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Where To Locate Tethered Aerostats for an Effective Surveillance System: A Case Study on Southern Turkey

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Abstract

Due to its geostrategic position, security problems such as terrorism and illegal immigration have been experienced in southern Turkey so far. While Turkey uses UAVs to prevent the threats that may come from this region, National Defense Ministry is planning to use alternative technologies such as Tethered Aerostats. Because of the high investment cost, a considerable planning period is required before implementation of these systems. In this study; considering project budget, camera sensor capabilities, geographical analysis data and appropriateness parameters of candidate locations, three scenarios are developed for the site selection problem of Aerostats on southern Turkey. Goal Programming approach including Set Covering Algorithm and fuzzy-TOPSIS is applied and the results are tested with Viewshed Analysis of GIS. The study results present important recommendations for the probable success of TAs in southern Turkey.

1. INTRODUCTION

Border security is one of the most important concerns that countries have been encountering. Illegal immigration and terrorism draw attention to the security of border region. The usage of unmanned devices is becoming common in reconnaissance and surveillance process due to the physical and geographical obstacles in border regions. Today, many countries are seeking new technologies to ensure border security. The geographical structure of the area to be controlled and the severity of the threat have an important place on determination of the reconnaissance and surveillance system to be used. Such that; the most common surveillance agent UAV's, which provide dynamic surveillance opportunities, can be insufficient when the area to be tracked expands.

Nowadays, developed countries seem to use Tethered Aerostats (TA) to meet this need. TA is basically a balloon in vertebrate structure hosting a beneficial payload for information processing. Although these big balloons are used for transportation, mapping, advertising etc., they have been using for military purposes for many years. Some developments like fiber optic cable connection to the ground, integration of the stabilized camera systems, replacement of the gas system with helium, provision of fireproof and airtight exterior coating, lifting/elevating easily with special cranes have made it possible for TAs to stay in air longer than other agents.

Turkey provides reconnaissance and surveillance activities on southern borderline with thermal cameras, fixed/mobile radars, UAV's and watchtowers. But, increasing threat situations make the usage of more advanced systems necessary. The National Security Council (NSC), which determines the security policies of the country, supports this situation by planning to use TAs for border security [1]. The first studies on TAs in Turkey point out the "Doruk Balloon System" made by Otonom Technology Company

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in 2013. In the field tests conducted in 2014, the balloon system was reported to be an approptiate platform for carrying out long reconnaissance missions [2]. An image of TA is shown in Figure 1.

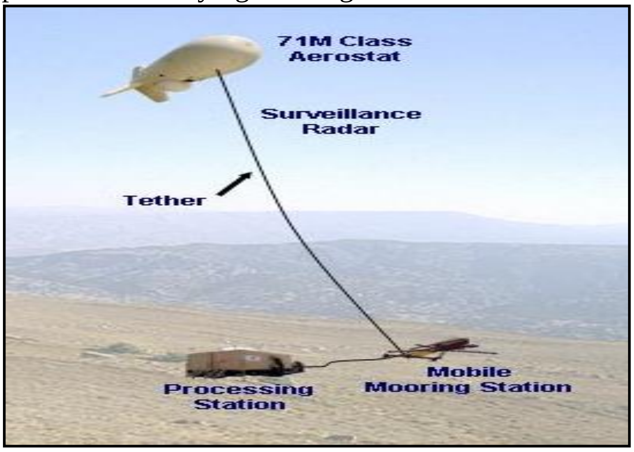

Figure 1. *An image of Tethered Aerostat*

In case of using these agents for border security, it is important to determine where the TAs will be deployed. Thus, before using these systems a considerable planning period is required. This problem can be described in “Site Selection Problem” which is frequently encountered in daily life. In this study; solutions are sought to the site selection problem of TAs considering the project budget constraints, sensor capabilities, geographical analysis data and appropriateness parameters provided by military experts’ opinions on candidate locations.

The progressive phases of the work are as follows: literature review is given in Section 2, the problem and the contribution of Geographical Information System (GIS) are addressed in Section 3, developed scenarios and solution proposals are introduced in Section 4, the results of the study are evaluated using GIS in Section 5 and suggestions for further studies are presented in the last section. The motivation behind the work is to make a contribution to the NSC decisions related to the use of TAs in Turkey’s southern borderline.

