Site selection for the next Chinese Antarctic research station

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Abstract: Site selection for the Antarctic research station is of great importance and necessary for Antarctic expedition, affecting both scientific investigations and service life of the station. This study was conducted to identify suitable sites for an Antarctic research station, by Geographical Information Systems (GIS) and Fuzzy Analytical Hierarchy Process (FAHP). Considering the natural environment and built environment in the study area, fifteen criteria were proposed as multiple evaluation sub-criteria and were grouped into four main criteria: scientific interest, environment, accessibility and topography. Weights of all the sub-criteria and main criteria were calculated through the FAHP. The weights were then multiplied with the suitability scores for each grid on raster maps of criteria in GIS software to produce the suitability maps in a hierarchical way. All the suitability maps in different levels were aggregated to allocate the most suitable areas for Chinese new Antarctic research station. Further, comparisons were also made between predicted suitable areas and existing stations and camps in Antarctica to show the fitness-for-use of the modeling results. After considering the locations of existing Chinese stations, the scientific interest of Chinese Antarctic expedition and relationships with stations of other countries, we suggested the candidate site for Chinese new Antarctic research station in the range of 166.53°-167.16°E, 77.699°- 77.847°S and gave the final mapping.

Keywords: Geographic Information System, Fuzzy Analytical Hierarchy Process, site selection, Antarctic research station

1. Introduction

The ever-increasing scientific interest of Antarctica amplifies the demand for new research stations. Due to the climatic extremes and geographical isolation, research stations on Antarctica are necessary to be maintained

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using the art technology to protect scientists from the environment and to provide a level of comfort which enables them to live and work there safely. The accurate identification and characterization of site suitability for station building are crucial since it impacts on scientific activities and the environmental protection in Antarctica. When choosing a site, numbers of criteria should be considered from the aspects of scientific interest, environment, logistics support, terrain conditions, and etc. [Final Comprehensive Environmental Evaluation(CEE) of , Norwegian summer station Troll(2004), German Neumayer III(2005), new Belgian research station(2007), English Halley VI research station(2007), new Indian research station(2010)station and Korea Jang Bogo Antarctic research station(2012)]. Therefore, many spatial variables are involved while selecting a suitable site and each of them must be weighted according to their relative importance on optimal building conditions for stations as well as research convenience. The allocation modeling result will be influenced by the uncertainty inherent in describing and ranking available criteria based on effective parameters (Vahidnia et al., 2009).

Fuzzy Analytical Hierarchy Process (FAHP) is a decision-making approach which can be used to calculate the suitability index to analyze and support decisions with multiple and even competing objectives (Wang et al., 2009). The selection problem first is divided into a number of simpler problems in the process of an analytical hierarchy (Saaty, 1980). After the hierarchy has been established, pairwise comparison matrices of main criteria and sub-criteria showing their relative importance are constructed under the study goal. FAHP, combined with GIS, has been used to address the suitability rating problems in various context, such as for hospital site selection (Vahidnia et al., 2009), solid waste management (Kahraman et al., 2003; Chang et al., 2008 and 2009; Ekmekçioğlu et al., 2010) and supplier selection (Kahraman et al., 2006). In this paper, the methodology was utilized in the process of Antarctic research stations' site selection. Compared with the costly field surveys in the past time, GIS is expected to efficiently simplify the selection procedure and make the decision more comprehensive and scientific.

This study aims to identify the optimum site for Antarctic research station based on FAHP and GIS. The extraordinary nature of Antarctic environment requires consideration of multiple evaluation criteria. Fifteen related criteria, grouped in four main criteria: scientific interest, environment, accessibility and topography, were analyzed in GIS according to their relative importance and suitability levels to produce the overall suitability model. The modeling result was used to suggest sites for Chinese new Antarctic research station. The final candidate site was further allocated by considering the relationships with other existing stations.

2. Study area

The study area covers major part of Antarctica (Figure 1) and has area about 12,086,200 km^2. The ice shelves are thick floating platforms of ice with accelerated mass loss (Rignot, et al., 2004). Due to the movement of the ice shelf and large snow accumulation, most stations built on the ice shelves have been abandoned, like British Halley I to IV stations(Final CEE, English Halley VI research station, 2007). Therefore, ice shelves that cover about 10% of the whole Antarctica were excluded from the study area. Besides, the South Orkney Islands was not included either from the prospective of scientific interest, since it is far away from the continent of Antarctica.

