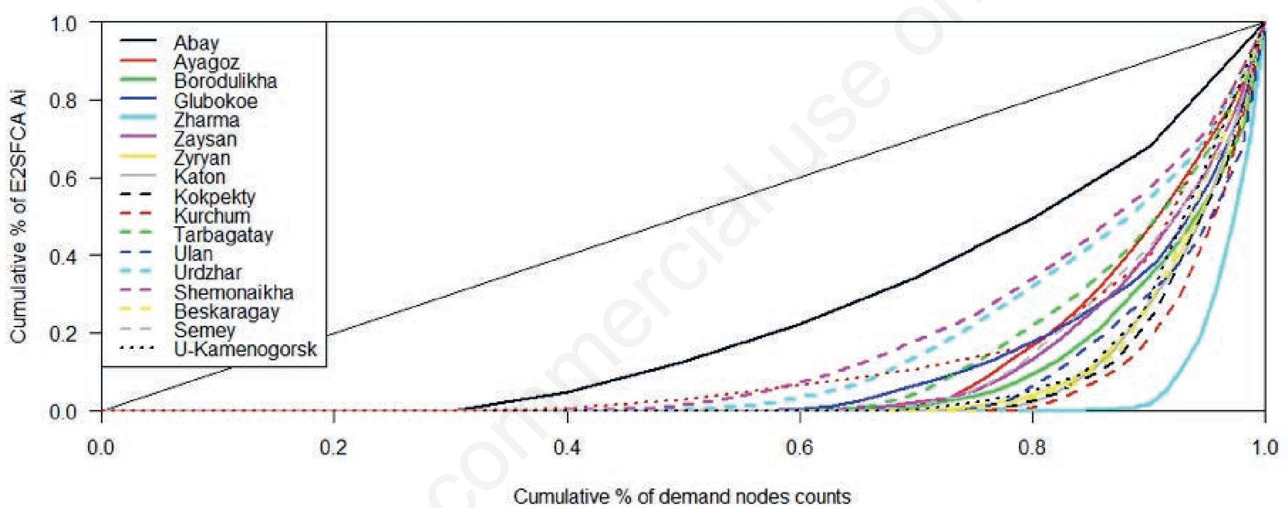

Figure 8. Lorenz curves of A_i for East Kazakhstan districts.

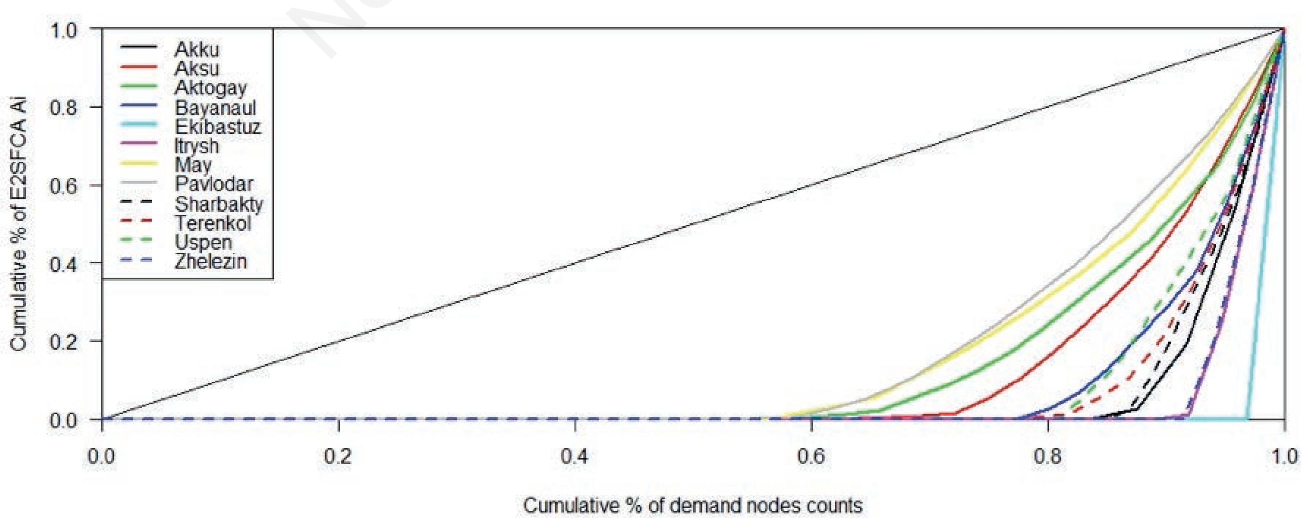

Figure 9. Lorenz curves of A_i for Pavlodar districts.