2. SITE SELECTION LITERATURE

The theory of site selection is one of the topics that has been studied since the 1900s. The issue was firstly addressed by Alfred Weber who focuses on how one depot should be placed closest to customers in different positions. Hakimi [3], called the problem of placing the facilities at minimum distance to the customers as "P-Median Problem". Church and Revelle [4], White and Case [5] concentrated their work on minimizing the number of installed facilities. Gary and Johnson [6] showed that the problem can be solved in a certain time by integer programming, but intuitive techniques are needed for large N (node number) and P (possible points) values. The "Greedy Adding with Substitution" algorithm used by Church and Revelle [4] seems to be the first intuitive study in the literature. In the following periods; they have theoretically pointed out the relation between the P-Median Model of Hakimi [3] and the Maximum Covering Model (MCM). Schilling [7], Boeffey and Narula [8] used Multi-Criteria Decision Making techniques in location selection problems, Megiddo et al. [9] developed a network theory based algorithm for MCM. In general, site selection problems deal with covering maximum number of demand centers with minimum number of facilities under the constraints of time, cost, distance etc. Due to the structure of objective function, the problem is also referred as "Min-Max Problems". According to Mehrez and Stulman [10], there are often a set of infinite solutions for such problems rather than a single one. Schilling et al. [11] reviewed site selection literature from 1900 to 1991 and classified models which use the concept of covering in two categories: (1) Set Covering Problem where coverage is required and (2) Maximal Covering where coverage is optimized. More detailed review can be found in [12]. Numerous studies have been conducted for the real-living conditions so far [13-18].

It is also possible to see the location selection applications in military and defense science. Some of them are summarized as follows. While MC algorithm was used to determine the location of gendarmerie stations [19], the positions of air defense systems [20], the responsible zones for the search and rescue teams [21], the base zone for the heterogeneous UAV fleet [22]; SC algorithm was used to locate the coastal surveillance radars in Aegean Region [23]. In the work on scanning an area with short-range UAVs, Kress and Royset (2007) purposed a two-stage model to determine the location of UAV's control station and flight path. In the relevant work, the geographical data of the scanned region is included in purposed SC model [24]. Kurban and Can (2015) used stochastic MC algorithm in control station location selection of mini UAVs with different coverage distances. In the relevant study, it is seen that the probability of giving/not giving services is determined by using the geographical structure of the region [25].

Since the terrorism and immigration incidents are encountered intensely on Southern regions of Turkey, it is seen that the location selection studies related to military issues are focused on these regions [26]. However many studies on surveillance and reconnaissance issues can be found in literature, studies on TAs seem as very limited.

3. LOCATION SELECTION PROBLEM OF TETHERED AEROSTATS ON SOUTHERN TURKEY

Turkey has a total border of 2573 km with two European (Bulgaria and Greece) and six Asian (Azerbaijan, Armenia, Georgia, Iraq, Iran and Syria) countries. Due to its geostrategic position, especially in Iraq, Iran and Syria, security problems such as terrorism and illegal immigration have been experienced. Therefore, constant surveillance of borderline gets importance for national defense. While Turkey uses UAVs to prevent the threats that may come from this region, National Defense Ministry is planning to use alternative technologies such as TAs due to the size of the area and the growing threat structure. To find out where to locate these TAs for an effective surveillance on southern borderline of Turkey, 107 critical locations are identified depending on the views of the military experts and the statements issued by Turkish Armed Forces. The image of the candidate points is given in Figure 2.

Figure 2. *Candidate points on geographic map*

The purpose of the problem is to determine the minimum number and the locations of TAs for continuous monitoring of the critical points at Turkey's south borderline. Considering that the field of view of a TA is related with the geographical nature of the area and the capability of camera sensor, the problem becomes more complicated.

3.1. The Role of Geographical Information System

Geographical Information System (GIS) is frequently used for geographical analysis and digital map processing. Visibility analysis in GIS searches for whether a location is visible from another location. The inputs of visibility analysis are the properties of natural or man-made layers. Using the Digital Elevation Model (DEM) data, an imaginary line is created between the target cell and the viewpoint. If both cells are located on this imaginary line, it is understood that there is visibility [27].

GIS is frequently used in military and defense applications, especially in the examination of geographical features, the movement planning of military units [28]. In this study; ArcGIS's Viewshed Analysis and Line of Sight modules are used for geographical analysis.