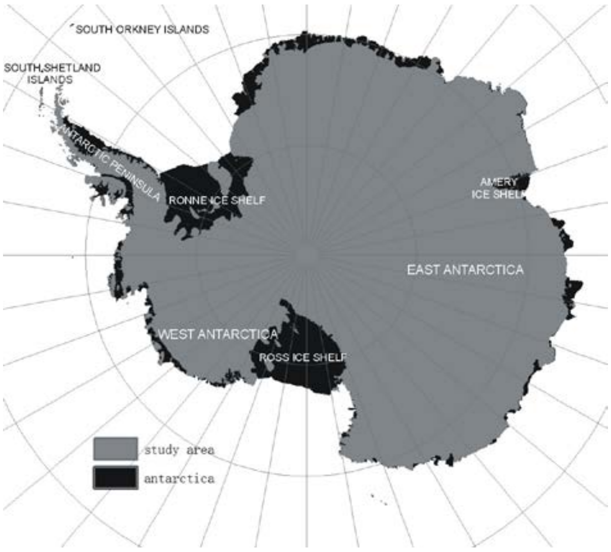

Figure 1. extent of the study area.

3. Method

Generally, FAHP and GIS were used to build the hierarchical criteria structure and integrate all the spatial data to generate suitability map. Five main steps are: (1) identify main criteria, related sub-criteria and collect corresponding data showing spatial distribution of criteria, (2) use FAHP to calculate the suitability index, namely weights of main criteria and sub-criteria, (3) give suitability scores on the map to each sub-criteria, (4) use GIS to aggregate the weights and scores in different levels and to obtain the overall suitability map, (5) verify the accuracy of the model with existing stations and camps in GIS capability. In this study, for selecting Chinese new Antarctic research station, we analyzed the scientific interest of Chinese expedition to partially assess the fitness-for-use of the suitability map, and further reduced the candidate site though the location of existing research stations. The research scheme is illustrated in Figure 2.

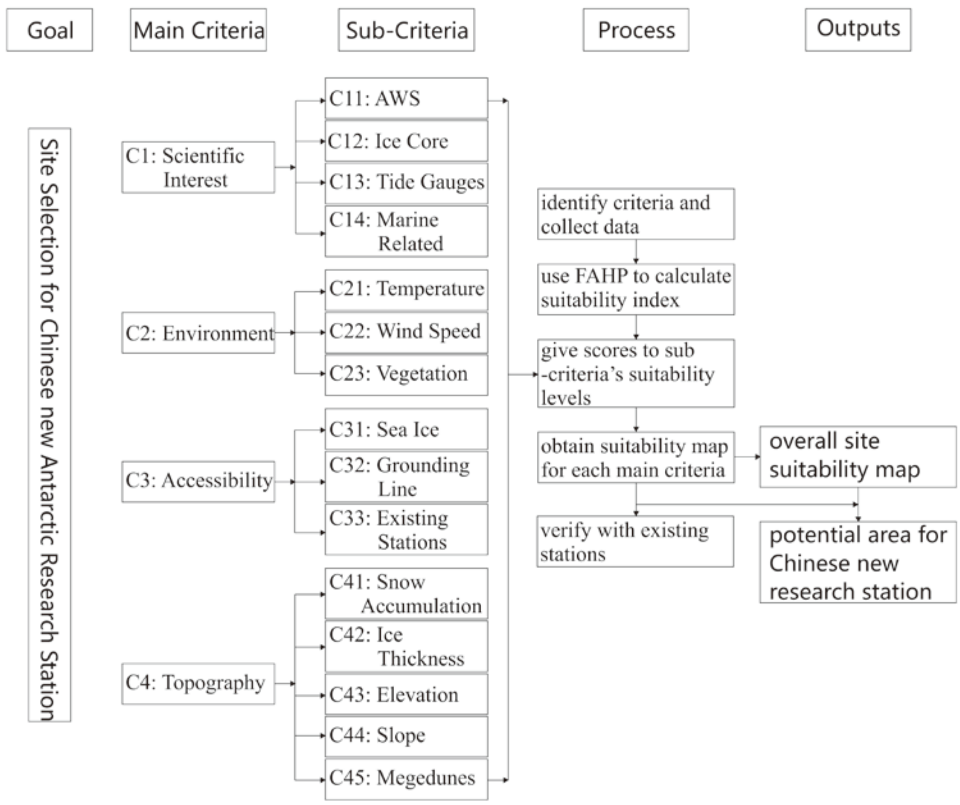

Figure 2. Schematic diagram of modeling procedure for Chinese new Antarctic research station's site selection.

