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GIS-Based Multi-Criteria Analysis for Hospital Site Selection in Haidian District of Beijing

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Abstract

China has the largest population and the fastest growing economy in the world. The general public's demand for health is rising promptly with the improvement of the living standard. However, the limited and unbalanced medical resources have caused the prominent problems of the society, even in the capital city Beijing, the new hospital constructions with rational allocation is imminent and significant. Along with the technology development and Internet popularization, GIS approaches and related products has been widely used in the people's daily life. The main focus of this paper is to select a site for building a new hospital in Haidian District of Beijing using GIS-based Multi-Criteria Analysis (MCA). With Analytical Hierarchy Process (AHP) and Rank Order Method (ROM) for the weight setting on factor criteria, necessity tests and sensitivity tests are applied to check which criteria are really necessary and how the results are sensitive to their weight change. The optimal site located in Wenquan Town (E: 116.182, N: 40.039) is screened from several candidate sites using Google Earth maps, which makes the ultimate result more convincing and practical. It can be concluded that GIS-based MCA with necessity and sensitivity tests proposes a novel and useful reference to other site selection decision makers, and also provides constructive tools for the public administration to set up efficient databases for decision makers to carry out spatial analyses. To make it more maneuverable and practical, a further research on the improvement of this method will have a promising future.

Key words: Hospital site selection; GIS-based MCA; AHP; ROM; Necessity tests; Sensitivity tests

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1 Introduction

1.1 Background

Hospitals are one of the most important infrastructural objects. The increasing population, especially in developing countries, amplifies the demand for new hospitals. Hospitals are usually funded by the public sectors, by profit or nonprofit health organizations, charities, insurance companies or even religious orders. No matter who provides the answer, where to locate a new hospital is an important question to ask.

Hospital site selection plays a vital role in the hospital construction and management. From aspect of the government, appropriate hospital site selection will help optimize the allocation of medical resources, matching the provision of health care with the social and economic demands, coordinating the urban and rural health service development, and easing social contradictions. From aspect of the citizen, proper hospital site selection will improve access to the health care, reduce the time of rescue, satisfy people’s medical needs as well as enhance the quality of life. From the aspect of the investors and operators of the hospital, optimum hospital site selection will definitely be cost saving on capital strategy. It is an inevitable trend for hospitals to adopt cost accounting in order to adapt to the development of the market economy. Besides, better hospital site selection will promote the strategy of brand, marketing, differentiation and human resource, and enhance the competitiveness.

China has the largest population and the fastest growing economy in the world. The general public’s demand for health is rising promptly with the development of the economy. Figure 1 below shows the gross diagnosis and treated numbers of patients as well as their increment speed in Beijing during year 2007 to 2011 (Beijing Public Health Information Center, 2012). The diagnosis and treated number rose much more than ten millions every year. This is the official statistic data mainly collected from big state-run hospitals. As a matter of fact, along with the China health care system reform in recent years, the public administrations relax restrictions on hospital building. A lot of non-governmental hospitals and private clinics spring up and occupy a large part of market share. A great quantity of residents tends to go there due to a much more flexible and patient-centered service. Hence, the actual increasing number might be two or three times than ten millions every year, and it will be much more in the following years owing to the population aging process of China.

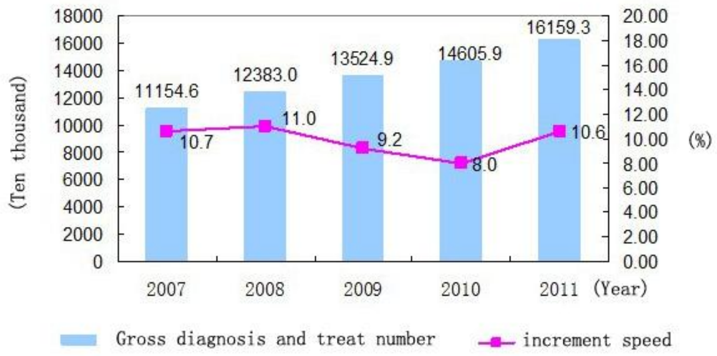


Figure 1 Gross diagnosis/treated number and increment speed in Beijing (2007 -2011)

It is undeniable that the medical resources of the whole China are severely unbalanced from region to region due to the great differ on economy growth and unreasonable distribution by government. Beijing, the capital of China, possesses superior medical resources and medical talents compared with other regions. Even though, there still exits unbalances between different districts, urban and rural areas. For example, inside the Fourth ring road of Beijing, hospitals are already saturated, outside the Fourth ring road, the quantity of hospitals are sharply reduced. With the reconstruction and speedy extension of Beijing, the population continues to spread into the areas outside the Fourth ring road, and the contradiction between supply and demand for hospitals is getting increasingly serious. Furthermore, there is a strange but common phenomenon with Chinese characteristics. Beijing owns many huge general hospitals, and almost has all the best specialized hospitals of the country such as Beijing Children's Hospital. A great many people are accustomed to follow the good fame of hospitals blindly. Even if for minor ailments, they would try to see the best doctors. However, the high quality medical resources are severely limited. It is inconceivable that the patients have to queue up at hospital at four o'clock in the early morning to wait for the register. If lucky, it takes the whole day, but normally it takes several days without leaving. As for the online appointment or reservation by phone, it usually takes more than three months to register at a hospital. Thus gives rise to corruption of those authorities and doctors, sending gifts or money to them becomes an unspoken rule. Especially for those who are seriously sick and from other provinces, the costing and risk is also unimaginable. On the contrary, it is very typical in Beijing that the small Community Health Stations are left without anybody to care for them, even though they absolutely have the ability to cure the normal diseases. Hence, guiding the perception changes of the patients and building quality hospitals with rational distribution are imminent and significant.

Beijing has 16 districts. This study focuses on Haidian District because a large part of it is outside the Fourth ring road of Beijing. Furthermore, to meet the pace of construction, there are removal activities in many places of Haidian, the government now begins to build several new areas, such as Wenquan Town, Xibeiwang Town, Shangzhuang Town and Sujiatuo Town. As one of the most important infrastructure, hospital construction has attracted attentions both from the administrations and the residents.

Various studies have employed geographic information systems (GIS) to settle hospital or health care related problems. Gordon and Womersley (1997) elaborated the availability of GIS and it's superiority of using map in public health and planning health service. Perry and Gesler (2002) applied GIS approach to find out the residents' access to the health care center in a distant area of Andean Bolivia. Maglogiannis and Hadjiefthymiades (2007) combined GIS and Location-Based Servises (LBS) to settle the affairs of emergency medical incidents. Hare and Barcus (2007) took into account of the geographical distributions, travel times, and used a GIS framework to figure out the relevance between accessibility and health in the heart-related hospitals in Kentucky. Astell-Burt et al. (2011) used GIS and Poisson regression to analyze a dataset from Tayside (Scotland) and figured out the strong associations between HCV detection and socioeconomic deprivation. As for the aspects of location allocation, hospital site selections should take into account numerous parameters, such as the existing hospitals, population, pollution, economic factors, temporal administrative laws and regulations. How to classify and analyze these parameters then integrate them together for the whole project? Many studies are devoted to this problem: Nobre et al. (1999) adopted multi-criteria analysis to assess priorities in health care. Ohta et al. (2007) used GIS and AHP to analyze the geographical accessibility of neurosurgical emergency hospitals in Sapporo city. Cheng-Ru et al. (2007) implemented an AHP-based evaluation model to choose the optimal site for the Taiwanese hospital. Meanwhile it conducted a sensitivity test based on the criteria weight change to determine its' effectiveness. Mohammad et al. (2009) applied fuzzy analytical hierarchy process (FAHP) methods to overcome the multi-criteria decision analysis (MCDA) problems of hospital site selection.

Hospital site selection is related to various aspects of the society. Mixed views and debates on which criteria are most important would confuse even health care experts. Hence, the selection process requires an interdisciplinary approach involving hospital management personnel, government officials, engineers, environmental and social scientists. GIS-based MCA method with factor criteria necessity tests and sensitivity tests in this study transfers all these qualitatively determined criteria into a quantitative analysis, making the results more convincing. It also helps the decision makers achieve a deeper understanding about the structure of the problem.

As a matter of fact, there is not an explicit and unified regulation on hospital site selection in Beijing health department. Most of the final decisions are subjectively and randomly relied on the government officials. This optional unspoken rule has given rise to corruption, especially for the site selection of private profit hospital. Therefore this study can be regarded as an example to give some scientific and valuable suggestions to promote the health department to consummate the laws and regulations on hospital site selection.

The study will illustrate how spatial decision-making tools such as GIS-based MCA can assist decision makers in the health care field.

1.2 Aims of study

This study intends to select a site for building a new hospital in Haidian District of Beijing using GIS-based Multi-Criteria Analysis (MCA). Considering various factor criteria, Analytical Hierarchy Process (AHP) and Rank Order Method (ROM) are used here for weight setting.

Compared to previous studies, instead of taking all the criteria into MCA process at one time to get the final results, firstly, this study performs two necessity tests and two sensitivity tests on the factor criteria. All tests are conducted with the AHP and ROM methods for the MCA process. After that, the candidate sites with maximum values are selected. Finally, taking into account the sites' ambient conditions and subjective parameters, the optimal site for the new hospital is decided.

2 Study Area

The study area is located in Haidian District of Beijing, the capital of China. As Figure 2 depicts, the Beijing administrative zoning map is extracted from the China map, and the study area Haidian District is inside, colored in light blue. The area is nearly in the middle of the whole Beijing, but actually is in the northwest of the metropolitan area. It extends from 39.89 ° to 40.16 ° north and from 116.04 ° to 116.39 ° east, covering approximately 430.77 km^2. By year 2008, the administrative areas of Haidian District are composed of twenty-two sub-districts, five towns and two special regions. The population is about 3.281 millions.

Haidian District possesses a great many world famed places of interest like the Summer Palace and the Fragrant Hill, which attract countless tourists come here especially. Besides, Haidian is the district where famous universities gathered, such as Beijing University, Tsinghua University and Renmin University of China. Innumerable society elites assemble here for school and career, making it matches the names "university town" and "intelligence bank". Furthermore, the National Library and a series of other national-level cultural facilities are allocated here, has attracted a large number of people to settle here. Based on these unique cultural and technological advantages, high-technology industry is booming. The typical representative is Zhongguancun Science Park. Now the Information Technology Industry Base has extended into Shangdi, and continued spread to the more north areas. Along with this extension, there are new regions or bases need to be constructed. In brief, famous for the tourism, education, culture, and high-technology resources, Haidian District attracts more and more people to move here and the population is continue growing.

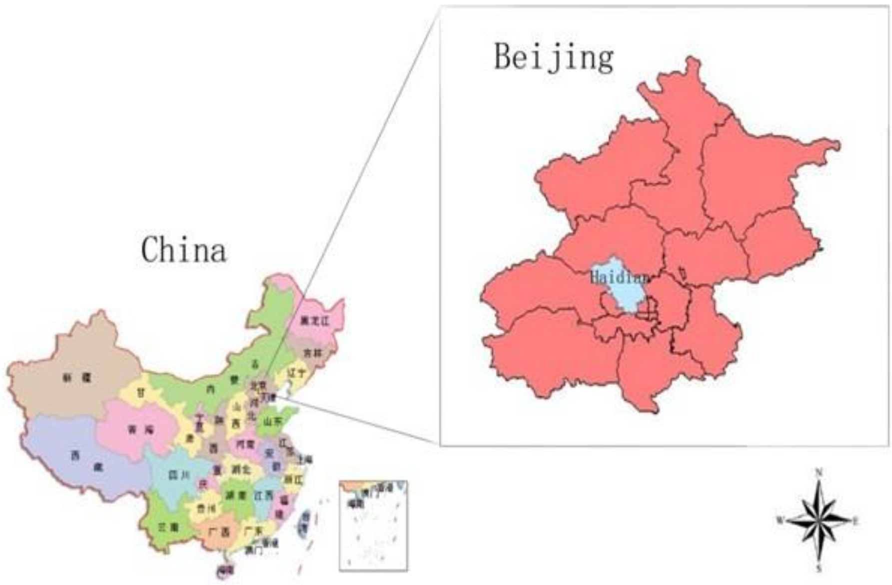


Figure 2 Haidian District of Beijing in China

From the perspective of medicals resources, by the year 2010, there are 907 hospitals (including community health stations, small clinics, etc.) for 3.281 millions of population in this district (Baidu library, 2012), so it is about 3617 persons per hospital. As for the whole Beijing, there are 9537 hospitals for approximately 20.186 millions of population. It is near 2117 persons per hospital (Beijing Public Health Information Center, 2012). Another common index is the number of hospital beds, Derived from the same data collected source above, It is calculated that for Haidian District is about 3 beds per 1000 persons, and for the whole Beijing, it is about 5 beds per 1000 persons. Obviously, the medical resources in Haidian District are much more limited than the rest of Beijing, which probably means more hospitals will be built here in the future. To meet the great medical demand of residents in Haidian District, this study sets the new hospital with a floor space 3000 m^2.