4. APPLICATION

Different scenarios are developed for the application process. In the first scenario; to determine the minimum number of TAs, their locations and the sensors types are aimed. In the second scenario, the candidate locations are assessed according to the criteria related to the geographical and military features. In the third scenario, Goal Programming approach is applied by combining maximum coverage and highest appropriateness value goals. The scenarios are conducted under some conditions, for example: the geographical data of Turkey's south borderline is used in application process, same structured TAs are used in open weather conditions and the cable length is determined as 1 km. The integration costs and the view ranges of the sensors are given in Table 1.

Table 1. *Integration costs and view ranges of sensor types*

Sensor Type	Maximum View Range	Purchasing & Integration Cost
s_1	20 km	\$ 100
s_2	40 km	\$ 200
s_3	60 km	\$ 300
s_4	80 km	\$ 400
TA purchasing & integration cost	\$10.000	

Scenario 1: Covering Candidate Points with Minimum Cost

The linear model developed for the scenario is as follows:

Indices:
i= Candidate TA settlement points. $i = \{ i_1, i_2, \ldots, j, \ldots, i_{107} \}$
s_k = Sensors. $s_k = \{s_1, s_2, s_3, s_4\}$

Parameters:
$d(i,j)$ = The imaginary line segment connecting i and j points.
c_B = Purchasing cost of TA. $c_B = \{ \$10.000 \}$
c_{s_k} = Purchasing and integrating cost of sensors. $c_{s_k} = \{ \$100, \$200, \$300, \$400 \}$
$v(i, s_k, j)$ = If imaginary line segment "$d(i,j)$" can be observed from the TA placed at point "i" with the sensor "s_k", then "1", otherwise "0".

Decision Variable:
x_{is_k} = If the TA using sensor "s_k" is placed at point "i" , "1" otherwise "0".

Model:

$$\text{Min } Z = \sum_{s}^{s4} \sum_{i}^{i_{107}} (x_{is_k} * (c_B + c_{s_k})) \tag{1}$$

st.

$$v(i, s_k, j) = \begin{cases} 1, & d(i,j) \in v(i, s_k, j) \\ 0, & dd. \end{cases} \tag{2}$$

$$\sum_{i}^{i_{107}} \sum_{s_1}^{s4} (x_{is_k} * v(i, s_k, j)) \geq 1 \qquad \forall j \tag{3}$$

$$\sum_{s}^{s_4} x_{is_k} \leq 1 \qquad \forall i \tag{4}$$

$$x_{is_k} = \begin{cases} 1, & \text{If the TA using sensor } s_k \text{" is placed at point "i".} \\ 0, & dd. \end{cases} \quad (5)$$

$$x_{is_k} \in \{0,1\} \quad (6)$$

In the developed model; Eq. (1) implies that covering all points with minimum cost is aimed. Eq.(2) tests whether imaginary line of sight segment "$d(i,j)$" between "i-j" points can be observed from the TA placed at point "i". This data is obtained from the Line of Sight module of ArcGIS. Eq. (3) provides that a point is observed by at least one TA. Eq.(4) states that only one sensor can be integrated on a TA. Eq.(5) and Eq.(6) are the descriptive constraints for the decision variable. The solution of the developed linear model is summarized in Table 2.

Table 2. *Model solution for Scenario 1*

TA Settlement Point and Sensor Type Used "x_{is_k}"	Total Cost "Z_{min}"
x_{1s_1} x_{8s_4} x_{30s_4} x_{62s_4} x_{75s_4} x_{93s_4}	\$62.100

According to results; all points are observed with a total of six TAs located at points 1, 8, 30, 62, 75, 93 and using one unit of 20 km - five units of 80 km sensors.

Scenario 2: Considering Maximum Appropriateness Values of Candidate Points

In order to reflect the geographical features into mathematical model, the candidate locations are examined by specialist military experts regarding to the "distance to the borderline", "terrorist activities in the region", "illegal immigration activities", "transportation easiness" and "closeness to the maintenance center". The linguistic expert opinions are included in the model with fuzzy-TOPSIS method. The TOPSIS (Technique for Order of Similarity to Ideal Solution) is a Multi-Criterion Decision Making method developed by Hwang and Yoon [29]. Chen [30] developed the method using Euclidean calculations to determine the distance between triangular fuzzy numbers. In Chen's fuzzy-TOPSIS, linguistic preferences can easily be converted to fuzzy numbers [31].