3.1. Criteria identification and data collection

The criteria for selecting the best sites for station building in Antarctica were built under a hierarchical structure, which breaks down all criteria into small groups in different levels. Criteria are grouped according to the similarity of the elements with respect to the function they perform or property they share (saaty, 1980) and they are identified as influencing the goal of the study (Hossain et al., 2009).

Main criteria	Sub-criteria	Describing	data
C1: Scientific interest	C11:Automatic weather stations	distance to the location of the AWS.	AWS
	C12: Ice core	distance to the location of the ice core.	Ice core
	C13: Tide gauges	distance to the location of the tide gauges.	Tide gauges
	C14: Marine related	linear distance to the coast line.	Antarctica coastlines
C2: Environment	C21: Temperature	Summer air temperature	July
		Winter air temperature	January
	C22: Wind speed	Summer wind speed	July
		Winter wind speed	January
	C23: vegetation	area where vegetation grows and the linear distance to the area.	Vegetation regions
C3: Accessibility	C31: Sea ice	linear distance from the outer edge of the sea ice to the inland of Antarctica.	July
	C32: Grounding line	linear distance to the grounding line.	Grounding line
	C33: Existing stations	distance to the location of the year-round stations.	year-round stations
		distance to the location of the seasonal stations.	seasonal stations
C4: Topography	C41: Snow accumulation	height of the snow accumulation.	Snow accumulation
	C42: Ice thickness	height of the ice thickness.	Ice thickness
	C43: Elevation	height of the elevation.	Surface elevation
	C44: Slope	percent value of the surface slope.	Antarctic 1km DEM
	C45: Megadunes	megadunes regions and the linear distance to them.	Megadunes regions

Table 1. Criteria system and corresponding data.

In this study, the site selection work is for the Chinese new station, which is planned to be a year-round station that contributes to the international collaboration and multidisciplinary studies in support of both Chinese and foreign scientists. The criteria selection is based on extensive literature review, and the criteria system was derived from the site selection part of German Neumayer III station's Final CEE (2005), Final CEEs of Norwegian summer station Troll (2004), new Belgian research station (2007), English Halley VI research station (2007), new Indian research station (2010) and Korea Jang Bogo Antarctic research station (2012). Limited by data availability, we tried to make the criteria system involve comprehensive and operational, non-redundant and minimal set of criteria. Four main criteria, namely scientific interest, environment, accessibility and topography were chosen in the general level, and fifteen sub-criteria were grouped under the main criteria in the detailed level. A brief description for the main criteria and the related sub-criteria is listed in Table 1.

GIS is used as a tool for management, manipulation, representation and analysis of spatial data to facilitate the site selection process. Spatial data representing distributions of criteria were collected from various resources. Some topographical data, such as elevation, slope, grounding line, etc., were produced several years ago, but we assume that there is a little change with in the short time which can be ignored in the site selection. Meanwhile, the temperature changed in the last ten years from 0.1℃ decade^{-1} to 0.56℃ decade^{-1} (Turner er al., 2005 and Steig et al., 2009). Compared with the isotherms in degrees, the error is in the negligible range. All maps and thematic data were transformed into Stereographic South Pole projection and scaled to the same resolution 1 km, same as the DEM resolution. They were prepared and implemented in the GIS software ArcGIS in the whole modeling process.

3.2. FAHP methodology

The Analytical Hierarchy Process(AHP), initiated by Saaty (1980), is a flexible multi-criteria decision-making methodology that transforms a complex problem into a hierarchy with respect to one or more criteria (Mohajeri, 2010), each of which can be analyzed independently. In this study, the hierarchy is constructed to involve the four main criteria and their sub-criteria (Figure 2 and Table 1). FAHP (Fuzzy Analytical Hierarchy Process) is an extension of AHP to involve the inherent uncertainty and imprecision in human thinking in the decision-making process. It allows decision-makers to express approximate preferences using fuzzy memberships to add fuzziness into the judgment (Mikhailov and Tsvetinov, 2004; Wang et al., 2008; Erensal et al., 2006; Lee et al., 2008). To be specific, the single valued element in AHP is replaced by a triangular fuzzy number $\tilde{a}_{ij}$, denoted as $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ in the FAHP. After determining the hierarchy, the pairwise comparison matrix A has been set up to estimate the weight of each criterion according to Equation 1.

$$\tilde{A} = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn} \end{bmatrix} = \begin{bmatrix} (l_{11}.m_{11}, u_{11}) & (l_{12}.m_{12}, u_{12}) & \cdots & (l_{1n}.m_{1n}, u_{1n}) \\ (l_{21}.m_{21}, u_{21}) & (l_{22}.m_{22}, u_{22}) & \cdots & (l_{2n}.m_{2n}, u_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (l_{n1}.m_{n1}, u_{n1}) & (l_{n2}.m_{n2}, u_{n2}) & \cdots & (l_{nn}, m_{nn}, u_{nn}) \end{bmatrix}, \tag{1}$$

Where l_{ij}, m_{ij}, and u_{ij} are the x-coordinates of the three endpoints of the triangular. $a_{ij}(1 \le i, j \le n)$ is the relative importance value of criterion C_i to criterion C_j, and all the element in the comparison matrix are positive, $a_{ji} = (1/u_{ij}, 1/m_{ij}, 1/l_{ij})$.

