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Optimizing allocation of colorectal cancer screening hospitals in Shanghai: a geospatial analysis

Jiaqi Huang,[1]* Yichen Chen,[2]* Gu Liu,[3] Wei Tu,[4] Robert Bergquist,[5] Michael P. Ward,[6] Jun Zhang,[1] Shuang Xiao,[1] Jie Hong,[1] Zheng Zhao,[1] Xiaopan Li,[7,8] Zhijie Zhang[1]

[1]Department of Epidemiology and Health Statistics, School of Public Health, Fudan University, Shanghai, China; [2]Center for Disease Control and Prevention, Pudong New Area, Shanghai, China; [3]Department of General Surgery, the first people's Hospital of Chenzhou, Hunan, China; [4]Department of Geology and Geography, Georgia Southern University, Statesboro, GA, USA; [5]Ingerod, Brastad, Sweden; [6]Faculty of Veterinary Science, University of Sydney, NSW, Australia; [7]Department of Health Management Centre, Zhongshan Hospital, Fudan University, Shanghai, China; [8]Office of Scientific Research and Information Management, Pudong Institute of Preventive Medicine, Pudong New Area, Shanghai, China

***These authors contributed equally**

Correspondence: Zhijie Zhang, Department of Epidemiology and Health Statistics, School of Public Health, Fudan University, Shanghai, China.
Tel.: +86.2154237410
E-mail: epistat@gmail.com

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Abstract

Screening programmes are important for early diagnosis and treatment of colorectal cancer (CRC) but they are not equally efficient in all locations. Depending on which hospital people belong to, they often are not willing to follow up even after a positive result, resulting in a lower-than-expected overall detection rate. Improved allocation of health resources would increase the program's efficiency and assist hospital accessibility. A target population exceeding 70,000 people and 18 local hospitals were included in the investigation of an optimization plan based on a location-allocation model. We calculated the hospital service areas and the accessibility for people in communities to CRC-screening hospitals using the Huff Model and the Two-Step Floating Catchment Area (2SFCA) approach. We found that only 28.2% of the residents with initially a positive screening result had chosen follow-up with colonoscopy and significant geographical differences in spatial accessibility to healthcare services indeed exist. The lowest accessibility was found in the Southeast, including the Zhangjiang, Jichang and Laogang communities with the best accessibility mainly distributed near the city centre of Lujiazui; the latter also had relatively a high level of what is called "ineffective screening" as it represents wasteful resource allocation. It is recommended that Hudong Hospital should be chosen instead of Punan Hospital as the optimization, which can improve the service population of each hospital and the populations served per colonoscope. Based on our results, changes in hospital configuration in colorectal cancer screening programme are needed to achieve adequate population coverage and equitable facility accessibility. Planning of medical services should be based on the spatial distribution trends of the population served.

Introduction

The World Health Organization (WHO) estimates that colorectal cancer (CRC) was the third leading cause of all cancer deaths in the world in 2020 (Chiu *et al.*, 2017; Siegel *et al.*, 2018). Although its incidence and mortality rates are decreasing in most industrialized countries, CRC is increasing in developing countries such as China. According to the population-based cancer registry system of China, the CRC incidence in Shanghai has doubled in the past two decades and is still increasing (Gong *et al.*, 2018). Precancerous lesions that represent early stages of CRC can be effectively diagnosed by colonoscopy and intervened in advance, thus effectively delaying the progression of the disease and reducing mortality (Issa *et al.*, 2017). Previous studies have found that populations attending at least one round of initial CRC-screening by faecal occult blood testing (FOBT) reduces the relative risk (RR) of mortality by 25% (Hewitson *et al.*, 2008; Navarro *et al.*, 2017). Thus, an efficient and effective CRC screening programme is crucial for prevention of this disease.

CRC-screening programmes have already been initiated in many industrialized countries and also in some developing countries. However, problems such as a large population base, lack of technology, high cost and uneven distribution of medical resources can obstruct the implementation of extensive screening programmes in developing countries, while low participation rates lead to low screening efficiency (Navarro *et al.*, 2017). Many countries organize CRC-screening programmes of various kinds and most try to maximize cost-effectiveness by focusing on high-risk population sectors, *e.g.*, through selecting higher age groups (Benard *et al.*, 2018; Schreuders *et al.*, 2015). Although many previous studies recommend improving the screening efficiency in this way, few focus on the need to improve medical resource allocation (Gheysariyeha *et al*., 2022; van Hees *et al*., 2015). Although colonoscopy is the preferred approach for CRC screening programmes, both hospital equipment and targeted populations are often unevenly distributed (Mandal *et al.*, 2018). Some studies have used spatial methods to evaluate accessibility to healthcare services in cancer screening programmes as exemplified by Texas and Florida in the United States (Jia *et al.*, 2015; Wan *et al.*, 2012) but they were limited to analyzing the rationality of the configuration and did not answer the issue of optimal configuration.