Figure 3 depicts an area with an extension of 500 meters (highlighted with light blue color) along with the outline of Haidian administrative area, labeling the main existing hospitals and some other important layers such as transportation routes. With this extension, some of the data can be better processed and get more accurate results.

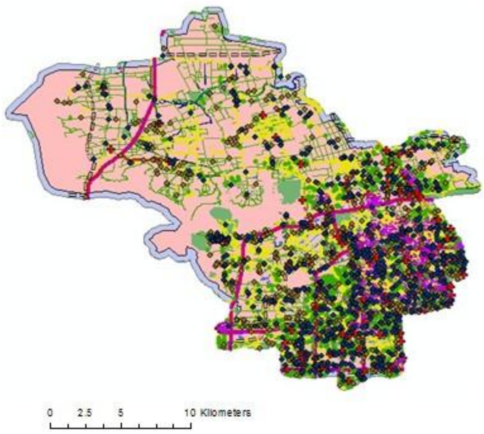


Figure 3 Extension 500m of Haidian District

3 Methodologies and analyses

The methodologies and analyses for the site selection used in this study are: AHP, ROM, GIS-based MCA, necessity tests and sensitivity tests. Necessity tests check the necessity of factor criteria. Sensitivity tests assess the sensitivity of the result to the weights' change of factor criteria. The variables and weights are described below.

3.1 Data source and software

The manipulation and analysis of data in a geographic information system is not automatically achieved. The users are required to be involved in the specification of the necessary functions and performance levels of the systems (Aronoff, 1993). In this case, most of the layers of the study area needed are clipped from the digital map and Digital Elevation Model (DEM) of the whole city of Beijing (Data derived from National Administration of Surveying, Mapping and Geoinformation in China), and a few layers are got from digitizing on Google Earth maps.

The software employed here are Erdas Image 9.2, ESRI's ArcMap 9.3, AHP v. 2.0 (Brandt, 2006) and Google Earth. Almost all the maps derived from the raw data were in Shapefile vector format. However, raster data are needed to execute the MCA model, Shapefile format files are thus converted to raster format. Erdas Image 9.2 and ArcMap 9.3 are applied throughout the whole process. They work together and crosswise to derive what the exact data needed. AHP v2 is specifically used for the weight setting of factor criteria. Google Earth is used to digitize the layer of metro, check the altitude of DEM, and acts as the on-the-spot investigation to the candidate sites derived from MCA process.

3.2 Spatial multi-criteria analysis

3.2.1 Conventional way of site selection

Site selection plays a vital role for both social and economic activities, from the habitat choice of our human ancient ancestors to all kinds of present commercial site selection. Everybody knows that inappropriate site selection leads to heavy losses, but may not very sure what is the exact importance. Take the business operations as an example, site selection is the first key factor and directly related to the customer groups, capital investment and recovery, development strategy. Therefore, making good preparations and analysis on the parameters of the site selection is absolutely necessary.

In the early stage, site selection was usually mixed up with large amount of statistics, written narrative, questionnaires as well as some simple geographic methods. Probably the typical geographic approach was using Tieseen polygon. Voronoi diagram is a process to decompose a specific given space in the basis of distances and objects. These objects are usually called sites. The principle of this diagram is to produce regions whose boundaries define the area in which the distance of any location to the given site is not greater than the distance to other sites (Reem, 2009). It is well-known in computer science and employed in all kinds of fields, such as natural science or even art. In geographic category, the famous climatologist Thiessen (1911) introduced the diagram initially. He evaluated the average precipitation cover grand areas through allocating proximity polygons to sites.

The aim of this study is to select a new hospital site in Haidian District use GIS-based MCA. To throw out a minnow to catch a whale, it will be interesting that if the Teiseen polygon is firstly adopted here to further explain the site selection in a conventional way. The Figure 4 below displays the Thiessen polygons (inside the rectangle) created by existing hospital points in the area of Haidian District. Every point (hospital) has their domain area. People who live inside one of the area probably prefer going to the only point (hospital) to see the doctor, People who live in the boundaries can chose one of the two hospitals freely, since the distance is same.

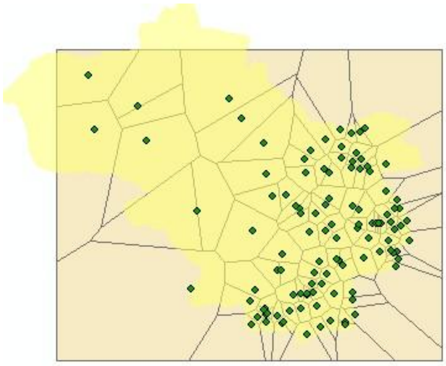


Figure 4 Thiessen polygons created by hospital points in Haidian

Whereas, the purpose here is to build a "new" hospital excluding existing hospitals in order to balance the medical resource in Haidian District. It is not appropriate just to consider Thiessen polygon in simple sense, therefore a deeper method of Thiessen polygon which is largest empty circle (Figure 5) is taken into account here. It is an issue to find the largest radius circle whose interior does not overlap with any barrier (Shamos & Hoey, 1975). The definition indicates that the center of the circle could either be any vertex of the polygon or the junction of a polygon edge. For this case, the center must be inside both the study area and the Euclidean plane.

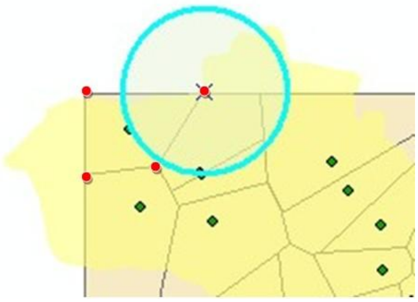


Figure 5 Largest empty circles in the Thiessen polygons

Taking the left four junctions (colored by red) as an example, the center of the circle is the intersection of the boundary of the polygon and the edge of the Euclidean plane. There is a problem with the distribution of these junctions. Obviously, there are a large number of junctions in the case, but there isn't a specific standard to distribute them in a fair way. In general, the method of largest empty circle is an efficient and conventional way to build a new site as far as possible from existing ones. Nevertheless, except existing hospitals, other point layers such as residential areas and metro stations will also be included in this study. If it considers all possible point layers, according to Reem (2010), a small change takes place in the shape or the location of the sites could give rise to the change of corresponding Thiessen cells. Thereby, it is very difficult to find the circles with the cells' change. Even though the circles can be found luckily, there are polyline layers (road) and polygon layers (university area) should be taken into account for this study as well, Thiessen polygon is a method based on points, when dealing with the multi-criteria, the drawbacks will follow close to another. Hence, with this substantive characteristic, even though the Thiessen polygon method also has been installed on GIS technology nowadays, it is still not suitable for modern site selection.

3.2.2 GIS applied on site selection

According to Environmental Systems Research Institute (ESRI, 1990), a geographic information system (GIS) is "an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information." From the perspective of application, GIS is consisted of five key parts: hardware, software, data, methods and people. The data and information in GIS is geographically referenced (geo-coded). For the GIS methods, as Lakhoua (2011) concluded that "A GIS has considerable capabilities for data analysis and scientific modeling, in addition to the usual data input, storage, retrieval, and output functions".

GIS is an innovative integrated technology base on many disciplines such as Computer science, Geography, Cartography, Statistics, Remote sensing, Land surveying and Navigation. With a period of nearly 50 years of development, together with the popularization of the Internet, GIS has been widely immersed in the people's daily life like Global Positioning System (GPS) navigation. In the Land Management domain, GIS has been applied efficiently to deal with the geo-spatial data for screening and evaluation, facilitating the optimal site selection. A number of tools are available to determine the optimum site (Witlox, 2005). Traditional methods of GIS site selection are based on the transformation of effective layers into a classified map, such as using a Boolean model (Louviere et al., 2000) or Index Overlay operations (Nikolakaki, 2004; Alesheikh et al., 2008; Alesheikh and Sadeghi, 2007; Kallali et al., 2007). Nowadays, the GIS approaches used in the site selection usually are network analysis, spatial analysis, proximity analysis, MCA with AHP, FAHP or ROM, etc. In the case of this study, GIS-based MCA with AHP and ROM wins the bidding.

3.2.3 Analytical Hierarchy Process (AHP)

AHP, which was proposed by Saaty (1980), is a structured technique for decision making based on a hierarchical framework constructed through mathematical pairwise comparisons. The weights for the decision making criteria are derived from the pairwise comparisons of the relative importance between each two criteria (the sum of the weights equals to 1). Saaty and Vargas (1991) portrayed a scare for the pairwise comparisons, where the judgments are represented by a degree of importance (Table 1). The reciprocals of the numbers are adopted to represent the inverse relationship (Mohammad et al., 2009).

Table 1 Scale for pairwise comparisons (Saaty & Vargas, 1991)

Intensity of importance	**Description**
1	Equal importance
3	Moderate importance
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocals	Values for inverse comparison

It is necessary to verify the consistency after the gaining of weight values (Chen et al., 2010). The consistency index (CI) and consistency ratio (CR) are depicted as Equation (1) and Equation (2) below:

$$CI = (\lambda_{max} - n) / (n - 1) \qquad (1)$$

Where n = the number of the criterion,
λ_{max} = the biggest eigenvalue of the comparison matrix.

$$CR = \frac{CI}{RI} \qquad (2)$$

Where RI = a constant corresponding to the mean random consistency index value based on n.

The AHP procedure generally is consisted of six steps (Lee et al., 2008; Hosseinali & Alesheikh, 2008):

1) As for the initial unstructured problem, define it and make the aims clearly as well as be sure what results expect to get.
2) Analyze the complicated problem, set the elements influenced into specific criteria.
3) Apply pairwise comparisons among these criteria to set up the comparison matrices.
4) Adopt some methods such as eigenvalue method to estimate these criteria's relative weights.
5) Check the consistency ratio of the matrices to make sure it is ok for the

weight settings

6) Determine the most appropriate weight settings and get an overall rating for these criteria.

Nowadays AHP has been extensively studied and refined in a wide variety of decision situations, in fields such as administration, commercial and industrial activity, public health and education (Boroushaki & Malczewski, 2008; Jyrki et al., 2008; Linkov et al., 2007; Nahid & Gholam, 2010; Raharjo et al,2009; Saaty, 2008). As in the MCA, it is especially important to determine the criteria weights, and the AHP is very popular mathematical approach to settle the problem of complexity. In the GIS domain, AHP is typically used with MCA for site selections or land suitability evaluations.

3.2.4 Rank Order Method (ROM)

ROM is another weight setting method, which orders all criteria from most important to least important. The Equation (3) shows the ROM process in getting weight value as following:

$$W(i) = \frac{2(n-i+1)}{n(n+1)} \qquad (3)$$

Where i = Rank position of criterion,
n = Number of criteria.

In GIS-based MCA, ROM usually acts as a comparison with AHP weighing method for factor criteria. Binh (2008) and Lin (2011) applied the ROM as well as AHP method to a hydropower station selection on the Reventazón River in Costa Rica. In this study, ROM is also adopted for MCA, especially plays a key role in the sensitivity tests.

3.2.5 Multi-Criteria Analysis (MCA)

MCA is a procedure that typically multiplies conflicting criteria that are essential to be evaluated in decision-making. It has a wide application whether in our daily lives or in professional settings. As Yassine and Adel (2011) elaborated, “The principal of the MCA is to condense complex problems with multiple criteria into finest ranking of the best scenarios from which an option is selected”. The criteria are weighted according to their importance, and their weights have a more or less favorable on the final decision than another (Diakoulaki & Karangelis 2007).

