Site Selection of the Colombian Antarctic Research Station Based on Fuzzy-Topsis Algorithm

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Abstract. By 2025 the Republic of Colombia aims to be an advisory member of the Antarctic Treaty System (ATS) and the installation of a scientific station is necessary to upscale the scientific capabilities. The aim of this paper is showing the results of the implementation of a Fuzzy TOPSIS algorithm for site selection of the Colombian Antarctic Scientific Station. A three-phase methodology was proposed, and the obtained results allowed to identify the optimum location for the station, considering key success factors and regulatory constraints.

Keywords: Site selection · Fuzzy TOPSIS · Antarctic station

1 Introduction

By 2025 the Republic of Colombia aims to be an advisory member of the Antarctic Treaty System (ATS). The location of a temporary scientific base in Antarctica before 2025 is one of the goals for the Colombian Antarctic Program agenda 2014-2035, looking for the exploration and exploitation of the Antarctic continent, as a space for geopolitical and scientific advances.

The objective of this project is to determine the optimal location of a temporary Colombian scientific base in the Antarctic that minimizes the total costs of the scientific operation subject to geographic and geopolitical restrictions. To determine the optimum location, a Fuzzy Topsis Algorithm was implemented.

Zadeh [1] implemented the concept of fuzzy sets theory to express the linguistic terms used in decision-making to alleviate the difficulty of operational management. Hwang and Yoon [2] first suggested the TOPSIS method, a linear weighting technique.

Different applications of this method have appeared in scientific literatures since then, but it has not been applied to optimization in Antarctic logistics [3–30].

In [31] was determinate a Site selection of the Turkish Antarctic Research station using Analytic Hierarchy Process. In [32] was determinate the sites for new a new Antarctic Chinese research station using geographical information systems (GIS) and the fuzzy analytical hierarchy process (FAHP).

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This paper is organized as follows: Sect. 2 shows the methodology stages that include data collection and the algorithm implementation. Section 3 shows the obtained results from the Fuzzy Topsis Methodology, and finally, Sect. 4 contains the main conclusions and main research opportunities.

2 Methodology

The proposed methodology is composed of three phases and aims the selection of the best site selection for the Colombian Antarctic Scientific Station Almirante Padilla (EACAP, for its acronym in Spanish).

2.1 Set of Alternate Locations and Key Factors for Location

Stage 1 aims the selection of a set of alternate locations for the EACAP, using geographic information systems (GIS). Ten alternate locations were selected, considering the research interests and their logistics capabilities.

Every alternate location complied with a set of requirements: proximity to other scientific stations, water supply (from glaciers), proximity to an airstrip, a sheltered bay, the existence of ship anchoring areas, some meteorological conditions, geopolitical restrictions within the Madrid protocol, and Antarctic Specially Protected Areas (ASPA).

2.2 Antarctic Expeditions and Fieldwork

Fieldwork in stage 2 consisted of two Antarctic expeditions: IV and V Colombian Expedition to Antarctica. The first in austral summer of 2017–2018, and the second expedition in 2018–2019, both with an approximate budget of 3.5 million dollars.

The expeditions included a schedule for visiting all alternate locations selected in stage 1. Soil composition analysis, drone mapping, and topographic studies were performed in every location. Also, wind sensors and wavemeters were installed in order to measure meteorological conditions. In this stage, every location was verified according to the protocol of Antarctic Specially Protected Areas (ASPA).

2.3 Fuzzy TOPSIS Algorithm for Site Selection

A multicriteria decision-making algorithm based on Fuzzy TOPSIS was implemented for the problem of site selection of the Colombian EACAP.

Step 0. Find the evaluation data. A group of scientists, expeditionaries, and military members with Antarctic expeditions experience were asked to judge and rank the selected weights and importances of criteria. A questionnaire (based on linguistics terms and triangular fuzzy numbers) was offered. Every participant assessed all alternate locations, establishing the importance of the criteria, the fulfillment of requirements, and the key success factors.