In Shanghai, China's largest economic centre, the incidence of CRC has been increasing in recent years (Gong *et al.,* 2018). To reduce the incidence and mortality of this disease more efficiently, a community-based CRC screening programme (C-CRCSP) was launched in 2013 by the Chinese Center for Disease Control (China CDC) in Shanghai. This is a major public health service programme with communities as screening units and risk assessment (RA) combined with FOBT for screening (Gong *et al.*, 2018). C-CRCSP has mainly been carried out for Shanghai residents aged between 50 and 74 years with initial application of FOBT and RA at community health centres. Participating residents with positive FOBT results were recommended colonoscopy in designated hospitals. The first two rounds of the C-CRCSP were completed by the end of 2016 (Li *et al.*, 2019) and the colonoscopy rate of participants with positive FOBT results was 39.8% (Gong *et al.*, 2018).

The Pudong New District (PND) is the largest of the 16 districts that make up Shanghai. The distribution of the existing medical resources is highly uneven across urban, suburban and rural areas within this district, which is mainly due to the existing hospital classification. Currently, the C-CRCSP programme designated a total of 13 hospitals for colonoscopy in PND with each hospital responsible for a catchment of community residents. This configuration was the result of a subjective choice made by the local government and generally without geographic specialist input. To improve this situation, it is vital to rationally direct hospital resources based on the need for CRC-screening hospitals. Importantly, while the effective primary FOBT screening rate of the total number (n=403,098) of PND residents, who participated in the programme and underwent FOBT, was 45.8%, while follow-up by colonoscopy was only 26.3%. There are many possible reasons for this, with differences in hospital accessibility likely to be an important spatial factor, as people prefer to do what is easy to achieve. If colonoscopy services are difficult to access, few people would approach them.

This study had two objectives, both based on spatial accessibility methods. One was to evaluate the spatial rationality of current location and allocation of the screening hospitals, and the other to propose an optimal configuration. We applied spatial methods to analyze the optimal configuration of hospitals for C-CRCSP in PND with the aim to evaluate whether the current subjectively chosen hospital distribution is appropriate; if not, we also aimed to find out the reason.

Coexisting with the low screening follow-up rate, people are often unnecessarily rescreened even after negative results. This is mainly due to skewed community mobilization or people volunteering because they are concerned about their health. This can be called "ineffective screening" as it represents wasteful resource allocation. Therefore, analysing allocation of health resources can both increase efficiency rates and improve accessibility to colonoscopy. Maximizing population coverage requires location-allocation network analysis, while optimization of hospital allocation aims at maximizing hospital access and capacity. This is an urgent and significant question for improving future CRC screening activities.

Materials and Methods

Study area

PND is located in the eastern part of Shanghai. With an area of 1,429 km^2, it accounts for about one-fifth of the city and is composed of 48 communities of three types, central urban, suburban, and rural (Li *et al.*, 2012). The registered population was about 2.95 million in 2016, about a quarter of Shanghai's total.

The crude incidence rate of CRC in PND from 2002 to 2012 was 42.65/100,000 person-years, ranking second of all malignant tumours in the city. The crude death rate of CRC in PND was 23.51/100,000 person-years, accounting for 3.3% of the total number of deaths. Compared with an estimated worldwide CRC crude incidence rate of 24.8/100,000 person-years and a mortality rate of 12.0/100,000 person-years in 2020 by the International Agency for Research on Cancer (IARC) at WHO, these high rates together with the regional disparity (coexistence of urban, town, and rural areas) makes PND a suitable area for the study.

Data sources

C-CRCSP data

The CRC screening data were collected from the CDC at PND. Shanghai residents aged between 50 and 74 years with at least one type of Shanghai basic medical insurance were considered as the target population, in this area amounted to about 19.2% of the residents. The size of the theoretical target population in each community was calculated using the following equation:

$$P=n\times \frac{m}{t} \quad \text{Eq. 1}$$

where P is theoretical target population, m the number of positive results at primary screening; t the total number of screened participants; and n the total number of residents aged between 50 and 74 years.

Hospital-related data

Hospitals in China are classified into three levels: primary, secondary and tertiary, where the latter represent the highest level with the best resources and the ability to provide the most comprehensive treatments. A total of 18 hospitals in PND were equipped to carry out colonoscopy and 13 were subjectively selected to participate in the C-CRCSP programme. Five of these were tertiary hospitals and eight secondary. At the time of the study, Renji Hospital had 13 colonoscopes, the southern branch of Shanghai East Hospital five, with the remaining hospitals on average two each. In addition, there were five hospitals with colonoscopy facilities that did not participate in the programme (Figure 1).

The postal addresses of hospitals were converted to points of latitude and longitude data using the coordinate system from Baidu Maps in China.

District-based PND map

The district and community boundaries map of PND were digitized based on an administrative division map (Shanghai Surveying and Mapping Institute, 2016). The road network data was downloaded from OpenStreetMap.