There are various types of FAHP methods in the literature (such as Laarhoven and Pedrycz, 1983; Buckley, 1985; Chang, 1996; Leung and Cao, 2000). In this study, we prefer Chang's (1996) extent analysis method to calculate the suitability index since this approach is relatively easier achieved than other FAHP approaches. The steps of the fuzzy extent analysis can be summarized as follows:

First, three experts, specializing in Antarctic snow and ice, geodesic and ecological research, are invited to give the importance weights a_{ij}, a_{ij} and a_{ij} for all the main criteria and sub-criteria. a_{ij}, a_{ij} and a_{ij} are selected from the linguistic variables representing several levels of preference according to Kahraman (2006) in Table 2. The relatively weight a_{ij} is calculated as the arithmetic average of the three weights from different experts (Chen, 2000). Considering the operational laws of triangular fuzzy number, the formula can be expressed by:

$$\tilde{a}_{ij} = \frac{1}{3}\left[\tilde{a}_{ij}^{1} + \tilde{a}_{ij}^{2} + \tilde{a}_{ij}^{3}\right] = \frac{1}{3}\left[l_{ij}^{1} + l_{ij}^{2} + l_{ij}^{3}, m_{ij}^{1} + m_{ij}^{2} + m_{ij}^{3}, u_{ij}^{1} + u_{ij}^{2} + u_{ij}^{3}\right], \tag{2}$$

where $\tilde{a}_{ij}^{K}$ is the importance weight assigned by the $K^{th} (K = 1, 2, 3)$ decision maker.

Second, to estimate the priority vector $w = (W_{C1}, \cdots, W_{Cn})^T$ of the fuzzy comparison matrix A, where W_{Ci} is the weight of C_i. The detailed calculation steps refer to (Chang, 1996).

Finally, the consistency ratio (CR) of $\tilde{A}$ should be examined by equation 3 .

$$CR = \frac{CI}{RI} \quad \text{and} \quad CI = \frac{\lambda_{\max} - n}{n-1} \tag{3}$$

$\lambda_{\max}$ is the maximum eigenvalue of $\tilde{A}$. RI is a random consistency index of a randomly generated reciprocal matrix. We adopted the values of RI from the previous study by Brent, er al. (2007), in which average values for matrices of orders 1-15 have been generated from a sample size of 100. If the value of CR is no bigger than 10%, the inconsistency of $\tilde{A}$ is considered acceptable. Otherwise, $\tilde{a}_{ij}$ should be reconsidered and modified.

Linguistic scale	triangular fuzzy numbers	Inverse Linguistic scale	Inverse triangular fuzzy numbers
Extremely strong important(ES)	(2,5/2,3)	Extremely weak(EW)	(1/3,2/5,1/2)
Very strong importance(VS)	(3/2,2,5/2)	Very weak(VW)	(2/5,1/2,2/3)
Fairly strong importance(FS)	(1,3/2,2)	Fairly weak(FW)	(1/2,2/3,1)
Moderately strong importance(MS)	(1,1,3/2)	Moderately weak(MW)	(2/3,1,1)
Equal(E)	(1,1,1)	Equal(E)	(1,1,1)

Table 2. triangular fuzzy numbers for the weights.

3.3. Scores of sub-criteria's suitability levels

The range of Antarctic characteristics can be divided into three classes: most suitable, moderately suitable and not suitable based on requirements for station building. Weights have been counted according to the relatively importance of the criteria. Each sub-criteria was also given scores on the map according to the level of suitability, i.e. most suitable was scored 3, moderately suitable scored 2 and not suitable scored 1 (Hossain et al., 2009). For each map, the specific division interval of the three classes is shown in Table 3. The suitability rating for each level of criteria, which provides conditions for the overlay analysis, was derived from the survey results, professional judgment of experts as well as the Final CEEs.