Step 1. Obtaining evaluation data from qualitative criteria. The evaluation data of qualitative criteria are given by experts in the form of fuzzy linguistic values that correspond to fuzzy numbers. The linguistic variable evaluation matrixes are transformed as fuzzy number matrixes, as shown below. The linguistic variable evaluation matrixes were transformed as fuzzy number matrixes, as $\tilde{x}_{i,j} = \left(\tilde{a}_{i,j},\ \tilde{b}_{i,j},\ \tilde{c}_{i,j}\right)$ and $\tilde{w}_j^k = \left(\tilde{w}_{j1}^k,\ \tilde{w}_{j2}^k,\ \tilde{w}_{j3}^k\right)$.
Step 2. The weighted fuzzy array was calculated from the aggregate decision variable $\tilde{x}_{i,j}$.

$$\tilde{x}_{i,j} = \left(a_{i,j},\ b_{i,j},\ c_{i,j}\right),\ \text{where } a_{ij} = \min_k\left\{a_{ij}^k\right\},\quad b_{ij} = \frac{1}{K}\sum\nolimits_{k=1}^{K} b_{ij}^k,\quad c_{ij} = \max_k\left\{c_{ij}^k\right\}.$$

In the same way, the weighted fuzzy array $\tilde{w}_j$ was calculated from the linguistic terms:

$$\tilde{w}_j = \left(w_{j1},\ w_{j2},\ w_{j3}\right),$$

where $w_{j1} = \min\limits_k\left\{w_{jk1}\right\},\quad w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{jk2},\quad w_{jk3} = \max\limits_k\left\{w_{jk3}\right\}$. And the aggregate decision matrix $\tilde{D}$ was obtained:

$$\tilde{D} = \begin{pmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \cdots & \cdots & \tilde{x}_{ij} & \cdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{pmatrix} \text{ and } \tilde{W} = \left(\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n\right)$$

Step 3. Normalized Decision matrix is calculated as
$\tilde{R} = \left[\tilde{r}_{ij}\right]_{m\times n} \forall i = 1,\ 2,\ \ldots,\ m; \forall j = 1,\ 2,\ \ldots\ ,\ n$. where every element $\tilde{R}$ is calculated depending on the type of criteria.

$$\tilde{r}_{ij} = \begin{cases} \left(\frac{a_{ij}}{c_j^*},\ \frac{b_{ij}}{c_j^*},\ \frac{c_{ij}}{c_j^*}\right) \textit{ and } c_j^* = \max\limits_i\left\{c_{ij}\right\} \textit{ if } \text{ the benefit criteria} \\ \left(\frac{a_j^-}{c_{ij}},\ \frac{a_j^-}{b_{ij}},\ \frac{a_j^-}{a_{ij}}\right) \textit{ and } a_j^- = \min\limits_i\left\{a_{ij}\right\} \textit{ if } \text{ the cost criteria} \end{cases}$$

Step 4. Normalized weighted matrix is calculated as
$\tilde{V} = \left[\tilde{v}_{ij}\right]_{m\times n} \forall i = 1,\ 2,\ \ldots\ , m;\ \forall j = 1,\ 2,\ \ldots\ ,\ n$ where $\tilde{v}_{ij} = r_{ij}(\cdot)\tilde{w}_j$.
Step 5. The fuzzy positive ideal solution (FPIS) is calculated as $A^* = \left(\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*\right)$ where

$$\tilde{v}_j^* = \max_i\left\{v_{ij3}\right\}\ \ \forall i = 1, 2, \ldots, m;\ \ \forall j = 1, 2, \ldots, n$$

And the negative ideal solution is calculated (NPIS) as $A^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-\right)$ where

$$\tilde{v}_j^- = \min_i\left\{v_{ij1}\right\}\ \ \forall i = 1, 2, \ldots, m;\ \ \forall j = 1, 2, \ldots, n.$$

Step 6. Distances from every alternate to every solution FPIS and FNIS were calculated as

$$d_i^* = \sum\nolimits_{j=1}^{n} d_v\left(\tilde{v}_{ij}, \tilde{v}_j^*\right),\ \ \forall i = 1, 2, \ldots, m \text{ and } d_i^- = \sum\nolimits_{j=1}^{n} d_v\left(\tilde{v}_{ij}, \tilde{v}_j^-\right),\ \ \forall i = 1,\ 2,\ \ldots,\ m$$

The distance of each alternate from FPIS and FNIS are calculated with Euclidean distance formula.

$$d_v\left(\tilde{a}, \tilde{b}\right) = \sqrt{\frac{1}{3}\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2\right]}$$

Step 7. The closeness coefficient of each alternate is calculated in order to ranking the alternates, the closest to FPIS and the farthest to FNIS.

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*}, \forall i = 1, 2, \ldots, m$$

By comparing values CC_i, the ranking of alternates is determined.