Spatial analysis

In order to evaluate the existing spatial configuration from the hospital and community perspectives, respectively, the study conducted the Huff model (Huff, 1963) and the two-step floating catchment area (2SFCA) method (Wang, 2014). The Huff model was used to delineate the hospital service area, which helps revealing the area of hospital services and the attractiveness of the hospital (Jia *et al.*, 2017). The 2SFCA method was used to calculate the spatial accessibility from communities to screening hospitals, with the aim to assess the current state of access to colonoscopy service in each community. The 'ineffective screening' rate was calculated to help evaluate the effectiveness of hospital utilization. Optimization of the spatial allocation was effectuated by matching the target population with the hospital's service capacity based on location-allocation network analysis. The goal was to find a rational medical resource allocation that could be used to promote a superior allocation of C-CRCSP medical resources that would contribute to a better follow-up rate after positive primary screening results.

Hospital service area

The hospital service area (HSA) refers to an area within which most local hospitalization occurs and each hospital services one or more communities (Jia *et al.*, 2015; Luo *et al.*, 2016). The HSA was measured as a probability which was estimated as the quantity and quality of the facility in question and the distance between the hospital and community. The Huff model was used to calculate the hospital HSAs in the screening programme. This model assigns each community to the hospital with the highest probability providing services for its residents. The model considers mainly a hospital's service capacity and the distance impedance between community and hospital.

This study used the Huff model tool kit to delineate the HSAs of the 13 designated hospitals in PND using the travelling time (average speed 60km/h) based on the available road network (Wang, 2014). The number of colonoscopies performed at the hospital was set as the facility size given. The distance decay coefficient value was set at 3 to ensure that the size of the service area was appropriate and close to the actual situation. This coefficient affects the degree to which the attractiveness of the destination is attenuated by the distance. For sensitivity analysis, the hospital service areas with distance decay coefficients of 2 and 4 were also analysed (*see Appendix*).

Spatial accessibility

Spatial accessibility refers to the relative ease by which the locations of activities can be reached from a given demand location (Wang, 2014). For the C-CRCSP programme, spatial accessibility depends mainly on the distance impedance between hospital and residence, but also on the total target population and the quantity of colonoscopies carried out in the hospitals (Wang, 2014).

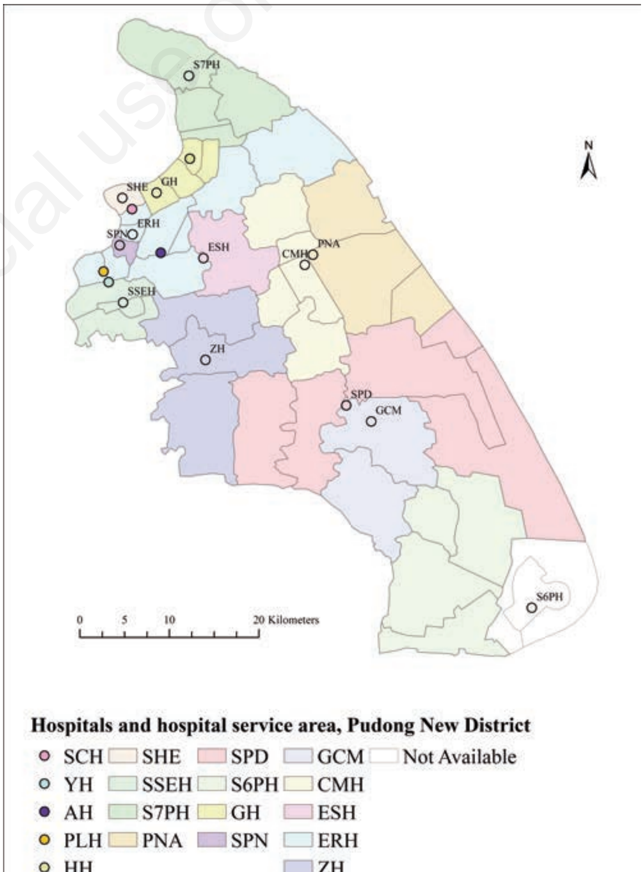

Figure 1. Distribution of the 18 hospitals with colonoscopes and the hospital service areas of the 13 designated hospitals in Pudong New District. For the 13 hospitals, the hospital service areas are shaded with the same colour as the mini-circles representing them. The hospital abbreviations in the legend refer to the full names given in Table 1. The mini-circles in the map represent colonoscopy-equipped hospitals with shades as given in the legend, in which hospitals included in the screening programme are represented by squares and hospitals not included in the screening programme as points.

We calculated the hospital accessibility for each community and used travel time on the road network according to the 2SFCA method (Kirby *et al.*, 2017; Radke *et al.*, 2000) due to easy implementation and intuitive visualization (Gu *et al.*, 2019).

In this study, the community locations were represented by their geometric centres a target population calculated for each community. The accessibility index was calculated using the 2SFCA toolkit (Wang, 2014). The number of colonoscopies per hospital was set as proxy for the supply value, with the theoretical target population of each community as the demand value. The length of the shortest (or most convenient) road from community to hospital was used to calculate the travelling time based using 60 km/h as average speed.