GIS-based MCA includes two essential parts: factor criteria and constraint criteria. Each of the criteria is appeared as a map layer, no matter for factor or constraint criterion. Factor maps are represented as spatial distributions to display the opportunity criteria and the quality of achieving an objective. Constraint maps are limitations or restrictions which prohibit certain elements to be taken into account the analysis (Malczewski, 1999). Correspondingly, the GIS-based MCA includes two major methods: weighted summations procedures and Boolean overlay operations

(Yassine & Adel, 2011).

As for the weighted summations procedures, the weighted linear combination of factor criteria is shown as Equation (4) below:

$$S = \Sigma w_i f_i \qquad (4)$$

where S = Suitability to the objective being considered,
w_i = Weight of factor i [the sum of all weights equal 1],
f_i = Criteria score of factor i.

As for the Boolean overlay operations, the formula for the constraint criteria is depicted in Equation (5) as following:

$$C = C_1 * C_2 * \ldots * C_n \qquad (5)$$

Where C = Integrated constraint
Cn = Criteria score of constraint n

After the factor criteria and constraint criteria being settled separately, the GIS-based MCA process integrates them together by multiplying S with C, and gets the final result. Figure 6 below gives an overview of GIS-based MCA model.

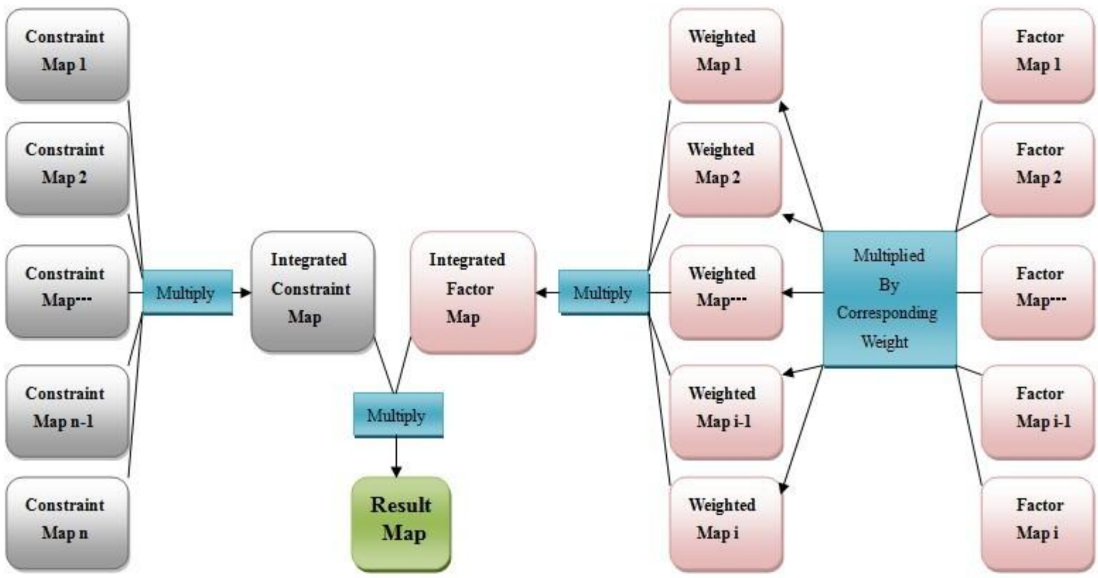


Figure 6 GIS-based MCA model

GIS-based MCA has been widely used in various studies, especially in the resources allocation and land suitability evaluations. Ni-Bin et al. (2008) combined GIS with fuzzy MCA to choose a landfill site in South Texas. Rob and Vasilis (2011) applied GIS-based MCA to select a wind turbine farm site in New York. Francisco et al. (2011) performed a GIS-based MCA to determine the site location for reclaimed water infiltration. Chen et al. (2011) adopted GIS-based MCA together with an uncertainty analysis for river catchment management. Imtiaz and Abd (2011) implemented a GIS-based MCA model to assess the land suitability for hillside development at Penang Island in Malaysia. No matter in which domain, GIS-based MCA has been proved as an advance and effective analysis tool in decision making.

3.3 Data processing

3.3.1 Data preprocessing

The data such as the geo-referenced Beijing electronic map and the DEM, are with different spatial reference. All data are set with unified spatial reference as shown in the Table A1 in the appendix:

The data of the geo-referenced Beijing electronic map with the main layers needed are in shapefile format. Considering the GIS methods used in this study, the data need to be converted to raster format before multiplying them to get the results, but the problem is that each layer has different cell size. Therefore, unifying them is an essential step. In this study, the cell size value 27.78 m of the original DEM data is set as the unified cell size.

The study area is covering only Haidian District of Beijing, but the raw data covers the whole Beijing. To get more accurate results, a 500 meter extension of Haidian District is necessary. Several layers have to be preprocessed. Some layers have to be digitized as polygons to get new maps. Some layers need to be buffered by using the Analysis tool in ArcMap. After being overlaid, conversion from shapefile to raster, making them to be easier reclassified in the further data processing needs to be carried out.

As it is said before, Haidian District is also famous for the name "University town". for the layer of existing university, because the areal extent of each university differs a lot, creating a buffer from the points is not appropriate, so instead with digitizing, a few polygons were drawn for those areas which universities are crowded together. The new hospital almost has no possibility to be built inside these polygons. Figure 7 shows the polygons drawn along the university areas for digitizing.

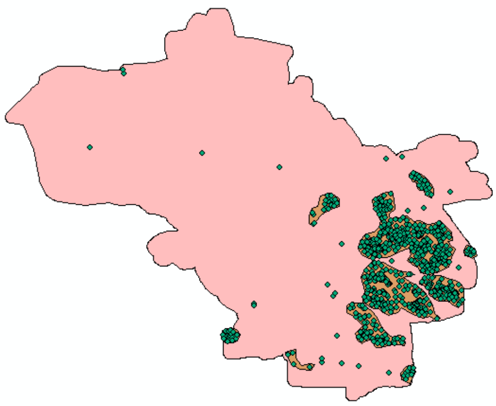


Figure 7 Digitizing along the university areas

As for the ring road layer, here are six rings in the traffic system of Beijing.

Inside the Fourth ring road, there are enough existing hospitals, and a new hospital built inside here is meaningless. Hence, a big yellow polygon has been digitized along the Fourth ring road and the boundary of study area as Figure 8, the new hospital is supposed to be set outside the Forth ring road.

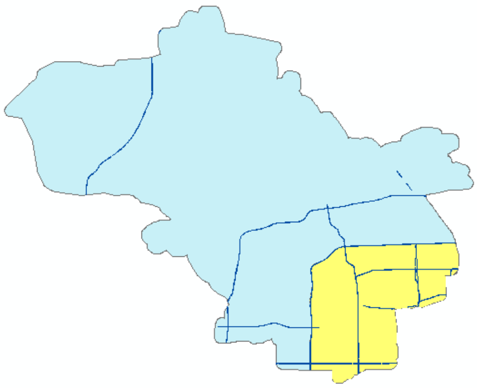


Figure 8 Digitizing inside the Fourth ring road

As for the yellow highway layer, a blue buffer zone of 500 meters is set as showed in the Appendix (FigureA1). Similarly, a light pink buffer zone of 1000 meters is set on the black railway layer as showed in the Appendix (Figure A2). As for the restaurant layer, a red buffer zone of 25 meters on the green points is set on the restaurant layer as showed in the Appendix (Figure A3). As for the greenbelt layer and reservoir layer, it is no need to do the digitizing and buffer on them, just extract them form the raw data as Figure A4 and Figure A5 showing in the Appendix.

The altitude layer (Figure 9) is extracted from the DEM data by using a mask. Google Earth shows that the average altitude of these areas is about 60 meters. While the northwest of Haidian District are mountainous areas, the average altitude on the edge of mountains is about 100 meters, and also, the areas over 100 meters are sparsely populated, therefore it should not be taken into account.

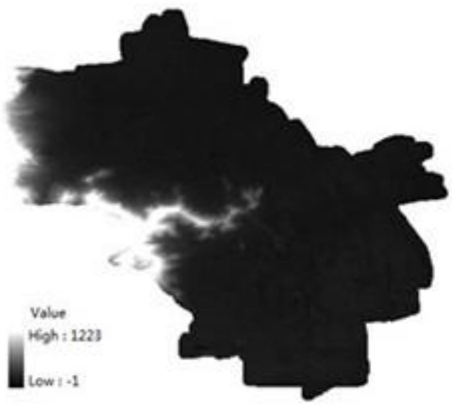


Figure 9 Altitude from DEM data

The existing hospital layer is buffered with 500 meters and composed with multiple rings showing as Figure A6 in the Appendix. Other layers such as river, public toilet, residential area, road, street and sub-street are processed in the same way as existing hospital. Their corresponding figures are also set in the Appendix (Figure A7 to A12).

As for the layer of metro, unfortunately, there is no related layer in the original Beijing digital map, and geo-referenced data regarding to Beijing metro also is hard to access. Instead, this study uses the Beijing metro planning chart (FigureA13 in Appendix) to check all the metro stations in Haidian District. Their geographic coordinates are found on Google Earth, then they are digitized and finally 100 meter buffer zones are made around the stations with multiple rings (Figure 10).

Figure 10 Buffer on metro station

Through preprocessing, such as data format conversion, clipping, digitizing, and buffering, the main criteria are extracted from the raw data. There are totally eight factor criteria (existing hospital, residential area, road, street, sub-street, metro, river and public toilet) and eight constraint criteria (university area, ring-road, highway, railway, restaurant, green belt, reservoir and altitude) that are taken into account for further processing such as reclassifying the maps and unifying scales.

These criteria considered here is an immeasurably vast difference compared with the hospital site selection conducted by Cheng-Ru et al. (2007). They implemented an AHP-based evaluation model to choose the optimal site for the Taiwanese hospital. The criteria adopted in their study include six kinds of criteria (factor conditions, demanded conditions, firm strategy, related supporting industries, government and chance) and their corresponding sub-criteria. For criterion of the factor conditions, it involves sub-criteria: capital, labor and land; for the criterion of the demanded conditions, it contains: sub-criteria population number, density and age distribution; for criterion of firm strategy, it includes: sub-criteria management objective, rank of competing hospitals and policymaker's attitude…apart from the capital, labor, land and population data, almost all the other criteria in Cheng-Ru's study are based on subjectivity. While in this study, all the criteria are based on objectivity, and they are all geo-referenced. The fundamental difference between these two studies is the methodologies. In Cheng-Ru's study, it used AHP to assess and select the optimal hospital site from three pre-estimated candidate sites in Taiwan, so it can focus on the macro level and regardless of the geographic parameters. While this study intends to apply GIS-based MCA with AHP and ROM to pick out one site among the whole area of the Haidian District in Beijing, hence, geo-referenced data is absolutely indispensible.

The criteria adopted by other previous studies were mainly classified into three categories based on the hospital type and scale (Ali & Ebrahim, 2011) as the Table 2 showing below:

Table 2 Hospital site selection criteria classification

Hospital type and scale	**Criteria**
General hospital	Capture rate of population, current and projected population density, travel time, proximity to major commuter and public transit routes, distance from arterials, distance from other hospitals, anticipated impact on existed hospitals, land cost, contamination, socio-demographics of service area.
Children hospital	Conformity to surrounding region, incremental operating costs, site purchase cost, travel time, proximity to public transport, traffic routes, site ownership, site shape, site gradient, ground conditions (soils/rock), access, ease of patient flow and staff movement, existing infrastructure and availability of services, perimeter buffer zone, environmental considerations, future population and prominence.
Professional medicine and cure hospital	proximity to future expansion space, consistency with city zoning/policies, compatibility with surrounding uses, character and scale, cost of site control, helicopter access, local community preferences, accessibility, centrality, environment, land ownership, size and future population and prominence.

Here in this study, the new hospital is oriented as a general hospital, and the eight factor criteria and eight constraint criteria partly match with the criteria represented in the Table 2 above, some criteria are not the same name with them, but deal with the similar problems, detailed elaborations of these criteria is portrayed as the following contents.