3 Results

3.1 Set of Alternate Locations and Key Factors for Location

One of objectives of Colombia during continuous polar expeditions is determining the optimum location for the settlement of a future Colombian Antarctic Scientific Station.

A set of key success factors was defined by the group of experts: 1) Accessibility, 2) Object of study, 3) Proximity to other stations, 4) Proximity to water resources, and 5) Personnel Safety.

According to these factors, a set of coordinates was defined, as shown in Fig. 1.

ALTERNATE LOCATION	LATITUDE	LONGITUDE
Alternate Location 1	62°40'9.58"S	60°24'6.25"W
Alternate Location 2	62°39'37.59"S	60°22'22.57"W
Alternate Location 3	62°38'48.32"S	60°22'23.79"W
Alternate Location 4	62°39'4.00"S	60°36'9.78"W
Alternate Location 5	62°37'4.94"S	60°19'37.50"W
Alternate Location 6	62°26'49.56"S	59°43'35.45"W
Alternate Location 7	62°12'35.10"S	58°47'55.70"O
Alternate Location 8	62°05'32"S	58°29'50"W
Alternate Location 9	62°04'31"S	58°18'00"W
Alternate Location 10	62°09'47"S	58°27'34"W

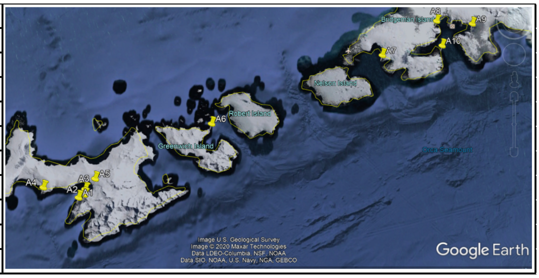

Fig. 1. Set of alternate locations for Colombian Antarctic Scientific Station.

3.2 Antarctic Expeditions and Field Work

The field work was carried out on board of the "ARC 20 de Julio", an offshore patrol vessel OPV80, made in Colombia [33]. The coordinates of the alternate locations were visited within the schedule of the IV and V Colombian Expeditions to Antarctica. These visits aimed obtaining information from each location based on the key success factors.

This step is illustrated with the exploration at the location that corresponds to Livistong Island with coordinates 62°38′48.32″S, 60°22′23.79″W which is close to the Juan

Carlos I base in Spain and the St. Kliment Ohridski of Bulgary. At this geographical point, a series of beaches with appropriate dimensions and a predominantly rocky composition were identified. The depth of its waters was optimal for access by ships, as well as the approach to the beaches in smaller boats. This point has a chain of mountains in the background and surrounding the bay which are a natural barrier to winds. It has no restrictions due to protected areas and in the upper part of the mountain there are water reservoirs which are used by Bulgaria. Stable rocky material was found in order to support buildings. A first exploration is carried out with a helicopter and then mapped with the drone to identify water sources, accesses and morphology (Fig. 2).

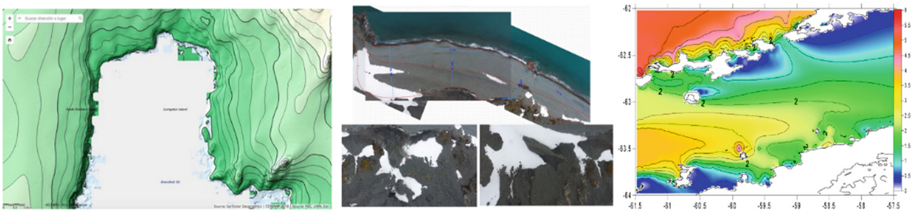

Fig. 2. Drone mapping image, Morphology, and meteorological conditions for the alternate locations.

3.3 Fuzzy TOPSIS Algorithm for Site Selection

The preliminary results from the Fuzzy TOPSIS algorithm for the location of the Colombian Antarctic scientific station are shown below.

According preliminary studies in stage 2, the results from the Fuzzy TOPSIS algorithm for the location of the Colombian Antarctic scientific station were obtained considering 10 alternate locations, 5 criteria, and a group conformed by 7 expert decision-makers.

Step 0: A questionnaire was prepared and based on the information collected at each alternate location during the field work of the expeditions, the linguistic assessment of each expert is constructed based on the assessment criteria (key success factors) and the assessment of each alternative based on to each criterion by each expert.
Step 1: A transduction of the linguistic matrix is made to Fuzzy numbers using the scale in the Table 1.