criteria	unit	Suitability rating and score		
		Most suitable(3)	Moderately suitable(2)	Not suitable(1)
Automatic weather stations(AWS)	km	0-15	15-25	>25
Ice core	km	0-1	1-2	>2
Tide gauges	km	0-15	15-25	>25
Marine related(coast line)	km	0-15	15-25	>25
Temperature(1)	℃	>-10	-10- -15	<-15
Temperature(7)	℃	>-20	-20- -35	<-35
Wind speed(1)	bft	<5	5-8	>8
Wind speed(7)	bft	<8	9-11	>11
vegetation	km	within	Outside 0-15	Outside >15
Sea ice	km	0-100	100-200	>200
Grounding line	km	0-15	15-25	>25
Year-round stations	km	5-20	20-200	0-5 and >200
Seasonal stations	km	1-20	20-100	0-1 and >100
Snow accumulation	mm	0-150	150-350	>350
Ice thickness	m	<100	100-300	>300
elevation	m	<800	800-2700	>2700
slope	%	0-2	2-5	>5
megadunes	km	Outside >5	Outside 0-5	within

Table 3. suitability levels of sub-criteria for station building in Antarctica.

3.4. Suitability map and model verification

Since suitability levels are determined, data is buffered according to Table 3 to produce suitable zones. Next, the reclassified grid of each sub-criteria was multiplied with the respective weight in GIS software to produce the suitability map for each main criteria. After all, the suitability maps of main criteria were aggregated to produce the overall suitability model.

$$\text{Overall suitability grid} = \text{Grid}_{\text{scientific}} \times W_{C1} + \text{Grid}_{\text{environment}} \times W_{C2} + \text{Grid}_{\text{accessibility}} \times W_{C3} + \text{Grid}_{\text{topography}} \times W_{C4}$$

Model verification was carried out in GIS capabilities by making comparison between predicted suitable areas and existing stations. All the stations and camps were included for subsequent assessment. The approach was to compare the locations and characteristic of existing stations with suitability area and suitability ratings provided by the GIS, which was much more effective than the traditional field investigation one by one. The purpose of verification was to testify the general applicability of the suitability model. An important assumption was that the stations had a preference for comprehensive survey just like the Chinese new research station.

4. Results

4.1. Weights of main criteria and sub-criteria

Main criteria	weights	Related sub-criteria	weights
C1: Scientific interest	0.1784	C11: Automatic weather stations(AWS)	0.2367
		C12: Ice core	0.1848
		C13: Tide gauges	0.1992
		C14: Marine related	0.3793
C2: environment	0.1534	C21: temperature	0.3943
		C22: Wind speed	0.3618
		C23: vegetation	0.2439
C3: accessibility	0.2722	C31: Sea ice	0.3325
		C32: Grounding line	0.3047
		C33: Existing stations	0.3628
C4: topography	0.3960	C41: Snow accumulation	0.2468

		C42: Ice thickness	0.2391
		C43: Elevation	0.1918
		C44: Slope	0.1421
		C45: Megadunes	0.1803

Table 4. normalized weight vector of main criteria and related sub-criteria.

Weights of main criteria and sub-criteria were derived (Table 4), with all the CRs in a satisfactory range (0.0357-0.0971). Topography (W_{C4}=0.3960) came to be the most important parameter for site selection, next with accessibility (W_{C3}=0.2722), and followed by scientific interest (W_{C1}=0.1784).

4.2. Suitability map and verification

The most suitable sites for Antarctic research stations in Figure are recognized as good topological condition with easy logistic support, favorable temperature, wind speed and scientific research foundations. They are centered on the South Shetland Island, Antarctic Peninsula and areas around the Groundling line. Limited by scientific interest and accessibility, the majority part of Antarctic hinterland is not suitable for station building.

Existing stations	Most suitable	Moderately suitable	Not suitable	Total number
Year-round	35	3	0	38
seasonal	50	9	1	61
Total number	85	12	1	98

Table 5. comparison of existing stations with suitable map.

Locations of 98 existing stations were compared with suitability zones on derived overall suitability map. The results were shown in Table 5 and Figure 3. 38 year-round stations are all sited in most suitable and moderately suitable zones. Only one station which is used as a camp locates in the not suitable zone according to our modeling result. The most suitable zone on the overall suitability map covers 86.74% of the existing stations, and the moderately suitable zone covers 12.24% of the stations. The modeling output, therefore, matches well with the site selection performed before and can be regarded to have 98.98% accuracy.