We had to clearly identify which communities had limited accessibility to hospital so we used a distance threshold of about 22 min (1,300 sec to be precise), which means hospitals within this driving distance from the communities were considered as reachable. We could not use the screening data to estimate travel time, but after performing a sensitivity analysis we found this value to be an appropriate value for the region. For the sensitivity analysis, thresholds of about 17 min (1,000 sec) and about 13 min (800 sec) were used with all the other model parameters remaining the same.

Analysis of the 'ineffective screening rate'

A situation when a resident is rescreened within three years in spite of a previous negative result amounts to an ineffective activity as this second screening must be considered unnecessary. In such cases, the purpose of the screening programme becomes skewed, which leads to a certain degree of waste of medical resources. Since each community is assigned a certain amount of people to be screened, the more people who are ineffectively screened, the less accessible it is for others in the area to participate in the screening. Therefore, the identification of locations with high 'ineffective screening rates' through monitoring of the communities' screening operations would lead to a less skewed mobilization that can free up resources and redirect allocations making the whole programme more effective. Here, the 'ineffective screening rate' of each community was calculated to find out how common it is. Tentatively, values greater than 20% were considered as high.

Optimum colonoscopy allocation

The number of colonoscopy facilities in a hospital cannot be changed so the situation can only be improved by including different hospitals in the screening programme. Thus, location-allocation (L-A) becomes the process of finding a set of facilities that would best serve demand from surrounding areas. It includes maximizing coverage, minimizing facilities and other methods suitable for solving optimal allocation problems under a variety of conditions and targets (Rahman *et al.*, 2000; ESRI, 2021). Maximizing capacity coverage solves the location problem where facilities have a finite capacity. It means that facilities be distributed in a way that permits the greatest amount of demand to be served without exceeding the capacity of any single facility. With respect to capacity, facilities are selected so that the total sum of weighted impedance (demand allocated to a facility multiplied by the impedance to or from the facility) is minimized. In the study, the target population of the community and the service capacity of the hospital were considered. Based on the specified number of hospitals and distance thresholds, the results reveal which hospitals were selected and matched with which communities, allowing the hospitals to maximize the amount of services they can provide, while at the same time minimize the total weighted impedance from communities to hospitals. With the primary goal of covering the needs of the target population, the method developed to maximize the use of the hospitals' available resources was adopted to optimize the configuration of the C-CRCSP hospitals (Polo *et al.*, 2015). Since the inclusion of all 18 hospitals would be a waste of available resources the minimum number of the hospitals required to meet all target population coverage while minimize the total impedance from communities to hospitals was calculated. Consistent with the accessibility measure, the threshold for travel from the community to the hospital was set at 1,300 sec, and which of these 18 hospitals to choose for C-CRCSP was based on the L-A method. This gave us the communities covered by each hospital. The service capacity of each hospital was calculated by multiplying the maximum number of consultations per week for colonoscopy patients in each hospital. As we only had data on the maximum number of weekly colonoscopy consultations per hospital, multiplying by the total length of the screening program's four years would yield a too large number. To get as close to the true number as possible, we chose two years as the best match between the number and the hospital service capacity. The number of communities and demand population corresponding to the hospital, and population served per colonoscope of the hospitals were compared before and after optimization to test the results of optimization. We considered the number of colonoscopies performed because they can represent the hospital's service capacity

All the above spatial analyses were done using ArcGIS 10.2 (ESRI, Redlands, CA, USA) and its extensions, including the Huff, the 2SFCA and the Network analyst tools.

Results

Implementation of the C-CRCSP programme

In the first round of CRC screening, 1,262,214 invitations were sent and a total of 421,384 residents within the targeted age range participated. A total of 77,473 participants tested positive by FOBT and were advised to have a colonoscopy examination. Among the 21,876 (28.2%) of the participants who accepted and received the colonoscopy examination, 348 were diagnosed with cancer. In PND, the theoretical target population for colonoscopy was estimated at 74,608 residents aged between 50 and 74.

The hospital service areas (HSAs)

Thirteen Huff-based HSAs are shown in Figure 1. Renji Hospital and Shanghai Pudong Hospital have the largest HSAs containing more than five communities, while Shanghai Oriental Hospital and Punan Hospital have the smallest, each consisting of only one community. Although the concern is essentially about the number of people that each unit can serve, the HSA approach only considers the location and capacity of the hospital facility and does not consider the demand population of the community. Thus, it is theoretically possible for the community population in the service area to exceed the hospital's capacity. In principle, however, the larger the service capacity of a hospital, the larger its service area; additionally, the more hospitals nearby, the smaller their service areas. Hospitals located in towns and rural areas often have larger service areas, such as Shanghai Pudong Hospital.