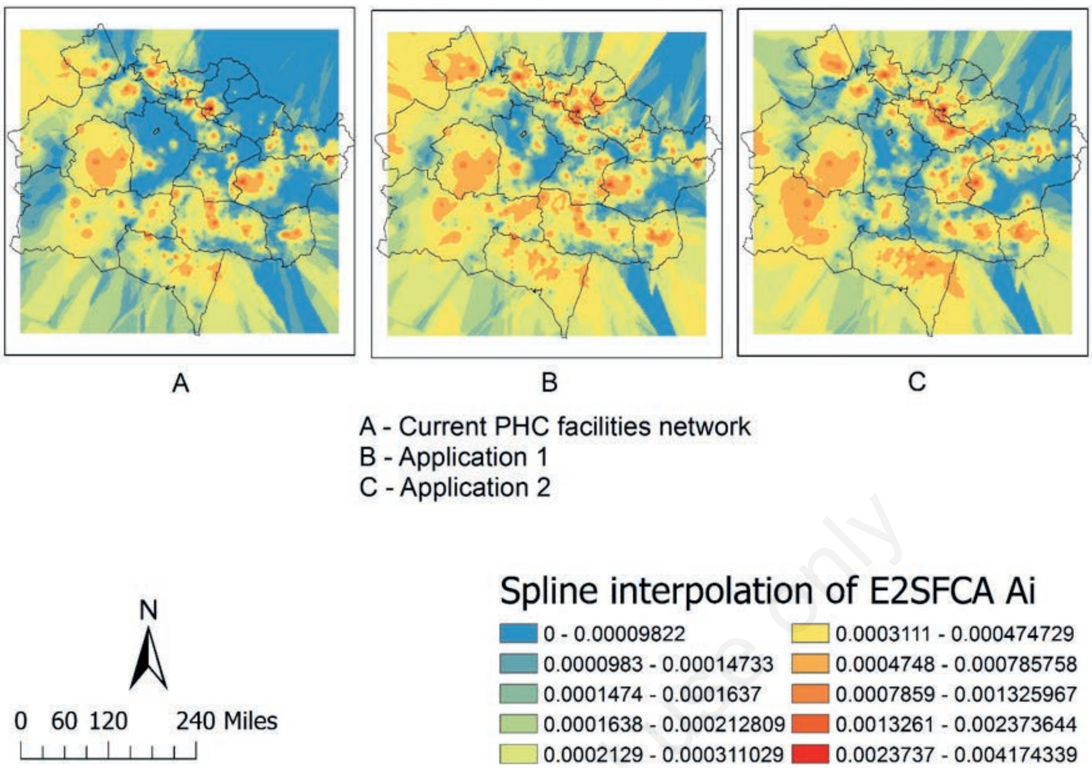

Figure 10. Comparison of East Kazakhstan region primary health care (PHC) service networks.