3.3.2 Factor criteria

The eight factor criteria include:

- Existing hospital: new hospital constructions should take this criterion seriously. Keeping the distance from other existing hospitals as well as anticipating impact from each other, is not only relevance to rational resource allocation, but also does matter to the fair competition in the market economy. “Although the civil service in Haidian District has not expressly stipulated the exact distance for the new hospital to keep from the existing hospitals, there is an oral agreement that normally the distance is 500 meters." said by Ji-Shun (2011), the deputy chief of the Medical Affairs Section in Haidian Health Bureau. Hence, in this study, the new hospital is also wished to keep a distance of 500 m from the existing hospitals, the further away the better.

- Residential area: the residential area in a way that means the resident population, so the nearer from the residential area, the better. Here are two reasons for taking the residential data to replace the population data. First, the latest detailed population data (the sixth census of China) has not been officially released. Second, the population data need to be converted to geo-referenced thematic map, if not detailed enough, the map will tend to show an average population level in a comparatively large area. Thus it will lead to a less precise result. On the other way around, the location and density of the residential areas can compensate these temporary drawbacks to some degree.
- Road: theoretically, a hospital should be located near the roads, especially the main roads. The nearer the better. However, the noise from motor vehicles passing by influences the patients in the hospital. Therefore a quiet distance of 100 meters is set. Outside the buffer zone, the nearer the better. Road here means main thoroughfare or trunk road.
- Street: street here means the main street, which is also very important for the hospital site. Most big hospitals in Beijing are allocated along side with the main streets.
- Sub-street: sub-street here means path or alley, which is countless and not so vital compared with road and street. That is why this study deals with road, street, sub-street separately.
- Metro: normally, metro is the fastest way of transportation in the urban area of big cities. More and more people prefer to go by metro than other transport methods because of the frequent traffic jam. Fast growing metro construction in Beijing also calls attention to hospital building decision makers.
- River: in case the new hospital drains sewage to river, at least 300 meters distance along the river should be used. Outside the buffer zone, the further away, the better.
- Public toilet: to avoid the new hospital being polluted by bad air and drainage around the toilet, a safe clearance of 200 meters is necessary. Outside the zone, the further away, the better.

All in all, the criterion of existing hospital mainly considers its distance from and impact on the new hospital. Residential area is corresponding to the population density and allocation. Road, street, sub-street and metro refer to the access to the public transit routes. River and public toilet are related to the contamination or population. The specific buffer requirements for these factor criteria are shown in the Table 3 below.

Table 3 Factor criteria setting

Factor	Setting
Existing hospital	The further away from the existing hospital (>=500m), the better
Residential area	The nearer away from the residential area, the better
Road	The nearer away from the road (>=100m), the better
Street	The nearer away from the street (>=100m), the better
Sub-street	The nearer away from the sub-street (>=100m), the better
Metro	The nearer away from the metro station (>=100m), the better
River	The further away from the river (>=300m), the better
Public toilet	The further away from the public toilet (>=200m), the better

After data preprocessing has been done, then reclassifying, stretching processes are conducted to make the layers ready for the MCA process. Figure 11 below shows the final factor map of existing hospital. Other seven factor maps are set in the Appendix from Figure A14 to Figure A20.

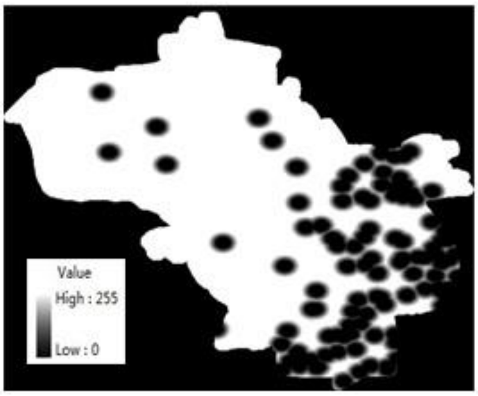


Figure 11 Factor map of residential area

3.3.3 Constraint criteria

The eight constraint criteria contain:

- University area: the Haidian District is an area with high-density universities. Those universities have their own subsidiary hospitals or big clinics. Hence, it is unnecessary to build new hospitals there.
- Ring road: there are six rings in the traffic system of Beijing. The government declared that there is no need for new hospitals anymore inside the Fourth ring road where hospitals or clinics are already saturated.
- Highway: the landuse around highway is usually open area. There is no need to have a hospital there, from the view of economy and resource, both are waste.
- Railway: obviously, patients will be disturbed by noisy sound when the train is passing by. Meanwhile, most railways are not near to the residential area, so hospital being built there is insignificant.
- Restaurant: hospital is the source of infection, to protect the general public,

keep a distance from the restaurants around is necessary. On the other hand, most hospitals in Beijing have their own canteen for patients. Therefore, to make hospitals near restaurants on purpose is also meaningless.

- Greenbelt: hospitals are rarely built inside the greenbelt such as parks, it is better to protect those areas which are grown much green from the pollution of hospital.
- Reservoir: a hospital cannot be built around a reservoir, in case the reservoir is polluted by construction or drainage discharged by the hospital in the future.
- Altitude: most areas of Haidian District are located in the flat region. While in the northwest of Haidian District, there are mountainous areas, which is not suitable for building a hospital.

Following the constraint criteria setting in Table 4, a reclassification process on the constraint criteria is indispensable. After that, the constraint map of university area is shown in Figure 12. Other seven constraint maps are set in the Appendix from Figure A21 to Figure A27.

Table 4 Constraint criteria setting

Constraint	**Setting (0= forbiddance; 1=allowance)**
University area	Inside the area =0, outside =1
Ring road	Inside the Forth ring road =0, outside =1
Highway	500 meters buffer zone is set. Inside =0, outside =1
Railway	1000 meters buffer zone is set. Inside =0, outside =1
Restaurant	25 meters buffer zone is set. Inside =0, outside =1
Greenbelt	Greenbelt area=0, others=1
Reservoir	Reservoir =0, others =1
Altitude	(DEM)100 meters over the sea level =0, others=1

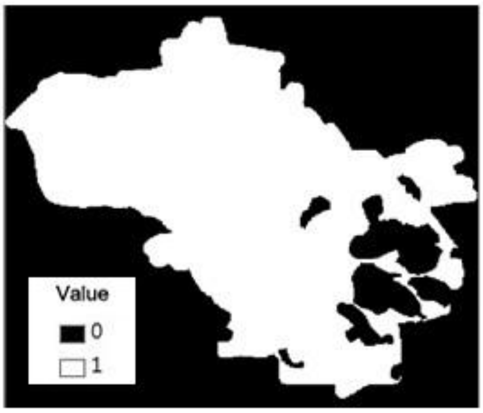


Figure 12 Constraint map of university area

3.4 Weight setting on the factor criteria

3.4.1 Weight setting (AHP)

Since there are necessity tests and sensitivity tests in this study, each MCA process needs a weight setting combination. For the AHP method, by using the AHP software, the weights are set as shown in Table 5.

Table 5 Weight setting (AHP) for both necessity test 1 and sensitivity test 1

No. / **Weight** / **Factor**	3	4	5	6	7	8
Existing hospital	0.3697	0.2931	0.2478	0.2202	0.2022	0.1919
Residential area	0.3447	0.2780	0.2465	0.2193	0.2016	0.1849
Road	0.2856	0.2335	0.2001	0.1788	0.1638	0.1539
Metro		0.1954	0.1689	0.1513	0.1384	0.1291
River			0.1366	0.1241	0.1169	0.1115
Street				0.1063	0.0981	0.0916
Sub-street					0.0791	0.0746
Public toilet						0.0624

(Where No. here means the number of factors)

3.4.2 Weight setting (ROM)

The ROM method is calculated with the formula mentioned in the preceding part, the weight set in the Table 6 and Table 7 show as below.

Table 6 Weight setting (ROM) for both necessity test 2 and sensitivity test 1

No. / **Weight** / **Factor**	3	4	5	6	7	8
Existing hospital *(Rank 1)*	0.5000	0.4000	0.3333	0.2857	0.2500	0.2222
Residential area *(Rank 2)*	0.3333	0.3000	0.2667	0.2381	0.2143	0.1944
Road *(Rank 3)*	0.1667	0.2000	0.2000	0.1905	0.1786	0.1667
Metro *(Rank 4)*		0.1000	0.1333	0.1429	0.1429	0.1389
River *(Rank 5)*			0.0667	0.0952	0.1071	0.1111
Street *(Rank 6)*				0.0476	0.0714	0.0833
Sub-street *(Rank 7)*					0.0357	0.0556
Public toilet *(Rank 8)*						0.0278

(Where No. here means the number of factors)

Table 7 Weight setting (ROM) for sensitivity test 2

Rank order	**Combination A**	**Combination B**	**Weight**
1	Existing hospital	Residential area	0.2222
2	Residential area	Metro	0.1944
3	Road	Existing hospital	0.1667
4	Metro	Road	0.1389
5	River	Street	0.1111
6	Street	River	0.0833
7	Sub-street	Public toilet	0.0556
8	Public toilet	Sub-street	0.0278

3.5 MCA process

According to the GIS-based MCA model shown in Figure 6 and the weight setting in the above three tables, there are totally 13 MCA models that have been made.

3.6 Factor criteria necessity tests and sensitivity tests

There are two necessity tests and two sensitivity tests, how they are operated is explained in the Table 8 below.

Table 8 Necessity tests and sensitivity tests

Test	**Method**	**Explanation**
Necessity test 1 (NT 1)	AHP	Starts with three factors, others are added one by one, each together with all the constraints. MCA model is produced after each factor addition, then results are compared: (Ar_3 vs Ar_4 vs Ar_5 vs Ar_6 vs Ar_7 vs Ar_8)
Necessity test 2 (NT 2)	ROM	The process is the same as NT1: (Rr_3 vs Rr_4 vs Rr_5 vs Rr_6 vs Rr_7 vs Rr_8)
Sensitivity test 1 (ST 1)	AHP ROM	Crosswise compare the results from NT1 and NT2: (Ar_3 vs Rr_3, Ar_4 vs Rr_4, Ar_5 vs Rr_5 , Ar_6 vs Rr_6, Ar_7 vs Rr_7, Ar_8 vs Rr_8)
Sensitivity test 2 (ST 2)	ROM	Select all the eight factors, change their rank order and weight values , together with all the constraints, make another MCA model, then compare the results: (Rr_8 vs $R'r_8$)

(Where “A” means AHP; “R” means ROM; “r” means result; “3,4,5,6,7,8” means the number of factors in each MCA model, “vs” means compare)

The necessity tests check the necessity of factor criteria. As shown in Table 8, the necessity test 1 (NT 1) firstly uses three factor criteria (existing hospital, residential area and road) together with all the constraint criteria to make a MCA model to get the result (Ar_3), then adds the fourth factor (metro), also combine with all the constraint criteria to conduct another MCA model and get another result (Ar_4). The rest can be done in the same manner. Finally, make a comparison between these results (Ar_3 vs Ar_4 vs Ar_5 vs Ar_6 vs Ar_7 vs Ar_8) to check the variations. If the variation changes a lot, which means the added factor criterion is necessary, otherwise is not. The same as necessity test 2 (NT 2), but it adopts ROM for factor criteria' weight settings, instead of AHP in NT 1.

The sensitivity tests assess the sensitivity of the result to the weight change of factor criteria. In sensitivity test 1 (ST 1), because the weight settings change between AHP and ROM, the results from NT 1 and NT 2 are crosswise compared, there are totally six pairs of comparisons (Ar_3 vs Rr_3, Ar_4 vs Rr_4, Ar_5 vs Rr_5 , Ar_6 vs Rr_6, Ar_7 vs Rr_7,Ar_8 vs Rr_8). Check their variations, if the corresponding results vary a lot, it means they are sensitive to the weight change of the factor criteria, otherwise are not. What needs to be attention here is the sensitivity test 2 (ST 2), based on ROM, it takes all eight factor criteria into account, totally change their rank orders to make a big change on their weight setting, then make a new MCA model and check the sensitivity (Rr_8 vs $R'r_8$).