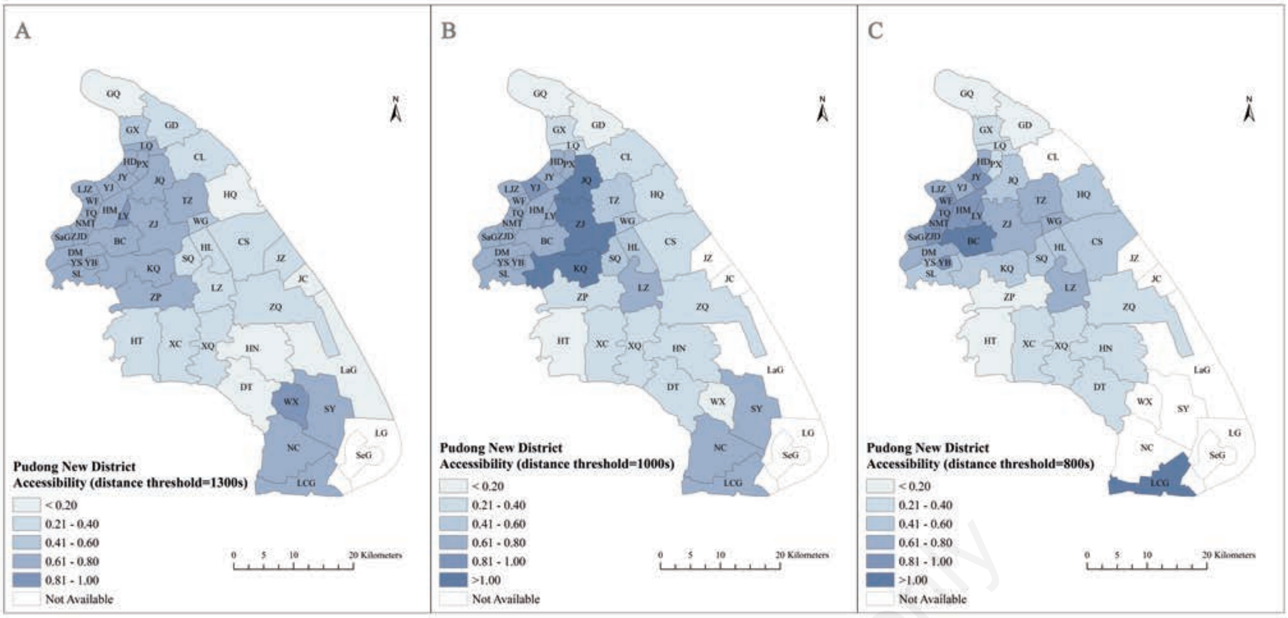

Figure 2. Access to CRC screening hospitals for target population with different distance thresholds.

Accessibility

The accessibility to the 13 designated hospitals in the 46 communities is shown in Figure 2. A threshold of 1,300 sec (Figure 2A) ensured that each community had access to at least one hospital. Some rural communities had very low accessibility scores, while most urban communities had much higher scores. Most of the low-access areas were found in suburban and rural communities in the East, such as Jichang, Laogang and Gaoqiao. After lowering the threshold value to 1,000 sec (Figure 2B), some rural and suburban communities, including Zhangjiang, Jichang and Laogang, lost their hospital access. Figure 2C confirmed a general pattern of high accessibility in urban communities and low or none in some suburban and rural communities at the 800 sec threshold. This shows that there are great differences with respect to hospital accessibility, with pronounced weaknesses in some communities.

'Ineffective screening rates'

Figure 3 shows that the high 'ineffective screening rates' were concentrated in PND's north-western region, a central area of Shanghai. It was found that Lujiazui, Weifang, Yangsi and Sanlin exceed 20% in this respect. This result illustrates that even communities in urban areas often have high 'ineffective screening rates'. Three communities in the Southwest also showed relatively high values. This information could be a reference of interest to the managers of screening programs even if we did not used it in the overall analysis because it was not regarded as the most important indicator.

Optimization

As shown in Figure 4, a minimum of 13 hospitals were needed to cover the demand of all the target population. Naturally, the overall accessibility score would be better if there were 18 hospi-