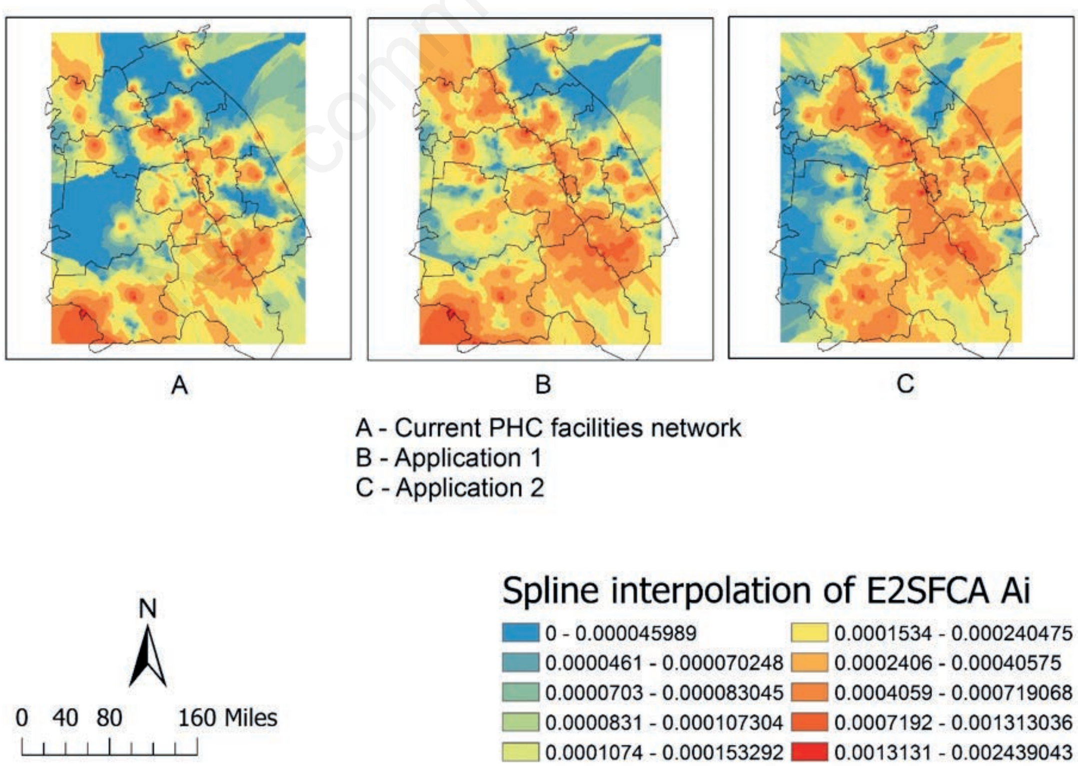

Figure 11. Comparison of Pavlodar primary health care (PHC) service networks.

The same approach has been used to improve access to healthcare in Saudi Arabia (Abdelkarim, 2019; El Karim and Awawdeh, 2020). In general, location/allocation problems (*p*-median, maximum covering location problem), E2SFCA A_i variance reduction, and their combination can be used to achieve spatial optimization towards a balance of efficiency and equality (Wang, 2020). Increasing coverage of PHC services further in remote areas is likely to be financially costly and require economic analysis.

The Gini index and the Lorentz curve are used to measure disparity among different decay functions or among different regions (Jamtsho *et al*., 2015; Tao *et al*., 2018). In our study, we examined the inequality in the E2SFCA A_i between the districts of two regions based on these indicators, which allowed us to clearly define areas into regions with equal and unequal access to PHC. We found that areas with high equity in accessibility to PHC have a higher average E2SFCA A_i and that inequality is typical of districts with low A_i.

Limitations

Spatial analysis with different geographical scales provides evidence-based documentation that is useful for prevention programmes (Shabanikiya *et al*., 2020). The computation of A_i indices for census blocks, block-groups, census tracts and correlation between them is better within urban than rural areas. However we did not have access to high-resolution data for the whole study area and had to settle for using courser data. Although the use of whole settlements and average A_i for districts as observation unit is an insensitive approach, the results would still be useful for future planning of PHCs. High-resolution census data by small administrative units in urbanized areas are likely to be available for developed countries (Bryant and Delamater, 2019).

We used the population data from the 2009 national census report, because more up-to-data data will not be available until the end of 2022. In addition, developed countries have access to agencies with knowledge of official road network data on which to base research, which was not available. However, there are also studies with road networks from Open Street Maps (OSM) and geofabrik files (Price *et al*., 2021; Subal *et al*., 2021). An additional limitation associated with the road network is the use of travel distance instead of travel time. We had valid locations for PHC facilities in cities, but they were generally tied to village locations in the rural areas.

Conclusions

Our study demonstrates the existence of areas with a shortage of PHC service resources in north-eastern Kazakhstan. This information should be useful for health policy decisions in for the planning of a better PHC service network. Our proposed models show, both statistically and visually, how the index could be improved in these regions.

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