In this study, Chen's fuzzy-TOPSIS is used. The algorithm steps are summarized as follows: obtaining weights of the criteria and determining the fuzzy ratings of alternatives with respect to each criteria, the linguistic evaluations are expressed in matrix format. After normalizing fuzzy decision matrix according to the benefit/cost criteria, the weighted normalized fuzzy decision matrix is constructed using criteria weights. Then, the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) are defined to calculate the distance of each alternative from FPIS/FNIS. Currently, closeness coefficients (CC_n) are defined to determine the ranking order of all alternatives [30, 31].

Fuzzy-TOPSIS is widely used in literature to solve various decision making problems, in example: for the selection of firms in air transportation sector [32], for the investment decisions on railway links [33], for evaluation of firms' financial performance [34], for selection of military base locations [35], for identifying the most appropriate alternative in industrial robotic system [36]. More detailed literature review can be found in reference [37]. After applying Chen's fuzzy-TOPSIS algorithm on linguistic evaluations of military experts for criteria/alternatives, the criteria weights and alternative's CC_n values are given in Table 3 and Table 4, respectively.

Table 3. *Evaluations by military specialists and weights of criteria*

Criteria (C_i)	Military Specialist Personnel (MSP_i)					Criteria Weight Vector (w_i)		
	MSP_1	MSP_2	MSP_3	MSP_4	MSP_5			
C1 (Distance to the borderline)	FS	FS	FS	AS	AS	(0,5	0,8	1)
C2 (Terrorist activities in the region)	AS	AS	AS	AS	AS	(0,8	1	1)
C3 (Illegal immigration activities)	AS	AS	AS	AS	AS	(0,8	1	1)

C4 (Closeness to the maintenance center)	S	FS	S	S	S	(0,5	0,8	0,9)
C5 (Transportation easiness)	FS	FS	S	S	FS	(0,5	0,7	0,9)

Table 4. *Closeness coefficients of candidate locations (x_i)*

x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
0,571	0,552	0,561	0,567	0,538	0,548	0,554	0,564	0,552	0,562	0,542	0,528	0,550	0,571	0,527
x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}
0,533	0,550	0,544	0,538	0,528	0,552	0,554	0,539	0,559	0,532	0,558	0,528	0,528	0,528	0,561
x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}	x_{38}	x_{39}	x_{40}	x_{41}	x_{42}	x_{43}	x_{44}	x_{45}
0,553	0,553	0,560	0,559	0,562	0,582	0,560	0,557	0,568	0,590	0,593	0,580	0,569	0,570	0,549
x_{46}	x_{47}	x_{48}	x_{49}	x_{50}	x_{51}	x_{52}	x_{53}	x_{54}	x_{55}	x_{56}	x_{57}	x_{58}	x_{59}	x_{60}
0,568	0,571	0,551	0,590	0,589	0,543	0,565	0,555	0,594	0,594	0,594	0,625	0,585	0,573	0,603
x_{61}	x_{62}	x_{63}	x_{64}	x_{65}	x_{66}	x_{67}	x_{68}	x_{69}	x_{70}	x_{71}	x_{72}	x_{73}	x_{74}	x_{75}
0,572	0,596	0,572	0,584	0,582	0,582	0,540	0,537	0,568	0,559	0,577	0,546	0,575	0,577	0,538
x_{76}	x_{77}	x_{78}	x_{79}	x_{80}	x_{81}	x_{82}	x_{83}	x_{84}	x_{85}	x_{86}	x_{87}	x_{88}	x_{89}	x_{90}
0,521	0,577	0,520	0,506	0,522	0,524	0,519	0,504	0,536	0,539	0,506	0,495	0,522	0,488	0,475
x_{91}	x_{92}	x_{93}	x_{94}	x_{95}	x_{96}	x_{97}	x_{98}	x_{99}	x_{100}	x_{101}	x_{102}	x_{103}	x_{104}	x_{105}
0,516	0,565	0,583	0,531	0,510	0,508	0,513	0,520	0,495	0,525	0,548	0,565	0,523	0,529	0,584
x_{106}	x_{107}													
0,537	0,534													

"p_i" notation is added to the new linear model in second scenario, with the constraints between Eq. (2) and Eq. (6) being valid. "p_i", is the appropriateness parameter determined by the fuzzy-TOPSIS method. Linear model developed for Scenario 2 is as follows:

Model:

$$\text{Max } Z = \sum_{s}^{s_4} \sum_{i}^{i_{107}} (x_{is_k} * p_i) \tag{7}$$

st.