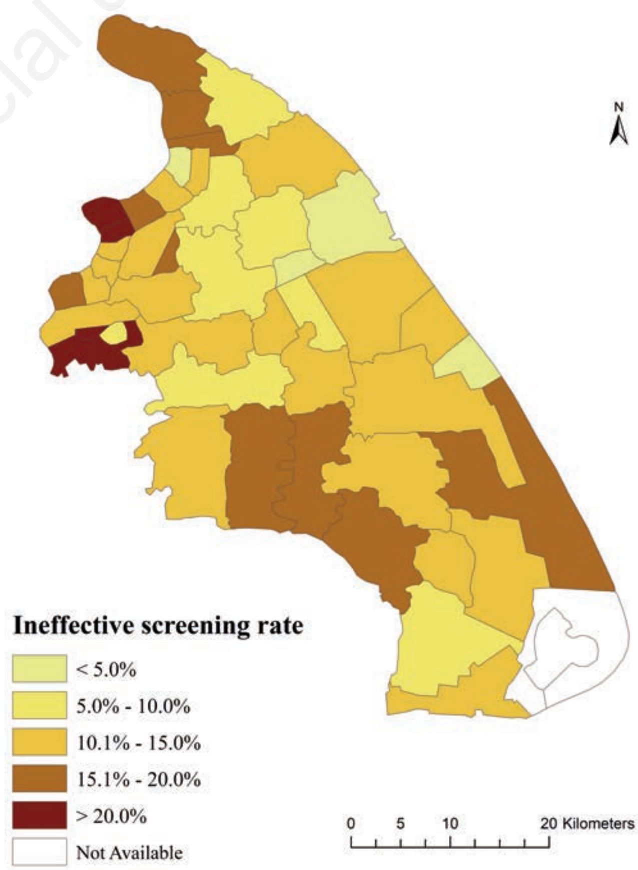

Figure 3. Map of the community-based 'ineffective screening rate' in Pudong New District.

tals, but this would only help areas with high accessibility to get better, while providing less for areas with low accessibility. In addition, including more hospitals would require more resources for the screening program. Although the calculated number was exactly the same as the one that was used in practice, the hospitals in each case were slightly different (Figure 5A,B). For example, Hudong Hospital was included and Punan Hospital was excluded based on our calculation. The number of communities covered by the PND Guangming Chinese Medicine Hospital, the PND Chinese Medicine Hospital of and the southern branch of Shanghai East Hospital increased, while the others decreased or remained the same. In addition, the results also indicate low accessibility in some rural communities in the Southeast.

Table 1 shows the service capacity of the hospitals designated by screening programme and the number of target populations assigned compared with the optimized performance. The percentage of the population served was equal to this number divided by the hospital's service capacity. Some hospitals were shown to have percentages higher than 100%, which means that the number of people trying to access them exceeded the hospital capacity, which would likely either lead to overload or that some of the target population drop out of the program. After optimization, the population served by each hospital no longer exceeded the capacity of the hospital. Overloaded hospitals such as Shanghai East Hospital,

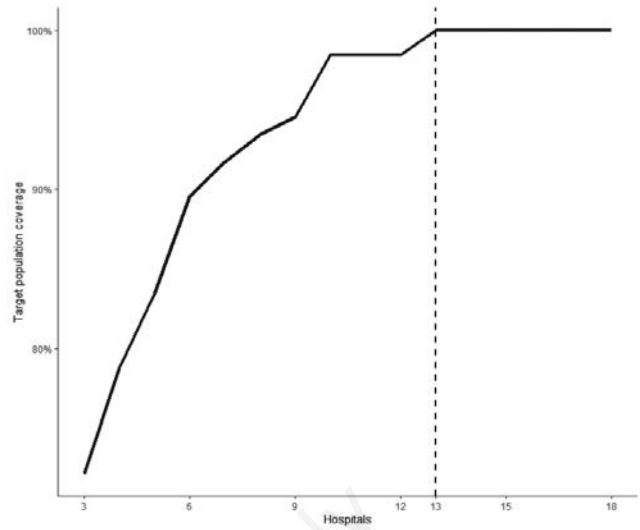

Figure 4. Number of hospitals - target population coverage curve with the calculated hospital capacity. The horizontal stretch between 10 and 12 hospitals is due to optimized accessibility of part of the area (*i.e.* minimizing the total impedance) rather than increasing the population covered.