4 Results

4.1 Necessity tests results

The results derived from Table 5 and Table 6 shown above, after the MCA process, they are shown as Figure A28 and Figure A29 in the Appendix. From these two result maps, no matter AHP method (necessity test 1) or ROM method (necessity test 2) is used, we can see that: as the fourth factor metro is added, there is a big change on the value range of the result map (AHP: from 0-255 to 0-215, ROM: from 0-255 to 0-234), while for the other 4 added factors, there is only little variation of their value range. As for the cells with maximum value, the quantities almost gradual reduce, which can be easily seen from the change of the areal extent. Here a small area is extracted from the huge result map of the AHP method to show the difference as Figure 13 (cells colored blue have the maximum value).

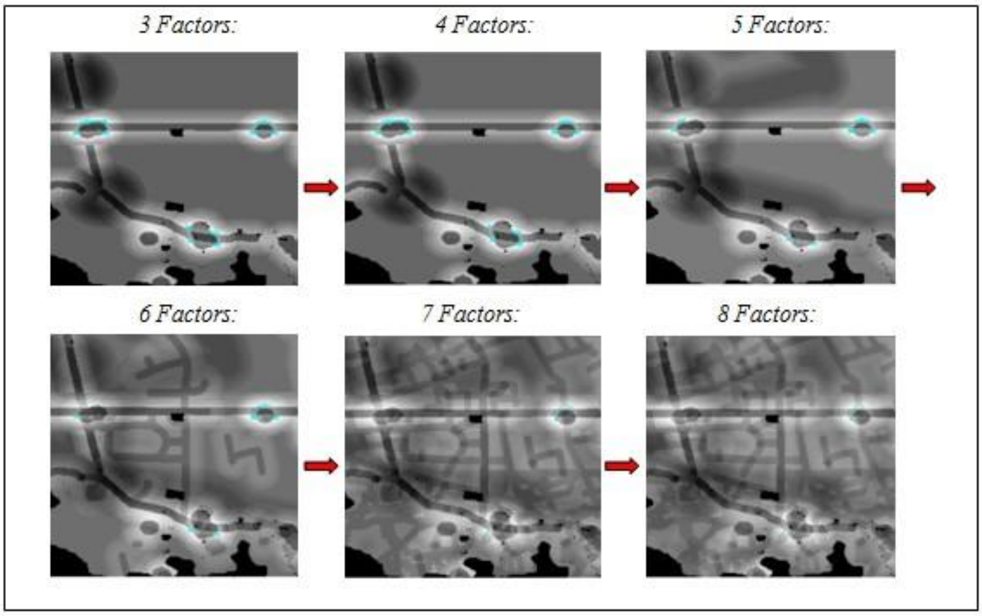


Figure 13 Comparison of cells with maximum value in NT 1

It can be seen from this figure that when the factors are added one by one, the cells with maximum value just group together and get fewer, but never gets separated far away to become a new group. From the perspective of areal extent decrease, apparently, when the factor river, street, sub-street is added separately, the extents of cells with maximum value quickly reduce, On the contrary, when the public toilet is added as the last factor criterion, the extent of cells with maximum value is almost the same as the former. The same situation also fits for other parts of the result maps.

As for the cells with other values, both the cells' quantities and locations vary quite a lot, which are manifested by the brightness variations in the maps compared.

4.2 Sensitivity tests results

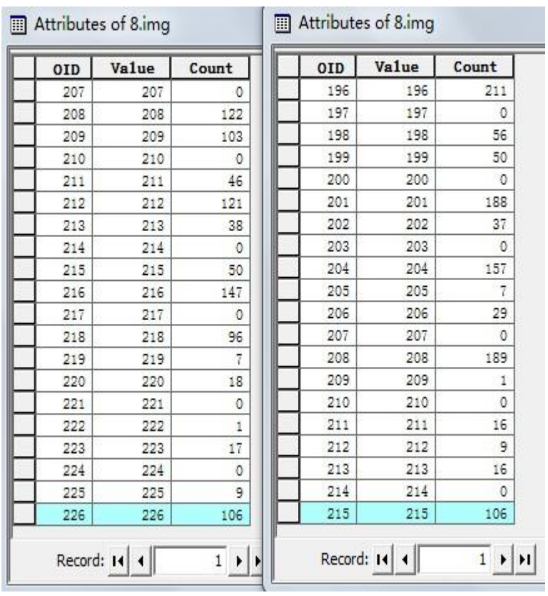
For sensitivity test 1, when making the crosswise comparison between the result maps from AHP method and ROM method, as the factor criteria are added one by one, it is interesting that although the cell maximum values are not usually the same on corresponding MCA models, the quantities and locations of the cells with maximum value are exactly the same. Table 9 shows the relations below.

Table 9 Comparison on maximum values and counts (AHP and ROM)

No. of factors	**3**	**4**	**5**	**6**	**7**	**8**
Count / Value / Method	600	600	453	251	121	106
AHP	255	215	220	224	231	228
ROM	255	234	227	225	225	226

For sensitivity test 2, with eight factor criteria all together, although the rank order and weight values totally changed, the quantities and locations of the cells with the maximum value (colored in light blue) still remain the same as before (Figure 14 and Figure 15). The variations just can be seen from cells with other values (Figure 14). Some of them can be clearly figured out as the green arrows show in Figure 15, the brightness of the compared areas apparently has changed.

Before change: After change:


Attributes of 8.img

OID	Value	Count
207	207	0
208	208	122
209	209	103
210	210	0
211	211	46
212	212	121
213	213	38
214	214	0
215	215	50
216	216	147
217	217	0
218	218	96
219	219	7
220	220	18
221	221	0
222	222	1
223	223	17
224	224	0
225	225	9
226	226	106

Record: 1

Attributes of 8.img

OID	Value	Count
196	196	211
197	197	0
198	198	56
199	199	50
200	200	0
201	201	188
202	202	37
203	203	0
204	204	157
205	205	7
206	206	29
207	207	0
208	208	189
209	209	1
210	210	0
211	211	16
212	212	9
213	213	16
214	214	0
215	215	106

Record: 1

Figure 14 Comparison attributes in ST 2

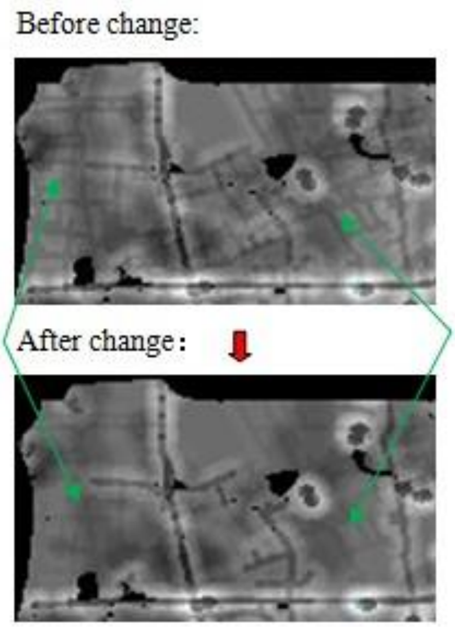


Figure 15 Comparison maps in ST 2

4.3 Site selection results

The purpose of the site selection is find the optimun site resulting from a series of pre-determined criteria. Typically the process includs two phases: the screeming and evaluation. After the GIS-based MCA models, usually there are several results with maximum value depending on the same selection standards, so they are screemed out as the candidate sites from massive geographical areas. Then a deep evaluation with extra standards on these alternatives should be carried out to get the optmum site.

4.3.1 Candidate sites with the maximum value

Since the counts and locations of cells with the maximum value are exactly the same both in AHP and ROM method, the result map of eight factors with AHP method is selected to show all the candidate sites in Appendix (Figure A30).

4.3.2 Comparison and the optimum site selection

As Figure A30 in the Appendix shows, there are eight regions of sites with maximum value as the strongest candidates for the new hospital. Because the scale for the hospital is about 3000 m^2, the region A and F with less than four pixels should be excluded (the unified cell size of each pixel is 27.78 m). As for region B, C, D, E, G, H, each region has more than one cells' group with maximum value. For this reason, there are two steps for the phase of evaluation to get the optmum site. Firstly the best site for each region needs to be singled out, and then move further to a final determination on the most suitable site.

According to the candidate sites' corresponding geographic coordinates in region B, C, D, E, G, H, they are repositioned on Google Earth maps (which act as the on-the-spot investigations) to check the best site of each region at first. For region B and E respectively, one site in the southeast has to be abandoned because it just occupies one pixel, and does not match the minimum standard (four pixels). For region C, D, G, H, all cells' groups are fulfill the four pixels demand, and near from each other, so the over-all surroundings are quite the similar, the best site for each region is set according to their specific landuse categories. For instance, the northwest cells' group in region C is allocated inside the playground of Beijing Haidian Fenglian primary school, beyond doubt, it should be eliminated. The west and south cell's group are very near the Beijing Aerospace City, which has its' own special medical centre strictly controlled by the central government. Thus, building a new hospital very close here is meaningless. Finally, the cells' group in the east is remained as the best in Region C. As the Figure 16 shows below, the best site for each region is approximately labeled with red triangle.

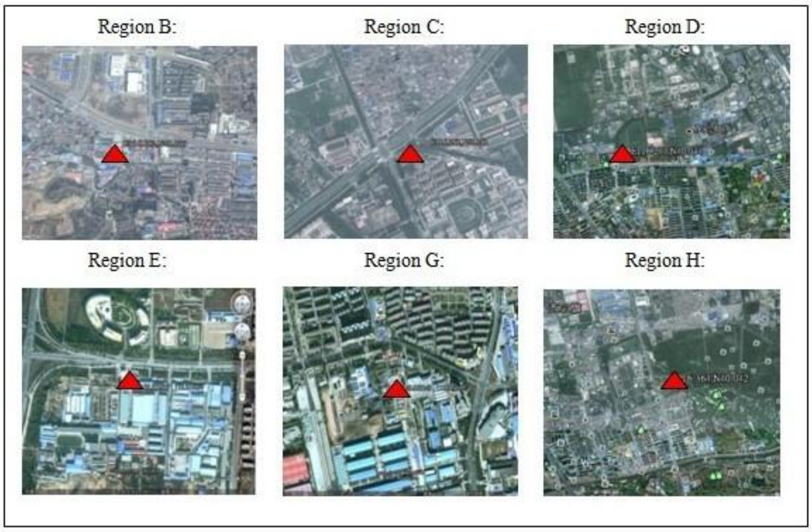


Figure 16 Best site of each region (red)

The best site in region C is allocated in a focal spot of super convenient transportation where in the north there is a big residential area. However, it still suffers an eclipse because of the surroundings in the other three directions. As for the best site in region D, the surroundings in the south direction are pretty good with many residential areas and nice transportation, but in the north, there is a huge Science and Technology Park, which is not fit for the hospital allocation. In region E and G, both the best sites are inside the big factories. What should be highlighted here is the site in region G. It is inside the 500 m extension area which does not belong to Haidian District, so without doubt that it should also be eliminated. The best site in region H is still inside of the Haidian District but very near the border line with Changping District. Furthermore, the tremendous forest park in the east is the main reason for excluding this site.

Taking into account all the sites' ambient conditions, economic and social development as well as subjective parameters, the site (E: 116.182, N: 40.039) in region B is selected as the optimum site for the new hospital. Figure 17 shows the expanded area around region B to better elaborate the reasons.

Figure 17 The optimum site for the new hospital in Haidian (red)

As the Figure 17 above shows, the optimum site is allocated in the center of the Wenquan Town, which is among the four towns being newly rebuilt in Haidian District. Besides, the optimum site is surrounded by large residential areas, covering a huge and high density population. Besides, the transportation facilities around is well suited and convenient. Furthermore, because Wenquan Town is a new fast developing town, the medical facilities are insufficient. Meanwhile, huge population continues to swarm into here, especially for the older and the younger come from the migrant workers' family, most of them cannot have designated hospital associated with medical insurance. Therefore, building new hospital here is extremely urgent.

5 Discussions

For the part of necessity tests results, it is obvious from the variation tendency that in this study the metro is absolutely necessary, as well as the indispensable factor criteria (existing hospitals, residential area and road). The public toilet, however, is not indispensable. The remainders: river, street and sub-street are necessary. Necessity test 2 with the ROM method acts as a supplement of necessity test 1 with AHP method, to reconfirm the necessity of the factor criteria.