Equation $(2) - (6)$

$$p_i \in \{0,1\} \tag{8}$$

In the developed model; Eq.(7) seeks to observe all points so that the maximum appropriateness value is achieved. Eq.(8) is the descriptive constraint for the parameter " p_i". The solution is summarized in Table 5.

Table 5. *Model solution for Scenario 2*

TA Settlement Point and Sensor Type Used " x_{is_k} "	x_{1s_1}	x_{2s_3}	x_{3s_4}	x_{4s_3}	x_{5s_4}	x_{6s_4}	x_{7s_4}	x_{8s_1}	x_{9s_1}	x_{10s_4}	x_{11s_1}
	x_{12s_4}	x_{13s_1}	x_{14s_1}	x_{15s_4}	x_{16s_4}	x_{17s_4}	x_{18s_3}	x_{19s_3}	x_{20s_4}	x_{21s_1}	x_{22s_1}
	x_{23s_1}	x_{24s_1}	x_{25s_1}	x_{26s_1}	x_{27s_1}	x_{28s_1}	x_{29s_1}	x_{30s_1}	x_{31s_1}	x_{32s_1}	x_{33s_1}
	x_{34s_1}	x_{35s_1}	x_{36s_1}	x_{37s_1}	x_{38s_1}	x_{39s_1}	x_{40s_1}	x_{41s_1}	x_{42s_1}	x_{43s_1}	x_{44s_1}
	x_{45s_1}	x_{46s_1}	x_{47s_1}	x_{48s_1}	x_{49s_1}	x_{50s_1}	x_{51s_1}	x_{52s_1}	x_{53s_1}	x_{54s_1}	x_{55s_1}
	x_{56s_1}	x_{57s_1}	x_{58s_1}	x_{59s_4}	x_{60s_4}	x_{61s_4}	x_{62s_4}	x_{63s_4}	x_{64s_4}	x_{65s_4}	x_{66s_4}
	x_{67s_1}	x_{68s_1}	x_{69s_1}	x_{70s_1}	x_{71s_1}	x_{72s_1}	x_{73s_1}	x_{74s_4}	x_{75s_1}	x_{76s_1}	x_{77s_4}
	x_{78s_1}	x_{79s_4}	x_{80s_4}	x_{81s_4}	x_{82s_4}	x_{83s_4}	x_{84s_4}	x_{85s_4}	x_{86s_4}	x_{87s_4}	x_{88s_4}
	x_{89s_1}	x_{90s_1}	x_{91s_1}	x_{92s_1}	x_{93s_1}	x_{94s_4}	x_{95s_1}	x_{96s_1}	x_{97s_4}	x_{98s_1}	x_{99s_2}

x_{100s_1} x_{101s_2} x_{102s_2} x_{103s_2} x_{104s_1} x_{105s_1} x_{106s_4} x_{107s_1}	
Z_{max} (Total Appropriateness Value)	58,95
Total Cost	$1.092.200

According to the results; both maximum appropriateness value is achieved and all points are covered with a total of 107 TAs using 64 units of 20 km, 4 units of 40 km, 6 units of 60 km and 33 units of 80 km sensors.

Scenario 3: Goal Programming Approach

In the first scenario, minimizing the total cost of TA settlement is aimed. Thus, the appropriateness values of settlement locations are not considered. In the second scenario, the appropriateness values of the candidate settlement locations are taken into consideration, but the cost factor is ruled out. It may be useful to look for a solution taking into account the objectives of two previous scenarios. This emerging problem can be described in Multi-Objective Problems which includes multiple goals that may conflict with each other. Goal Programming (GP) is a practical methodology which was firstly proposed by Charnes and Cooper [38] to solve problems with parallel or conflicting goals. The methodology is then developed as priority/lexigraphic linear GP [39], min-max GP, compromise programming, reference point method [40], minimum-deviation method [41]. Although the Multi-objective programming approach is widely used in energy [41], project selection [42], investment decisions [43], production and inventory planning [44] etc., the usage of this approach for military matters such as surveillance and intelligence is very limited. The GP model developed for Scenario 3 is as follows:

Model:

$$\text{Min Z} = (m_1 * d_1^-) + (m_2 * d_2^+) \tag{9}$$

st.

$$\sum_{s}^{s4} \sum_{i}^{i_{107}} (x_{is_k} * (c_B + c_{s_k})) - d_1^+ + d_1^- = 62100 \tag{10}$$

$$\sum_{s}^{s_4} \sum_{i}^{i_{107}} (x_{is_k} * p_i) - d_2^+ + d_2^- = 3{,}41 \tag{11}$$

$$d_i^- * d_i^+ = 0 \qquad \forall i \quad i = \{1,2\} \tag{12}$$

$$p_i \in \{0,1\} \quad d_i^-, d_i^+ \geq 0 \tag{13}$$

Equation $(2) - (6)$

In the developed model; Eq.(9) enables the objective function to minimize deviations from constraints. Since the variable " d_1^+ " represents the unused portion of the budget constraint and the variable " d_1^- " represents the overused portion, the variable " d_1^- " is tried to be minimized in the Eq.(9). Because the variable " d_2^+ " represents the decrease from the appropriateness value found in Scenario 2 while variable " d_2^- " represents the increase, the variable " d_2^+ " is tried to be minimized in Eq.(9). In Eq.(10) the objective function of Scenario 1 is transformed to a constraint. In Eq.(11) the objective function of Scenario 2 is constrained. Eq.(12) forces at least one of the deviation variables to have a value of "0".

The constraints between Eq. (2) and Eq. (6) are valid for all scenarios. As can be seen; the solution results obtained in the previous scenarios are used as constraints in goal programming approach. The solution results are given in Table 6. No value is assigned to the variable "m_i" in the objective function, since it is assumed that the objectives are not superior to each other.

Table 6. *Model solutions for Scenario 3*

TA Settlement Point and Sensor Type Used " x_{is_k}"	Z_{min}	Total Cost	Total Appropriateness Value

x_{4s_4}	x_{10s_4}	x_{33s_4}	d_1^+ : 20800		
x_{42s_1}	x_{63s_4}	x_{71s_4}	d_2^- :54,41	\$82.900	4,537
x_{84s_4}	x_{93s_4}		Z_{min} : 20854,41		

According to the results; to satisfy the goals, a total of 8 TAs are located at points 4, 10, 33, 42, 63, 71, 84, 93 and one unit of 20 km - 7 units of 80 km sensors are integrated on these TAs. The model is re-solved for different "m_i" values in order to monitor the effect of the priority values of the objectives. Renewed results are presented in Table 7.

Table 7. *Goal programming solution results for different priority values*

TA Settlement Points and Sensor Type Used " x_{is_k} " mi $[m1\,;\,m2]$										
Snr-4 *[0,05; 0,95]*	Snr-5 *[0,1; 0,9]*	Snr-6 *[0,15; 0,85]*	Snr-7 *[0,25; 0,75]*	Snr-8 *[0,35; 0,65]*	Snr-9 *[0,5; 0,5]*	Snr-10 *[0,65; 0,35]*	Snr-11 *[0,75; 0,25]*	Snr-12 *[0,85; 0,15]*	Snr-13 *[0,9; 0,1]*	Snr-14 *[0,95; 0,05]*
x_{2s_1}	x_{4s_4}	x_{4s_4}	x_{2s_1}	x_{4s_4}	x_{4s_4}	x_{6s_4}	x_{4s_4}	x_{4s_4}	x_{4s_4}	x_{2s_1}
x_{4s_4}	x_{10s_4}	x_{10s_4}	x_{4s_4}	x_{10s_4}	x_{10s_4}	x_{13s_4}	x_{10s_4}	x_{10s_4}	x_{10s_4}	x_{4s_4}
x_{23s_4}	x_{23s_4}	x_{33s_4}	x_{23s_4}	x_{33s_4}	x_{33s_4}	x_{37s_1}	x_{33s_4}	x_{33s_4}	x_{33s_4}	x_{23s_4}
x_{42s_4}	x_{42s_1}	x_{42s_1}	x_{42s_4}	x_{42s_1}	x_{42s_1}	x_{42s_4}	x_{42s_1}	x_{42s_1}	x_{37s_1}	x_{42s_4}
x_{64s_4}	x_{63s_4}	x_{63s_4}	x_{64s_4}	x_{63s_4}	x_{63s_4}	x_{64s_4}	x_{63s_4}	x_{63s_4}	x_{63s_4}	x_{64s_4}
x_{71s_4}	x_{71s_4}	x_{71s_4}	x_{71s_4}	x_{71s_4}	x_{71s_4}	x_{71s_4}	x_{71s_4}	x_{71s_4}	x_{71s_4}	x_{70s_4}
x_{84s_4}	x_{84s_4}	x_{84s_4}	x_{84s_4}	x_{84s_4}	x_{84s_4}	x_{84s_4}	x_{84s_4}	x_{84s_4}	x_{84s_4}	x_{84s_4}
x_{93s_4}	x_{93s_4}	x_{93s_4}	x_{93s_4}	x_{93s_4}	x_{93s_4}	x_{93s_4}	x_{93s_4}	x_{93s_4}	x_{93s_4}	x_{93s_4}
Total Appropriateness Value										
4,518	4,537	4,537	4,518	4,537	4,537	4,518	4,537	4,537	4,517	4,5
Total Cost										
\$82.900										