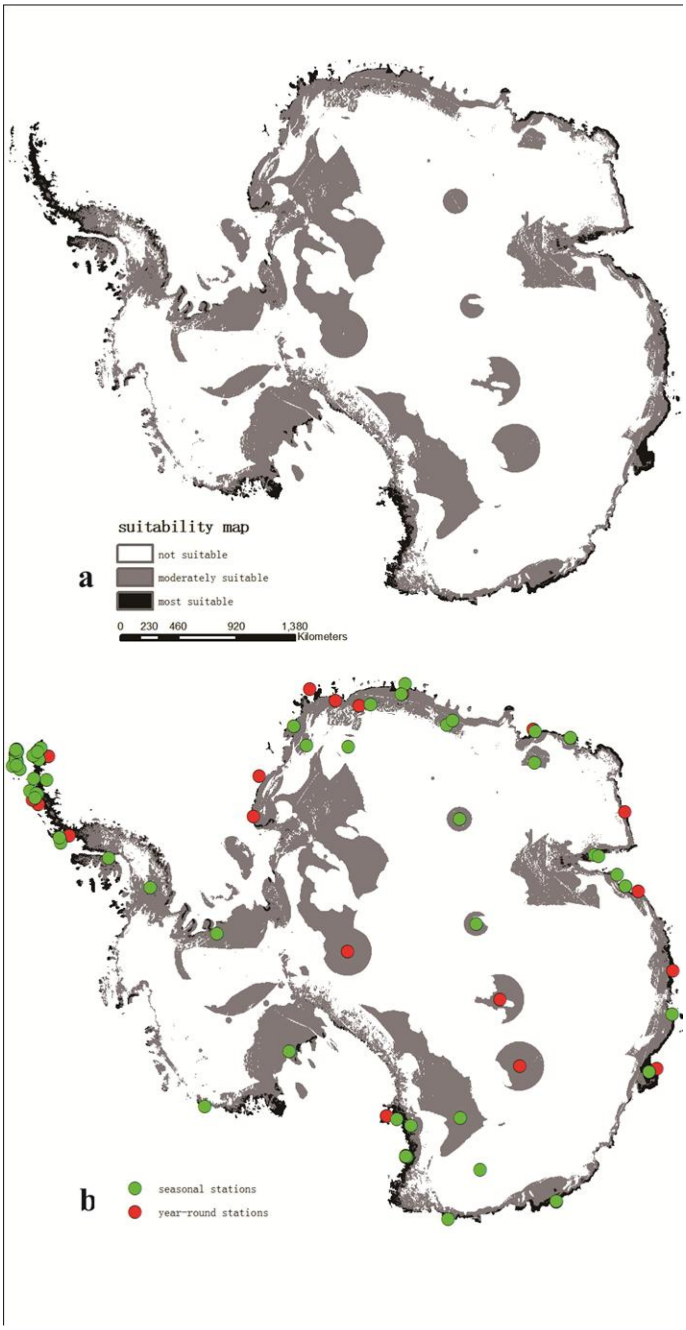

Figure 3. Overall suitability map(a) and location of existing stations(b).