Table 1. The scale of fuzzy numbers

Fuzzy numbers			Alternative assessment	QA weights
1	1	3	Very Poor (VP)	Very Low (VL)
1	3	5	Poor (P)	Low (L)
3	5	7	Fair (F)	Medium (M)
5	7	9	Good (G)	High (H)

The resulting matrix of 5 × 70 triangular numbers contains 1050 elements.
Step 2: The aggregate decision variable matrix and the weighted fuzzy array was calculated in Table 2 and Table 3. The normalized decision variable matrix is shown in Table 4.

Table 2. The aggregate decision variable matrix

$\tilde{D}$ D	A1			A2			A3			A4			A5			A6			A7			A8			A9			A10		
C1	3,00	6,14	9,00	3,00	6,52	9,00	5,00	7,14	9,00	1,00	4,71	9,00	1,00	4,71	9,00	1,00	5,19	9,00	3,00	6,14	9,00	1,00	5,57	9,00	1,00	6,71	9,00	1,00	5,38	9,00
C2	1,00	2,43	9,00	3,00	5,76	9,00	5,00	6,67	9,00	1,00	5,29	9,00	3,00	5,29	9,00	1,00	5,19	9,00	3,00	6,14	9,00	3,00	5,76	9,00	1,00	5,76	9,00	1,00	5,38	9,00
C3	1,00	5,48	9,00	1,00	5,76	9,00	7,00	7,05	9,00	1,00	5,86	9,00	1,00	5,86	9,00	1,00	6,05	9,00	5,00	7,19	9,00	1,00	4,81	9,00	1,00	5,29	9,00	1,00	6,43	9,00
C4	3,00	5,29	9,00	1,00	2,62	9,00	5,00	5,00	9,00	3,00	5,29	9,00	1,00	5,29	9,00	1,00	6,33	9,00	3,00	5,29	9,00	1,00	5,29	9,00	1,00	5,57	9,00	3,00	5,29	9,00
C5	1,00	5,38	9,00	1,00	6,43	9,00	3,00	7,14	9,00	3,00	5,48	9,00	1,00	5,48	9,00	1,00	5,67	9,00	1,00	5,76	9,00	1,00	5,48	9,00	1,00	6,43	9,00	1,00	5,48	9,00

Table 3. The weighted fuzzy array

Wj			
C1	7,00	8,33	9,00
C2	3,00	7,10	9,00
C3	1,00	5,00	9,00
C4	1,00	5,57	9,00
C5	3,00	6,71	9,00

Table 4. The normalized decision variable matrix

Rij	A1			A2			A3			A4			A5			A6			A7			A8			A9			A10		
C1	0,33	0,68	1,00	0,33	0,72	1,00	0,56	0,79	1,00	0,11	0,52	1,00	0,11	0,52	1,00	0,11	0,58	1,00	0,33	0,68	1,00	0,11	0,62	1,00	0,11	0,75	1,00	0,11	0,60	1,00
C2	0,11	0,27	1,00	0,33	0,64	1,00	0,56	0,74	1,00	0,11	0,59	1,00	0,33	0,59	1,00	0,11	0,58	1,00	0,33	0,68	1,00	0,33	0,64	1,00	0,11	0,64	1,00	0,11	0,60	1,00
C3	0,11	0,61	1,00	0,11	0,64	1,00	0,78	0,78	1,00	0,11	0,65	1,00	0,11	0,65	1,00	0,11	0,67	1,00	0,56	0,80	1,00	0,11	0,53	1,00	0,11	0,59	1,00	0,11	0,71	1,00
C4	0,33	0,59	1,00	0,11	0,29	1,00	0,56	0,56	1,00	0,33	0,59	1,00	0,11	0,59	1,00	0,11	0,70	1,00	0,33	0,59	1,00	0,11	0,59	1,00	0,11	0,62	1,00	0,33	0,59	1,00
C5	0,11	0,60	1,00	0,11	0,71	1,00	0,33	0,79	1,00	0,33	0,61	1,00	0,11	0,61	1,00	0,11	0,63	1,00	0,11	0,64	1,00	0,11	0,61	1,00	0,11	0,71	1,00	0,11	0,61	1,00

Step 3: Normalized weighted matrix is shown in Table 5.
Step 4: Calculations of FPIS and FNIS are shown in Tables 6 and 7.