For the part of sensitivity tests results, in sensitivity test 1, when making the crosswise comparison, not only the quantity of the cells with maximum value with ROM method is the same as the corresponding result maps with AHP method, but also the locations of the cells are exactly the same. To some degree, this enhances the accuracy of the data processing and necessity tests above. Meanwhile, it proves that the weight change itself is not sensitive to cells with maximum value in this study. Maybe it is because that the rank order cannot be changed in necessity test 1, and relatively speaking, the variation of the weight for each factor criterion is not big.

To check whether this hypothesis is reasonable or not, the rank order as well as the weight values are totally changed in sensitivity test 2 with ROM method. The result shows that although the maximum values vary a little (from 226 to 215), the counts and locations of the cells with maximum value still remain the same as before, which overthrows the hypothesis, reconfirming that the weight change itself is not sensitive to cells with maximum value, and is seemingly unrelated with the rank order in this study. For the cells with other values, weight change is sensitive to them because both the quantities and locations have changed.

For the part of site selection results, during the process of screening the optimum site for the new hospital, it is easy to see that there are some other criteria lacking of consideration, such as huge areas like the Science and Technology Park. Hence, using Google Earth maps as the on-the-spot investigations is extremely important and essential for getting a reliable and practical optimum site.

What should be mentioned here is that although GIS-based MCA with necessity and sensitivity tests in this study can provide a novel and useful reference to other site selection decision makers, there still exists some drawbacks. One inevitable drawback is that there are totally 13 MCA models that should be performed separately, too many repeated operations in this study. This situation would be much more complicated if the criteria are increasing. How to improve this approach in an easier and convenient way is a burning question to be solved.

When doing GIS-based MCA, convincing results derive from reliable and updated data. In this study, residential area data are used to replace the population, because the latest detailed official data of the sixth census has not been released. In a way, the residential area data can not exactly show the population density and structure, therefore this limitation may make the results insufficient. The latest population, together with other data (such as disease, evaluation of real estate, income and consumption) can be considered and converted to geo-referenced data for a future GIS-based MCA study on hospital site selection.

Furthermore, the government administrations should enhance the information openness degree as well as speed up the information update. Meanwhile, interdepartmental cooperation in these administrations should be strengthened to make an easier access for the general public to the reliable databases, especially GIS-based database. For example, the Department of Statistics cooperates with the Bureau of Geographical Surveying and Mapping, to release effective and comprehensive geo-referenced thematic data publicly, so the information resources monopoly by the commercial corporations or government officers would be decreased. The general public can easily reach the data for free or at very reasonable expenses. To some degree, this can be cost saving and decrease the corruption resulting from information asymmetry.

6 Conclusions and further perspectives

Comparatively speaking, GIS-based MCA provides a more technological, convenient and precise way for hospital site selection than the traditional ways such as Thiessen polygon. It combines spatial and non-spatial data to construct visualized information that can be easily understood and analyzed by decision makers. By using such illustrative maps, decision makers can obtain very accurate solutions for problems. In this study, the optimal site for new hospital allocated in Wenquan Town approximately matches with the place expected before, which proves that the result from GIS method is, relatively accurate and practical.

Furthermore, a GIS-based MCA together with necessity tests and sensitivity tests, make the decision makers be aware of which criteria are really necessary and how the results are sensitive to the weights change. Hence, it can optimize the criteria combination, modify the analytical structure and reduce the deviation, making the results stronger and more convincing.

For the public health department in Beijing, it is necessary to revise the current vague laws and regulations on hospital site selection. According to the results of necessity tests and site selection, metro is very essential for the hospital site and will play an even more important role in the future. Factories should be taken seriously regarding to the pollution and noise. Public toilet can be left out because it is unnecessary.

For the decision makers of hospital site selection, when making GIS-based MCA, reliable data, especially the data for the factor criteria, should be taken seriously. It is essential to convert some tabulated data into geo-referenced data. Besides, in case of unexpected parameters, recheck the results, and match them with the reality is absolutely necessary.

In further research, GIS-based MCA together with necessity tests and sensitivity tests is expected to overcome the drawbacks of too many repeated operations on the MCA models. Instead of running every MCA model respectively on a routine way, a set of synthetic operation software for MCA models is expected to be developed. In this preconceived software, all the weights for these two tests can be input together as the Table 5, 6, 7 in an integrated MCA model. Then all the result maps come out simultaneously, along with an analytical tool to evaluate the necessity and sensitivity. Finally the criteria combinations are revised to get the optimum result. With this development, GIS-based MCA together with necessity tests and sensitivity tests will absolutely be much more maneuverable and practical. Hence, it will be useful to provide a high-performance application and reference to other site selection such as railway station and shopping mall, acting as an adequate tool for public administration and business market strategies.

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Appendix

Here in the appendix are the complementary of tables and figures for this thesis. Table A1 shows the spatial reference of all the data after been unified. Figure A1 to Figure A12 despict the data preprocessing for criteria. Figure A13 is the Beijing metro planning chart which used as reference for digitizing metro criterion on Google Earth maps. Figure A14 to Figure A20 are the factor maps of the seven remaining factor criteria (residential area, road, street, sub-street, metro, river, and public toilet). Figure A21 to Figure A27 are constraint maps of the seven remaining constraint criteria (ring road, highway, railway, restaurant, greenbelt, reservoir, altitude). Figure A28 and Figure A29 are the MCA result maps from AHP and ROM method. Figure A30 shows the candidate sites with the maximum value for the new hospital.

Table A1 Unified data spatial reference

Geographic coordinate system:	GCS_WGS_1984
Datum:	D_WGS_1984
Prime Meridian:	Greenwich
Angular Unit:	Degree