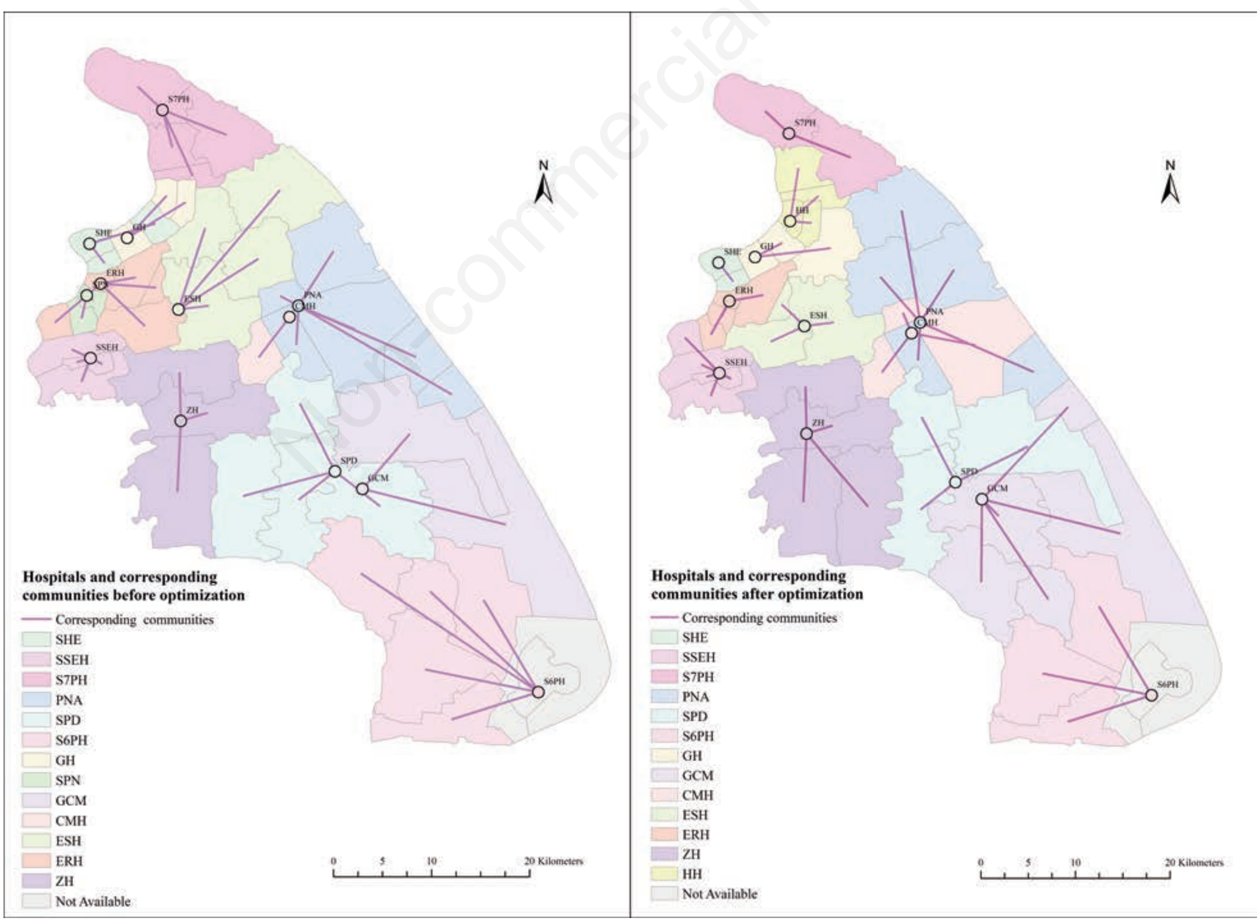

Figure 5. Comparison of hospital allocations before and after optimization. A) Original allocation of hospitals for the CRC programme; B) Suggested optimum allocation of the hospitals; abbreviation of the hospitals in the legend as shown in Table 1.

Shanghai Seventh People's Hospital and Shanghai Punan Hospital have seen a decline in the number of serving population and people are being placed in other hospitals that have spare capacity. The average population served per colonoscope decreased from 2360.10 before optimization to 2281.94 afterwards, with the standard deviation (SD) decreasing from 1212.46 to 1160.45. Although minor, these values indicate a reduction in the average load of the hospitals and a relative equalization of the load across hospitals.

Discussion

This study used spatial analysis techniques to quantitatively evaluate and optimize the resource allocation of CRC screening facilities in hospitals in Shanghai. An unequal resource allocation of hospitals and unequal accessibility between urban, rural and suburban areas were simultaneously identified. Urban and rural communities showed significant spatial accessibility disparities. The relatively high accessibility of urban areas indicated a larger number and higher service capabilities of the allocated hospitals, while the low accessibility in the south-eastern rural communities is without doubt related to the low number of hospitals, the distance of the community from the hospital, and the weak service capacity of local hospitals.

Our intention was to use the HSA approach to reveal the attractiveness of hospitals in their natural state, *i.e.* which hospitals are spatially capable of serving more communities. We did not have relevant screening data available to analyze the results associated with the Huff model for the Renji and Pudong hospitals, but the HSA results show that they have large service areas. Renji Hospital is a city-level district colonoscopy centre with far more colonoscopes than the other hospitals, which exerts a strong appeal even among communities far from this hospital, while the large HSA of Pudong Hospital is related to the scarcity of other hospitals in nearby areas. In addition, since Shanghai Oriental Hospital and Punan Hospital both have small HSA areas, they can still be considered reasonable since they are located in urban areas and serve a considerable population.

Higher rates of 'ineffective screening' occurred mostly in urban areas, possibly because people in urban areas had better health education and were more concerned about their health. Moreover, their residences there are close to the hospital, and it is convenient to seek medical treatment, which increased the willingness and opportunities for screening. The 'ineffective screening rate' results indicated that communities, including Lujiazui, Weifang, Yangsi and Sanlin, had high rates and the promotion of correct medical information needs to be strengthened in those communities. While neither relevant nor important for the overall

Table 1. The number of communities and serving population of the hospitals corresponding to the hospital and population served per colonoscope before and after optimization.