As seen in Table 7; the highest appropriateness value is obtained from the Scenarios 3, 5, 6, 8, 9, 11 and 12, which also recommend the same settlement plan. The lowest appropriateness value is obtained in Scenario 14. For the scenarios which have the same “Total Appropriateness Value” and “Total Cost”, the priority values of the objectives have no effect on the solution. Various TA settlement plans have been obtained from developed scenarios 1 to 14. Especially, the solutions between Scenario 3 to 14 give the same cost but different appropriateness values. In this case, which settlement plan of TAs provides the better reconnaissance and surveillance opportunity must be examined. This test can be done using Viewshed Analysis module of GIS.

5. VIEWSHED ANALYSIS WITH GIS

In the viewshed analysis of GIS, the elevation data of the relevant region is used as the base layer. While higher areas are colored with dark black in this layer, relatively lower areas are colored with white. The elevation layer data of Turkey's southern region is taken from the reference [45]. According to the solutions obtained from the scenarios, the images of fields of views provided by the TAs are shown in Figure 3.

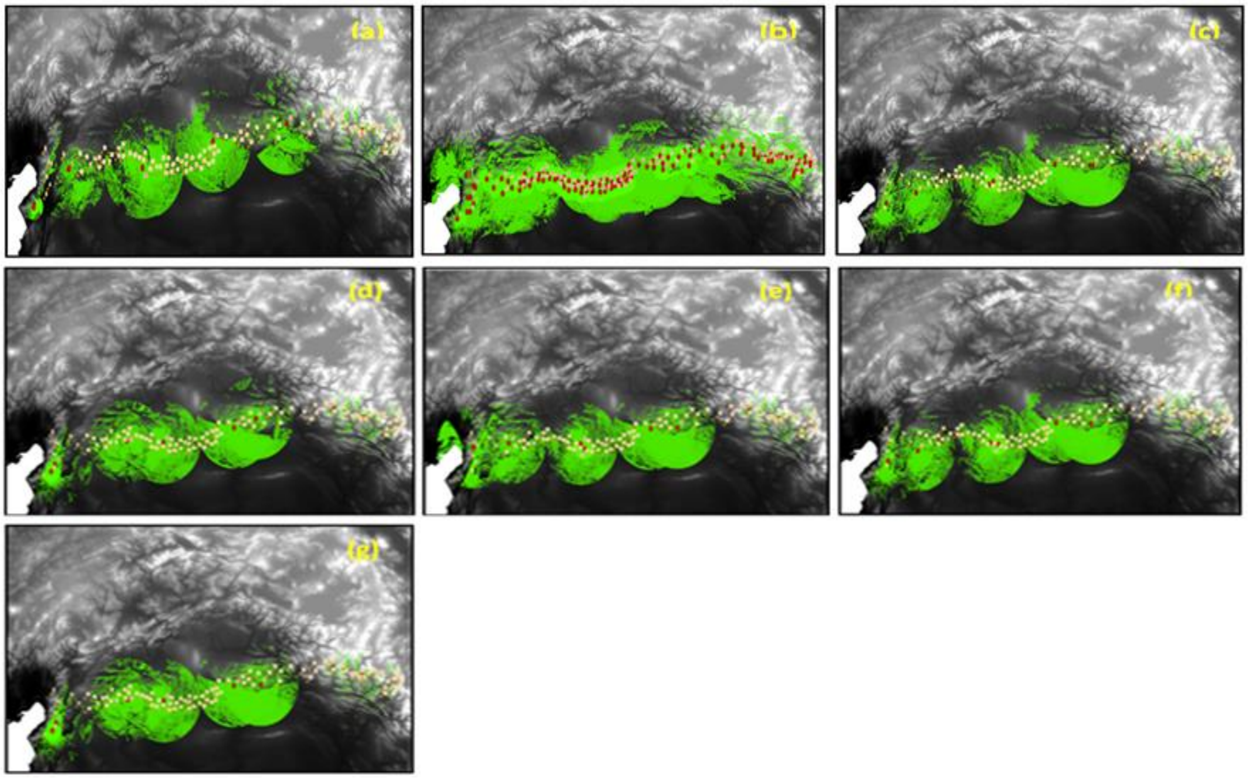

Figure 3. *Images of Viewshed Analysis for scenarios; a) Scenario 1 b) Scenario 2 c) Scenarios 3, 5, 6, 8, 9, 11, 12 d) Scenarios 4, 7 e) Scenario 10 f) Scenario 13 g) Scenario 14*

The yellow points in the images show candidate TA locations along the borderline. The red points in the images are the proposed TA settlement locations obtained from the relevant scenario. The areas that TAs can observe are colored with green. The reason why the green areas appear fragmented in all images is due to the lack of full visibility originating from the altitude differences and geographical obstacles.

When the images of visual analysis of proposed TA settlements are examined, it seems that the proposed layouts don't offer a full visibility of borderline except the solution of Scenario 2. It is not surprising that the widest field of view is reached in Scenario 2, as it recommends placing TAs at all candidate points. But, this solution exceeds the budget constraint with a cost value of $1,092,200. Considering the minimum cost and maximum appropriateness value, the TA layout purposed in Scenario 3 seems preferable. Besides this, it is noteworthy that the Southeastern regions of Turkey cannot be observed sufficiently due to the rugged terrain structure. The inability of fully vision brings out that the TA's may not be an effective surveillance agent in Turkey's Southeastern regions. In this case, it may be beneficial to support TAs with other surveillance agents like UAVs in this region.