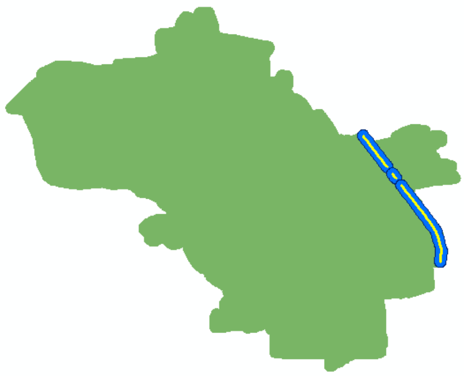

Figure A1 Buffer on the highway

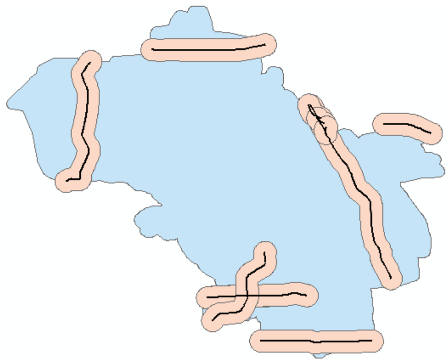

Figure A2 Buffer on the railways

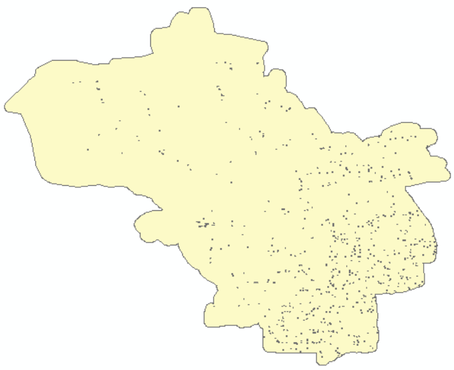

Figure A3 Buffer on the restaurants

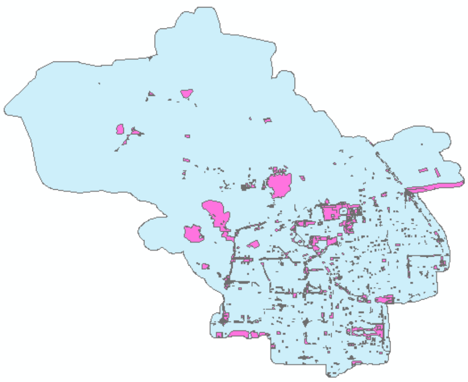

Figure A4 Greenbelt layer colored with Fushia pink

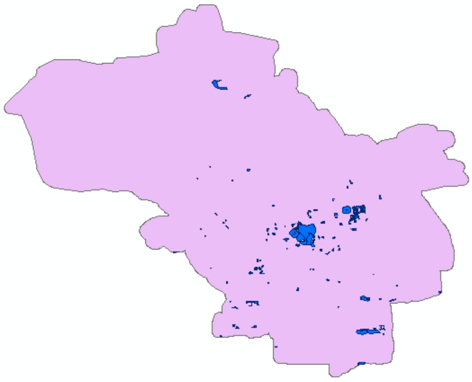

Figure A5 Reservoir layer colored with blue

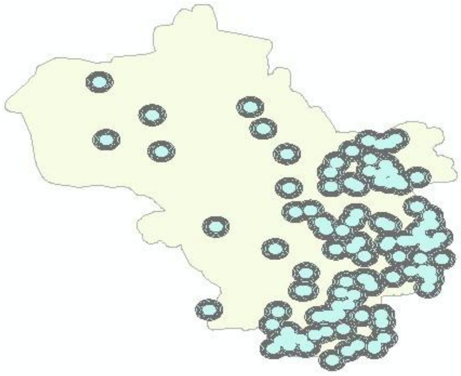

Figure A6 Buffer on existing hospital

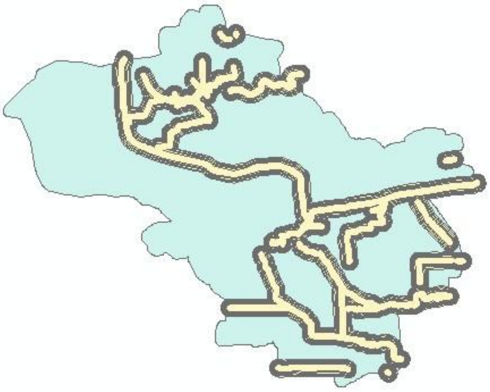

Figure A7 Buffer on river

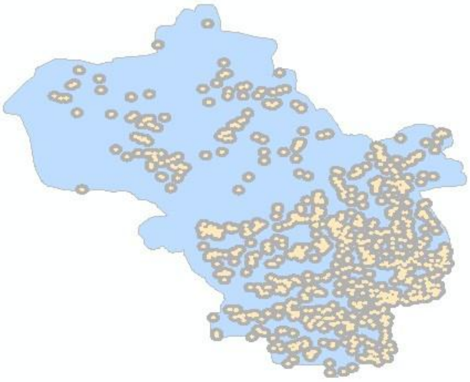

Figure A8 Buffer on public toilet

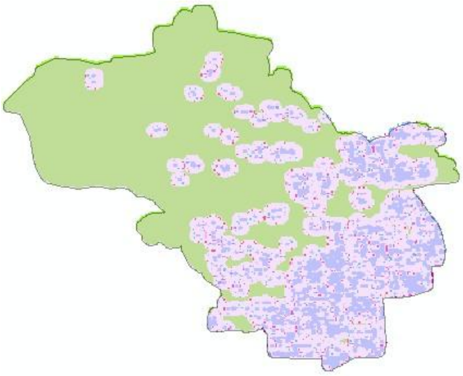

Figure A9 Buffer on residential area

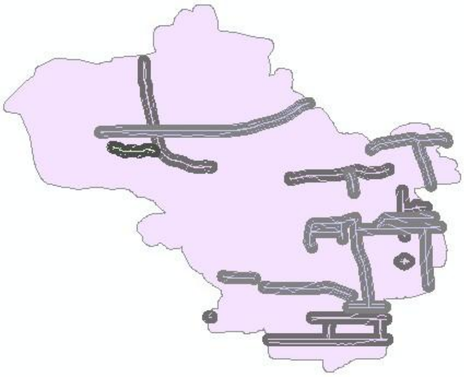

Figure A10 Buffer on road

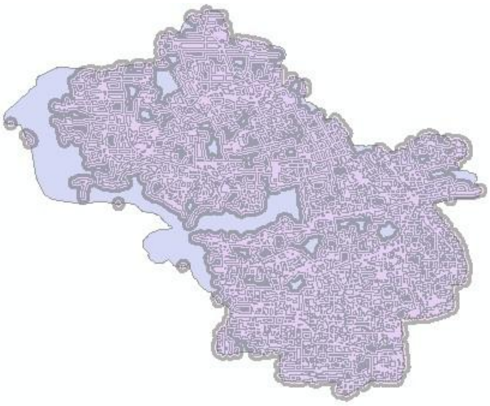

Figure A11 Buffer on street

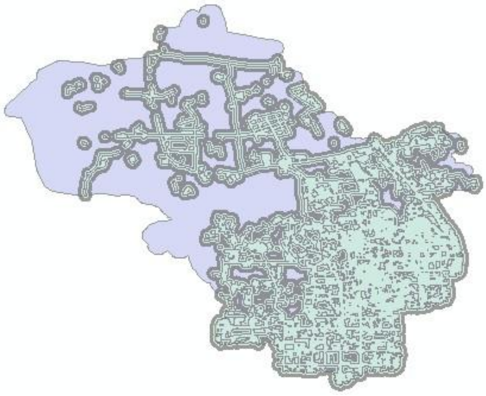

Figure A12 Buffer on sub-street

Figure A13 Beijing metro planning chart

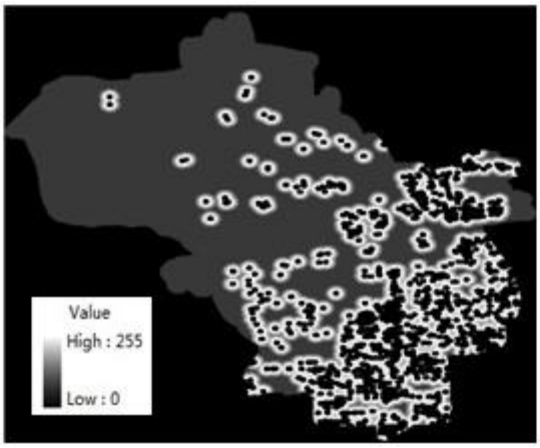

Figure A14 Factor map of residential area

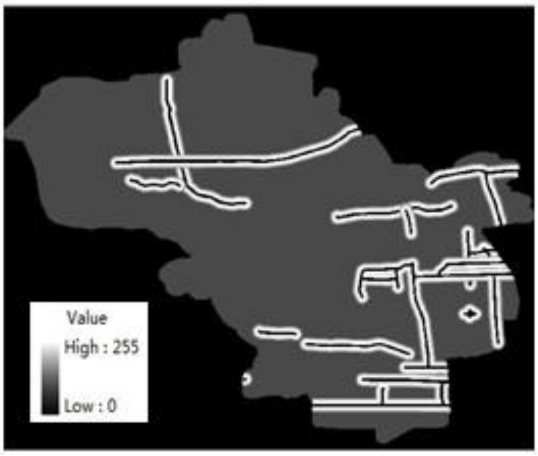

Figure A15 Factor map of road