Table 5. The normalized weighted matrix

V	A1			A2			A3			A4			A5			A6			A7			A8			A9			A10		
C1	2,33	5,69	9,00	2,33	6,04	9,00	3,89	6,61	9,00	0,78	4,37	9,00	0,78	4,37	9,00	0,78	4,81	9,00	2,33	5,69	9,00	0,78	5,16	9,00	0,78	6,22	9,00	0,78	4,98	9,00
C2	0,33	1,91	9,00	1,00	4,54	9,00	1,67	5,26	9,00	0,33	4,17	9,00	1,00	4,17	9,00	0,33	4,09	9,00	1,00	4,84	9,00	1,00	4,54	9,00	0,33	4,54	9,00	0,33	4,24	9,00
C3	0,11	3,04	9,00	0,11	3,20	9,00	0,78	3,92	9,00	0,11	3,25	9,00	0,11	3,25	9,00	0,11	3,36	9,00	0,56	3,99	9,00	0,11	2,67	9,00	0,11	2,94	9,00	0,11	3,57	9,00
C4	0,33	3,27	9,00	0,11	1,62	9,00	0,56	3,10	9,00	0,33	3,27	9,00	0,11	3,27	9,00	0,11	3,92	9,00	0,33	3,27	9,00	0,11	3,27	9,00	0,11	3,45	9,00	0,33	3,27	9,00
C5	0,33	4,01	9,00	0,33	4,80	9,00	1,00	5,33	9,00	1,00	4,09	9,00	0,33	4,09	9,00	0,33	4,23	9,00	0,33	4,30	9,00	0,33	4,09	9,00	0,33	4,80	9,00	0,33	4,09	9,00

Table 6. Calculations of FPIS

A*	FPIS		
C1	9,00	9,00	9,00
C2	9,00	9,00	9,00
C3	9,00	9,00	9,00
C4	9,00	9,00	9,00
C5	9,00	9,00	9,00

Table 7. Calculations of FNIS

A-	FNIS		
C1	0,78	0,78	0,78
C2	0,33	0,33	0,33
C3	0,11	0,11	0,11
C4	0,11	0,11	0,11
C5	0,33	0,33	0,33

Table 8. Euclidean Distances from every alternate to every solution FPIS

FPIS	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
C1	4,30	4,21	3,26	5,45	5,45	5,33	4,30	5,24	5,01	5,28
C2	6,46	5,29	4,75	5,73	5,40	5,75	5,21	5,29	5,63	5,71
C3	6,18	6,13	5,58	6,11	6,11	6,08	5,67	6,30	6,21	6,01
C4	6,00	6,67	5,95	6,00	6,11	5,91	6,00	6,11	6,05	6,00
C5	5,77	5,56	5,08	5,42	5,75	5,71	5,69	5,75	5,56	5,75
d	28,71	27,86	24,62	28,71	28,81	28,78	26,86	28,68	28,46	28,76

Step 5: Euclidean Distances from every alternate to every solution FPIS and FNIS were calculated as shown in Tables 8 and 9.
Step 6: The closeness coefficients were ranked as shown in Table 10.

Table 9. Euclidean Distances from every alternate to every solution FNIS

FPIS	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
C1	4,30	4,21	3,26	5,45	5,45	5,33	4,30	5,24	5,01	5,28
C2	6,46	5,29	4,75	5,73	5,40	5,75	5,21	5,29	5,63	5,71
C3	6,18	6,13	5,58	6,11	6,11	6,08	5,67	6,30	6,21	6,01
C4	6,00	6,67	5,95	6,00	6,11	5,91	6,00	6,11	6,05	6,00
C5	5,77	5,56	5,08	5,42	5,75	5,71	5,69	5,75	5,56	5,75
d	28,71	27,86	24,62	28,71	28,81	28,78	26,86	28,68	28,46	28,76

Table 10. The ranked closeness coefficients

Alternate location	CC(i)
A3	0,53823908
A7	0,5087023
A2	0,4972285
A9	0,49365632
A8	0,48667472
A6	0,48655725
A10	0,48636965
A4	0,48474844
A1	0,48443983
A5	0,48381333

These results allow to identify an optimum location for the Colombian Antarctic Scientific Station. According to the rank, the alternate location 3 is the best site to locate the Colombian Antarctic Station.

4 Conclusions

A Fuzzy Topsis algorithm was implement for selecting the optimum location for the Colombian Antarctic Scientific Station.

Future research opportunities include the application of alternate solution methods based on multicriteria approaches in order to validate the selected location.

Also, studies on simulations on direct and inverse logistics of the station will be performed in order to decide the final location.

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