Hospital (abbreviation)	Colonoscope (no.)	Capacity*	Before optimization			After optimization		
			Community (%)	Population served (%)	Population per colonoscope	Community (%)	Population served (%)	Population per colonoscope
Shanghai East Hospital (SHE)	2	5,200	3	9,067 (174)**	4,534	2	4,200 (81)	2,100
Southern branch of Shanghai East Hospital (SSEH)	5	26,000	4	6,645 (26)	1,329	5	10,312 (40)	2,062
Shanghai Seventh People's Hospital (S7PH)	2	4,368	4	5,281 (121)	2,641	2	4,335 (99)	2,168
Pudong New Area People's Hospital (PNA)	2	6,864	6	6,755 (98)	3,378	5	6,815 (99)	3,408
Shanghai Pudong Hospital (SPD)	2	5,616	4	5,022 (89)	2,511	3	4,585 (82)	2,293
Shanghai Sixth People's Hospital (S6PH)	2	18,720	5	4,987 (27)	2,494	3	2,723 (15)	1,362
Gongli Hospital (GH)	3	1,0400	3	4,745 (46)	1,582	3	6,589 (63)	2196
Shanghai Punan Hospital (SPN)	2	2,080	2	6,240 (300)	3,120	0	0	0
Guangming Chinese Medicine Hospital of Pudong New Area (GCM)	1	5,200	2	3,422 (66)	3,422	5	4,666 (90)	4,666
Chinses Medicine Hospital of Pudong New Area (CMH)	2	2,080	1	66 (3)	33	3	1,905 (92)	953
East branch of Shuguang Hospital (ESH)	3	15,600	4	5,457 (35)	1,819	3	5,585 (36)	1,862
East branch of Renji Hospital (ERH)	13	26,000	5	10,967 (42)	844	4	9,451 (36)	727
Zhoupu Hospital (ZH)	2	10,400	3	5,954 (57)	2,977	4	8,338 (80)	4,169
Shanghai Changhang Hospital (SCH)	1	1,872	0	0	0	0	0	0
Yangsi Hospital (YH)	5	5,200	0	0	0	0	0	0
Anda Hospital (AH)	1	5,200	0	0	0	0	0	0
Pudong branch of Longhua Hospital (PLH)	2	2,080	0	0	0	0	0	0
Hudong Hospital (HH)	3	5,200	0	0	0	4	5,104 (98)	1,701
Total	53	158,080	46	74,608	30,684	46	74,608	2,7966

*The service capacity was calculated by multiplying the maximum number of consultations per week by the number of weeks (in two years) rather than the number of colonoscopies. Although it is not perfectly reasonable to compare the population per colonoscope, the difference in population served is not as large as the service capacity; **Explained by the fact that the number of people accessing the hospital exceeds its capacity leading to overload.

spatial analysis, this information provides decision makers with some additional information for optimizing the screening strategies. An optimized configuration is proposed according to the L-A method. Through the calculation of this configuration, the adjustment effectively improved the rationale of the hospital service areas, while still meeting the need of coverage of the target population. Our optimization suggestions would make the population serviced by hospitals better match the number of their colonoscopes available and enhance efficiency by reducing the number of people served by each colonoscopy. This suggests that spatial analysis techniques can be applied to optimize the issue of health resource allocation as a feasible quantitative method.

The problem of unfair accessibility of communities still exists. The underlying reason is that there are no available hospitals near communities with low accessibility. Consequently, changing the selected hospitals cannot effectively improve the poor access in those areas. Hence, more colonoscopy services located in areas with lower accessibility are strongly suggested. According to the information of all the first-level, secondary and tertiary hospitals in PND provided by the local CDC, it is believed that the addition of colonoscopes at Nanhua Hospital and Laonian Hospital could help solve some of the problems of low accessibility areas (around Huinan, Xinchang and Xuanqiao). For the lowest accessibility areas, including Zhuqiao, Laogang, Jiangzhen and Jichang, it would instead be better to establish new colonoscopy service sites.

There are two limitations in this study. Firstly, the study assumed that all road sections in PND can be travelled at an average speed of 60km/h. If different driving speeds can be set according to road classifications, the total time spent could be more realistic and accurate when using time thresholds for the calculations. Secondly, we used the central points to represent the location of each community, which is a simplification; however, fine scale differences could not be incorporated, especially in large communities. If a smaller spatial unit were available, the accuracy of the results would be further improved.

This study discussed the optimum configuration issue of colonoscopy screening at hospitals from the perspective of geospatial analysis. We found significant differences of spatial accessibility to healthcare services in all of PND. Our results indicated that the least accessibility is mainly distributed around the south-eastern corner and the best accessibility was mainly distributed near the city centre around Lujiazui. It is recommended to change a designated hospital for CRC screening, and colonoscopy facilities and services should be increased in communities with low accessibility. We also wish to emphasize that the configuration plan needs to be combined with the actual situation of the implementation site, the current degree of cooperation between the service centre and the residents and the regional construction plan. The suggestions presented in this paper would have important practical significance for local policy makers and the optimization method combined with spatial analysis is valuable for making scientific decision-making based on objective results instead of the use of subjective selections for CRC screening hospitals.

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Online supplementary material:
Figure S1. The hospital service areas in Pudong New District when the distance decay coefficient was 2(A) and 4(B), respectively.
Abbreviations and full names of communities in Pudong New District.