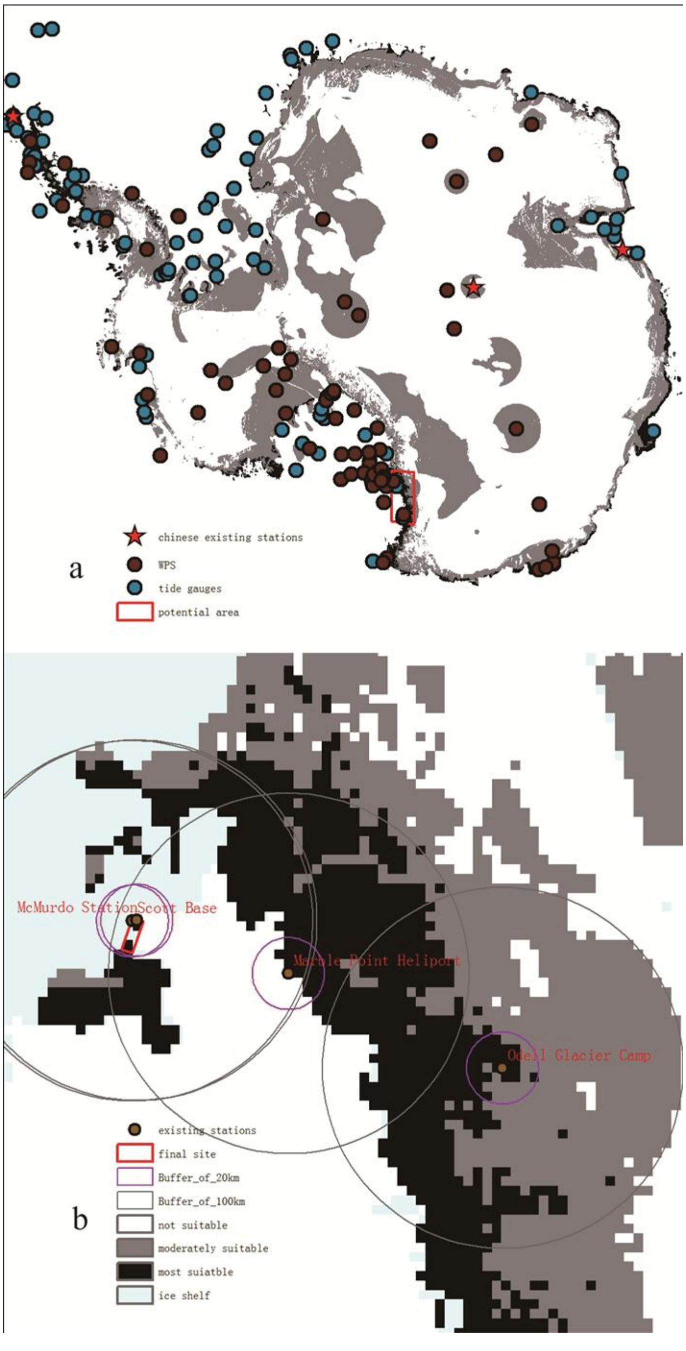

Figure 4. optimal site for Chinese new Antarctic research station.(a) potential area for site selection;(b):enlargement of the potential area and suggestion of the final site.

4.3. The optimal site of Chinese new Antarctic research station

China already has three Antarctic research stations, including Changcheng station in the South Shetland Island, Zhongshan station in East Antarctica near the Amery Ice Shelf and Kunlun station in the inland of Antarctica next to Dome A (Figure 4a). The Changcheng station and the Zhongshan station are year-round stations and the Kunlun station is a seasonal station for studying the inland topography and ice core. The new station is expected to be a year-round station. Considering the function of the station as well as the location of Chinese existing stations, we give the priory to the area in the West Antarctica showed in Figure 4a.

The suggested final site shown in Figure 4b (166.53°E - 167.16°E, 77.699°S - 77.847°S) near the Ross Ice Shelf -- the biggest ice shelf, is one of Chinese expedition's next emphasis. There are numerous automatic weather stations and tide gauges already established on the ice shelf, providing a good foundation for scientific study. The suitable environmental condition prevents the station from being abandoned in few years, and the adjacency to the coast facilitates water supply and accessibility. Moreover, two year-round stations, American Mcmurdo station and Zelanian Scott Base station, are in a reasonable distance and could provide scientific communication and international rescue when necessary.

5. Conclusion

For the increasing needs of scientific support and international cooperation, the site selection of Antarctic research station is the one of the greatest challenges faced by governmental authorities. In this study, a raster-based GIS model integrated with a multi-criteria evaluation technique, Fuzzy Analytical Hierarchy Process, was developed for optimal site selection of Antarctic research station. From the perspective of facilitating scientific investigation and station maintenance, scientific interest, environment, accessibility and topography factors, including 15 criteria, were considered in the computation process to create the overall suitability map. GIS was utilized as the analysis and verification tool to manipulate and present spatial data. The fuzzy extent approach is confirmed that it can offer an objective suitability index and correctly determine the priorities. Furthermore, the use of the set of weights provided great flexibility in the aggregation procedure, which can be utilized by other countries. The final site, stretching from 166.53°E to 167.16°E longitude and between 77.699°S and 77.847°S latitude, is suggested to be the suitable site for Chinese new Antarctic research station.

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References

Alfred Wegener Institute for Polar and Marine Research, German Federal Environmental Agency (2005) Final Comprehensive Environmental Evaluation of the Proposed Activities: Construction of the Neumayer III Station, Operation of the Neumayer III Station, Dismantling of the Existing Neumayer II Station

Belgian Federal Science Policy Office, the international Polar Foundation (2007) Final Comprehensive Environmental Evaluation: construction and operation of the new Belgian Research Station, Dronning Maud Land, Antarctica

Brent C, Rogers DEC, Ramabitsa-Siimane TSM, Rohwer MB (2007) Application of the analytical hierarchy process to establish health care waste management systems that minimise infection risks in developing countries. European Journal of Operational Research 181:403–424

British Antarctic Survey (2007) Final Comprehensive Environmental Evaluation: Proposed construction and operation of Halley VI research station, and demolition and removal of Halley V Research Station, Brunt ice shelf, Antarctica