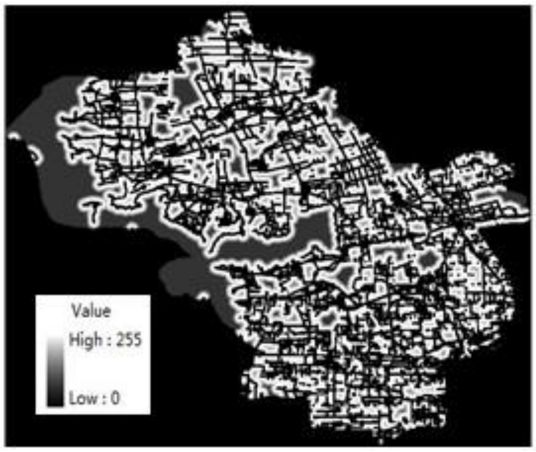

Figure A16 Factor map of street

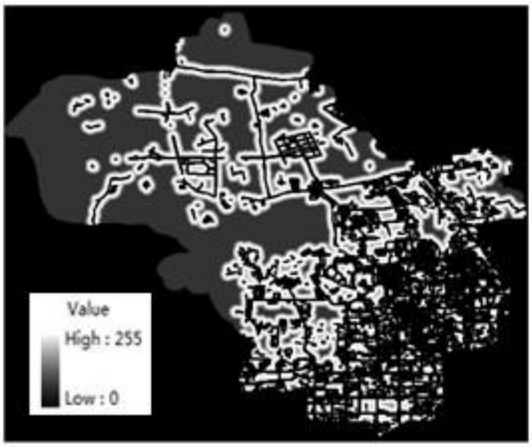

Figure A17 Factor map of sub-street

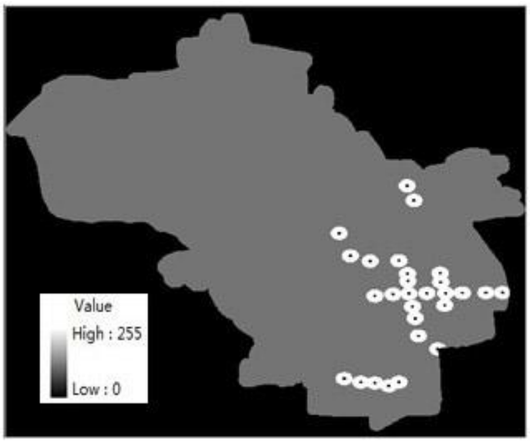

Figure A18 Factor map of metro

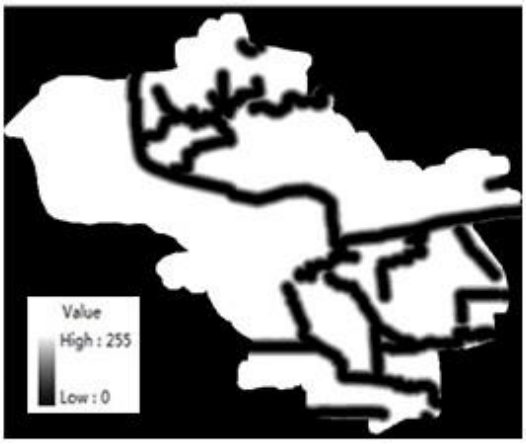

Figure A19 Factor map of river

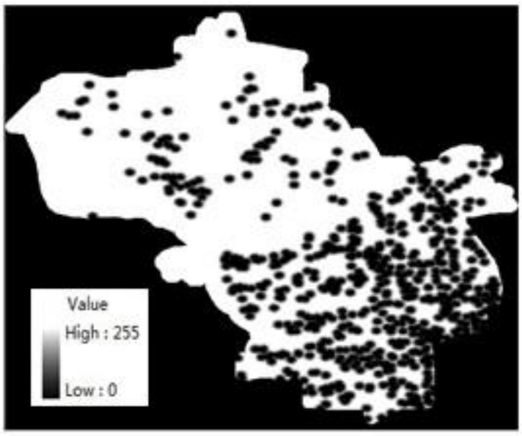

Figure A20 Factor map of Public toilet

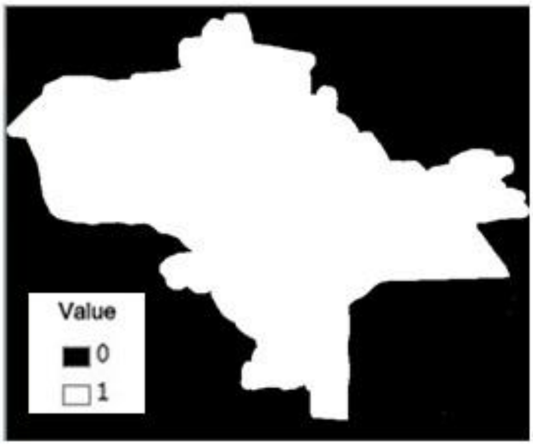

Figure A21 Constraint map of ring road

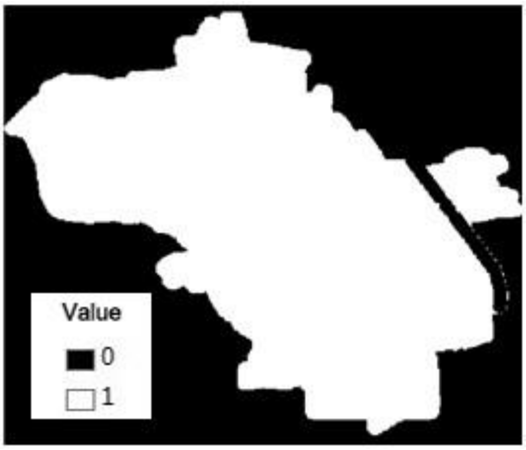

Figure A22 Constraint map of highway

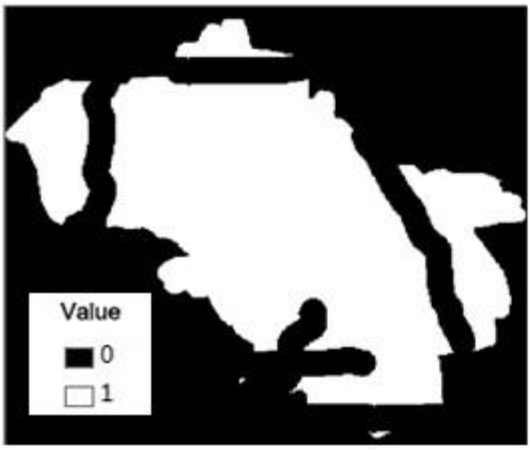

Figure A23 Constraint map of railway

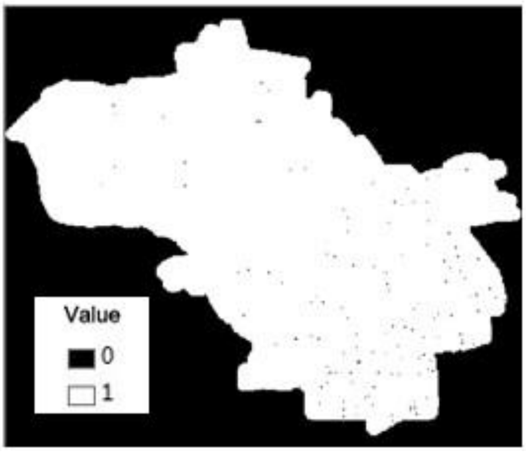

Figure A24 Constraint map of restaurant

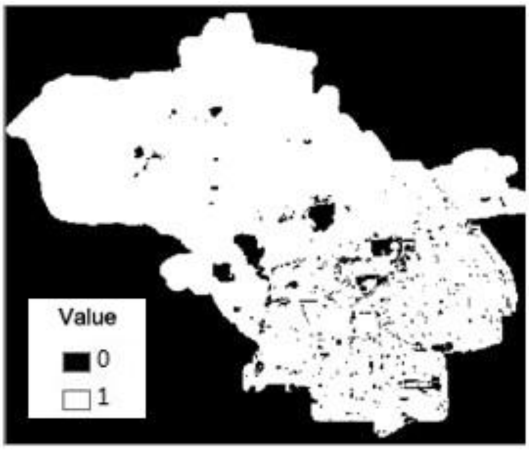

Figure A25 Constraint map of greenbelt

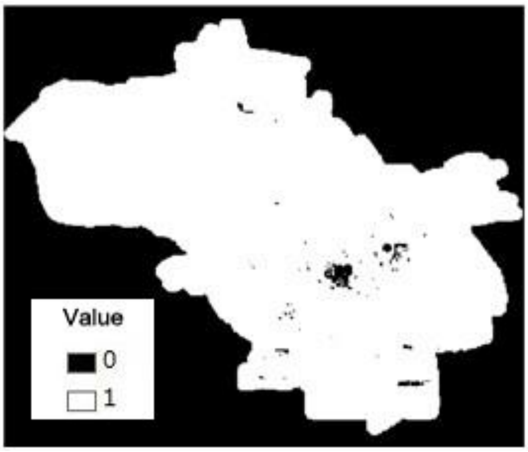

Figure A26 Constraint map of reservoir

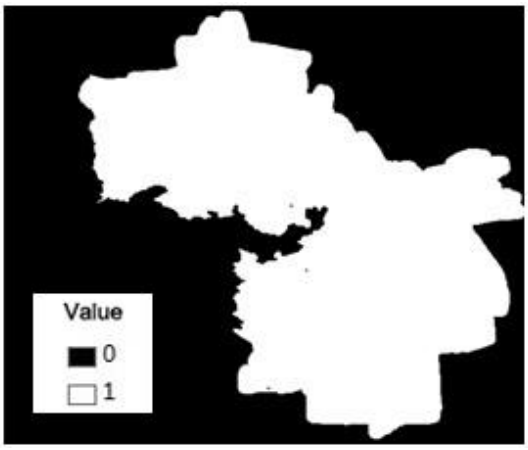

Figure A27Constraint map of altitude

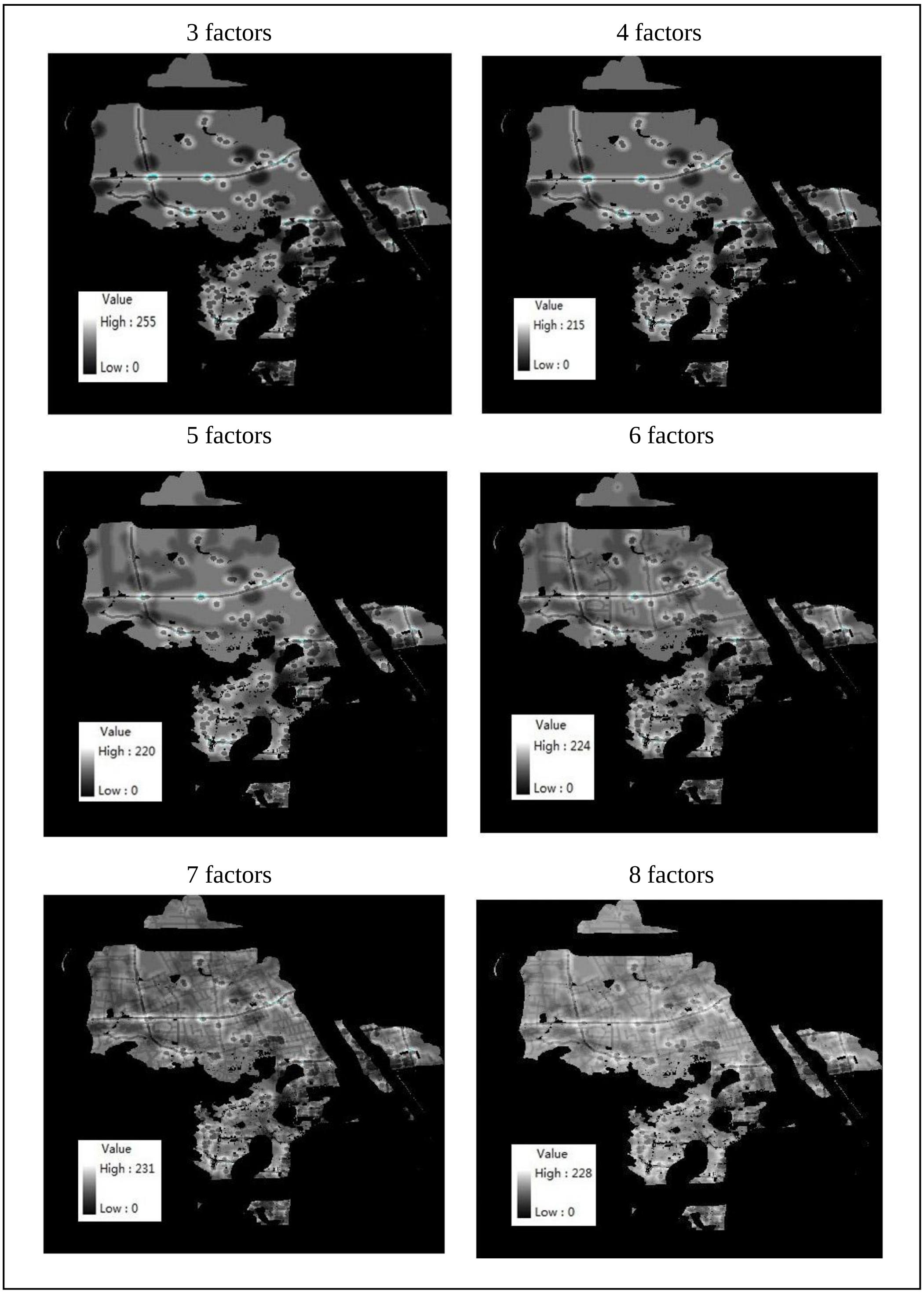

Figure A28 Result maps from AHP

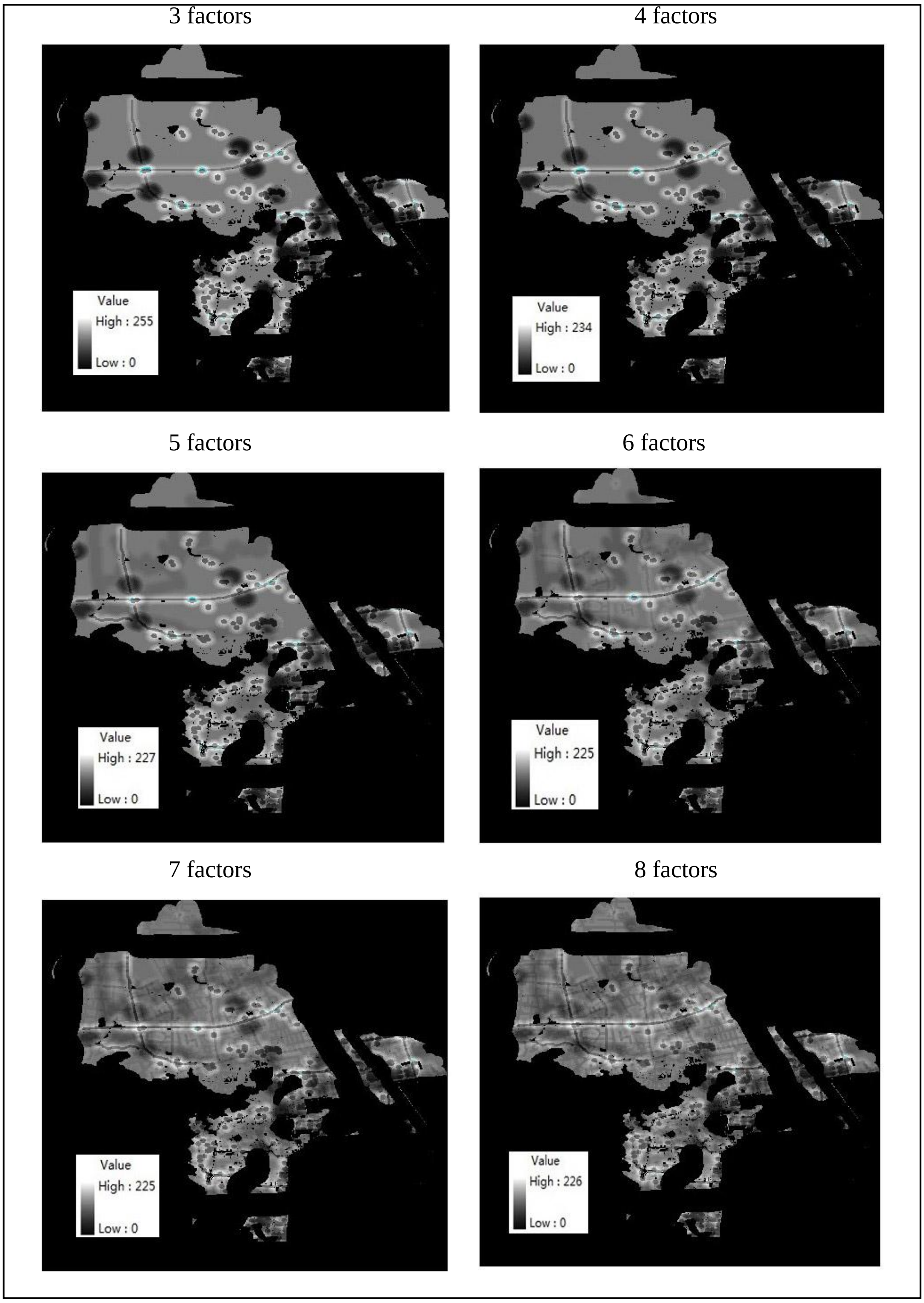

Figure A29 Result maps from ROM

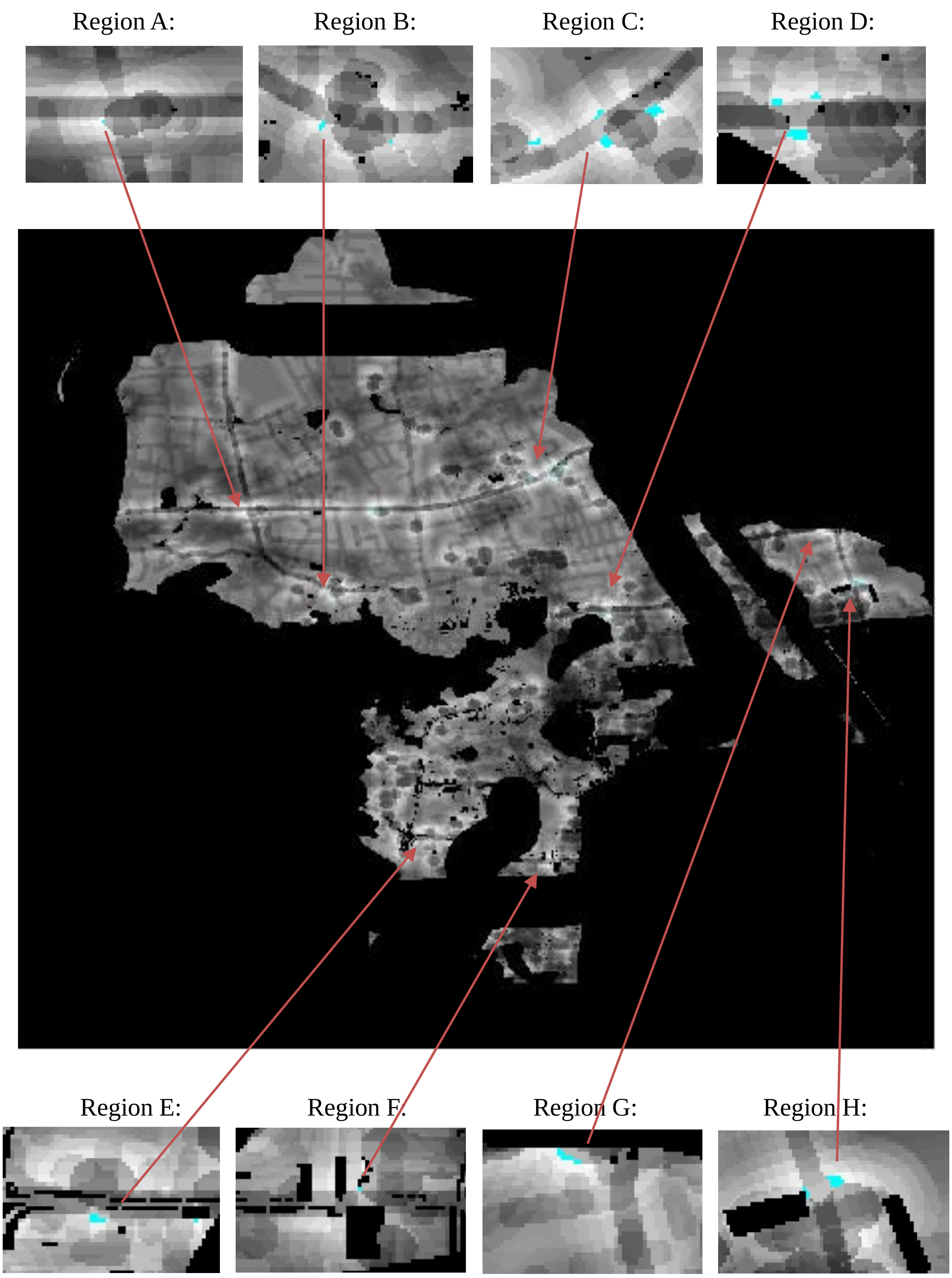

Figure A30 Candidate sites