6. CONCLUSIONS AND FUTURE WORKS

In this study; considering project budget, camera sensor capabilities, geographical analysis data and appropriateness parameters of candidate locations, three scenarios are developed for the site selection problem of Tethered Aerostats on southern Turkey. In the first scenario, determining the minimum number of TAs, their locations and the sensors types required to observe certain points in the borderline are aimed. In the second scenario, candidate positions are assessed by the military experts according to criteria related to the geographical features. After digitizing linguistic expert opinions with fuzzy-TOPSIS method, the layout of TAs that will provide the highest appropriateness value is sought. In the third scenario, the goals of previous scenarios are transformed to constraints and Goal Programming approach is applied. Then, a sensitivity analysis is performed in order to see the effects of the priority values of goals. After reaching the solution results of the scenarios, the field of view test is conducted using ArcGIS. According to the results of the viewshed analyzes; however all points expected to be observed are covered; it is not possible to monitor the entire border area due to the rugged terrain structure. Especially, the inability of fully vision brings out that the TA’s may not be an effective surveillance agent in Southeastern regions. Thus, the results of the study emphasize the use of a hybrid reconnaissance-surveillance system. This hybrid system may include the use of TAs for observable areas and UAVs for unobservable regions. For further studies, it will be beneficial to focus on hybrid systems, especially on examining the dynamic scanning of unobservable areas with UAVs.

The methods and approaches discussed in this study include the applicable steps for the countries planning to use TAs in reconnaissance and surveillance process. Different criteria can be used in assessing candidate positions, as countries' geographic structures and threat perceptions may differ.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors. Matters referred in this research don’t represent the official views of Turkish Armed Forces.

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