Buckley JJ (1985) Fuzzy hierarchical analysis. Fuzzy Sets and Systems 17 (3):233–247

Chang DY (1996) Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research 95:649–655

Chang NB, Chang YH, Chen HW (2009) Fair fund distribution for a municipal incinerator using GIS-based fuzzy analytic hierarchy process. Journal of Environmental Management 90 (1):441–454

Chang NB, Parvathinathan G, Breeden JB (2008) Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. Journal of Environmental Management 87 (1):139–153

Chen C (2000) Extensions of the TOPSIS for group decision-making under fuzzy environment. Fuzzy Sets and Systems 114:1–9

Ekmekçioğlu M, Kaya T, Kahraman C (2010) Fuzzy multicriteria disposal method and site selection for municipal waste. Waste Management 30(8–9):1729–1736

Erensal YC, Oncan T, Demircan ML (2006) Determining key capabilities in technology management using fuzzy analytic hierarchy process: a case study of Turkey. Information Sciences 176:2755–2770

Hossain MS, Chowdhury SR, Das NP, Sharifuzzaman SM, Sultana A (2009) Integration of GIS and multicriteria decision analysis for urban aquaculture development in Bangladesh. Landscape and Urban Planning 90:119-133

Kahraman C, Cebeci U, Ulukan Z (2003) Multi-criteria supplier selection using fuzzy AHP. Logistics Information Management 16:382 – 394

Kahraman C, Ertay T, Büyüközkan G (2006) A fuzzy optimization model for QFD planning process using analytic network approach. European Journal of Operational Research 171:390 – 411

Korea Polar Research Institute, Korea Environment Institute (2012) Final Comprehensive Environmental Evaluation: construction and operation of the Jang Bogo Antarctic Research Station, Terra Nova Bay, Antarctica

Laarhoven PJM, Pedrycz W (1983) A fuzzy extension of Saaty□s priority theory. Fuzzy Sets and Systems 11 (3):229 – 241

Lee AHI, Chen WC, Chang CJ (2008) A fuzzy AHP and BSC approach for evaluating performance of IT department in the manufacturing industry in Taiwan. Expert Systems with Applications 34:96–107

Leung LC, Cao D (2000) On consistency and ranking of alternatives in fuzzy AHP. European Journal of Operational Research 124:102 – 113

Mikhailov L, Tsvetinov P (2004) Evaluation of services using a fuzzy analytic hierarchy process. Applied Soft Computing 5:23–33

Mohajeri N, Amin GR (2010) Railway station site selection using analytical hierarchy process and data envelopment analysis. Computers & Industrial Engineering 59:107 – 114

National Center for Antarctic and Ocean Research (minister of earth sciences, government of India) (2010) Final Comprehensive Environmental Evaluation of New Indian Research Station at Larsemann Hills, Antarctica

Norwegian Polar Institute (2004) Final Comprehensive Environmental Evaluation (CEE) for the upgrading of the Norwegian summer station Troll in Dronning Maud Land, Antarctica, to permanent station

Parish TR (1988) Surface winds over the Antarctic continent: A review. Reviews of Geophysics 26(1):169-180

Rignot E, Casassa G, Gogineni P, Krabill W, Rivera A, Thomas R (2004) Accelerated ice discharge from the Antarctic Peninsula following the collapse of Larsen B ice shelf. Geophys Res Lett 31:L18401

Saaty TL (1980) The analytic hierarchy process: Planning, priority setting, resource allocation. New York, USA:McGraw-Hill

Steig EJ, Schneider DP, Rutherford SD, Mann ME, Comiso JC, Shindell DT (2009) Warming of the Antarctic ice-sheet surface since the 1957 International Geophysical Year. Nature 457:459–462

Turner J, Colwell SR, Marshall GJ, Lachlan-Cope TA, Carleton AM, Jones PD, Lagun V, Reid PA, Iagovkina S (2005) Antarctic climate change during the last 50 years. Int J Climatol 25:279–294

Vahidnia MH, Alesheikh AA, Alimohammadi A (2009) Hospital site selection using fuzzy AHP and its derivatives. Journal of Environmental Management 90:3048 – 3056

Wang GQ, Qin L, Li GX, Chen LJ (2009) Landfill site selection using spatial information technologies and AHP:A case study in Beijing, China. Journal of Environmental Management 90:2414 – 2421

Wang YM, Luo Y, Hua Z (2008) On the extent analysis method for fuzzy AHP and its applications. European Journal of Operational Research 186:735–747