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A New Approach for Site Selection of Air Quality Monitoring Stations: Multi-Criteria Decision-Making

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ABSTRACT

The main objective of this study was to choose appropriate locations for two air quality monitoring stations in an urban area in Turkey by using specific decision-making techniques. For this purpose, five different potential locations for an urban station and seven different potential locations for a rural station were evaluated according to two Multi Criteria Decision Making techniques (MCDM): Analytic Hierarchy Process (AHP) and Elimination Et Choix Traduisant la Realité III (ELECTRE III). The main inputs of these methods were the air quality levels and associated pollution hot spots estimated by an air quality dispersion model (AERMOD), and the rankings determined according to the views of experts and local authorities regarding the selection criteria. The prioritization and ranking of the alternatives were determined and compared for both methods. The results of the two methods validated each other since the same locations were determined as the best alternatives by both methods. In this study, AHP and ELECTRE III, which are two well-known MCDM techniques, were used for the first time for the selection of the optimal air quality monitoring stations using seven criteria (pollution levels, security, availability of electricity, collaborations, staff support, easy access, distance).

Keywords: Air quality monitoring station; Analytical Hierarchy Process (AHP); ELECTRE III; Multi Criteria Decision Making.

INTRODUCTION

Many city centers in Turkey suffer from air pollution, especially in winter season. Urban air pollution arises from various sources, especially as a result of combustion processes (WHO, 2004). The main reason for air pollution during winter season is residential heating and the use of low quality fuel, incorrect combustion techniques and inadequate maintenance of combustion systems (MEUP, 2013). Traffic emissions and industrial activities, such as thermal power plants, are other important pollutant sources around urban areas (Elbir *et al.*, 2000).

Inappropriate sampling point selection may also cause over- or underestimation of the effects of emissions from certain pollution sources. Because of the extensive use of local coal with poor heating value in coal-powered thermal power plants and the absence of control technologies in some facilities, emissions of sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), volatile hydrocarbons and ash problems occur (MEUP, 2010). Combination of emissions and meteorological conditions leads to serious air pollution situations in the urban atmosphere.

For measuring air pollutants, air quality monitoring stations are highly important. The main purposes of establishing air quality monitoring stations are determining the exposure level to air pollutants, estimating ambient air concentrations in residential and industrial areas as a basis to develop action plans, indicating the pollution sources and their risks (Yeşilyurt and Akcan, 2001).

Proper site selection of air quality monitoring stations is essential for the determination of air quality in a region. It is important to be precise about the process of observing the effects of pollutants coming from emission sources clearly. Site selection for an air quality monitoring station is challenging because of various parameters such as local meteorology, pollutant source varieties, electricity, safety of the equipment and representativeness of the produced data. There are some site selection studies for air quality monitoring stations in the literature (Noll *et al.*, 1977; Munshi and Patil, 1982; Noll and Mitsutomi, 1983). Kimbrough *et al.* (2008) used geographic information system (GIS) data,

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tools and techniques and on-site visits by project team members as a means of developing supporting information regarding each potential site. Other studies used different approaches like the pollution hot spots taken as the criterion for the site selection of the air quality monitoring stations (Munshi and Patil, 1982), quantitative methods (Noll *et al.*, 1977), and The Dosage Monitoring Survey Design (DMSS) analyses by dispersion modeling (Noll and Mitsutomi, 1983). However, up to now, Multiple Criteria Decision Making (MCDM) studies have not been employed for the selection of optimal air quality monitoring stations.

Various studies from other study fields that used MCDM techniques such as Analytic Network Process (ANP), Analytical Hierarchy Process (AHP) and Elimination and Choice Expressing Reality (ELECTRE; Elimination Et Choix Traduisant la Realité) have come out with successful results (Tran *et al.*, 2004; Kone and Buke, 2007; Özkan, 2013). MCDM techniques can be applied in many decision problems in environmental studies. There are several environmental studies that have used decision-making techniques in the literature for the evaluation of the alternative solid waste landfill sites in Eskişehir/Turkey (Acar *et al.*, 2003), choosing a recycling system (using ANP and Electre III Techniques) (Banar *et al.*, 2010), development of a solid waste management system (ELECTRE III method) (Özkan *et al.*, 2011), selection of groundwater remediation technologies (Khelifi *et al.*, 2006) and multi-criteria analysis of air pollution in an urban area around a Copper Smelter in Bor, Serbia (Djordje *et al.*, 2010). In this study, the aim was to apply MCDM techniques for air quality monitoring station site selection for the first time and the intention was to be an example for future studies.

METHODS

Study Area

The study area (the province of Kütahya - Turkey) is located between 38°70' and 39°80' North latitudes and 29°00' and 30°30' East longitudes. Kütahya is a province located in the mid-western part of Turkey. In summer period, Kütahya is a low-pressure center that is open to the north sector winds. The prevailing wind direction is generally North in all seasons. Kütahya and surrounding areas are affected by the Mistral winds in spring. The annual average wind speed is 1.7 m s^{-1}. The maximum hourly wind speed was 27.6 m s^{-1}, blowing from the northwest, for the year 2013 (Özkan *et al.*, 2013).

The industrial factories located at and around the Kütahya city center (Integrated Nitrogen Plant, Sugar Factory, Kütahya Magnesite Factory, Boron Mine Factory, Automobile manufacturing facility and Ceramics Factory), and the current air monitoring station operated by The Ministry of Environment and Urban Planning are shown in Fig. 1.The highlighted emission sources in Kütahya are; the Tunçbilek Thermal Power Plant (TPP) in Tunçbilek-Tavşanlı located 65 km Northwest of the city center, the Seyitömer TPP located in Seyitömer located 34 km North - Northwest of the city center, and the Orhaneli TPP located in Bursa province, 148 km Northwest of the city center (Governorship of Kütahya, 2002). The oldest facilities (TUGSAŞ and Tunçbilek TPP) were established in 1954 and located in the plain. These plants' elevations are approximately the same as that of Kütahya city center. In time, these plants remained in the middle of the densely populated urban center. The transport of pollutants, their amounts and especially residence time

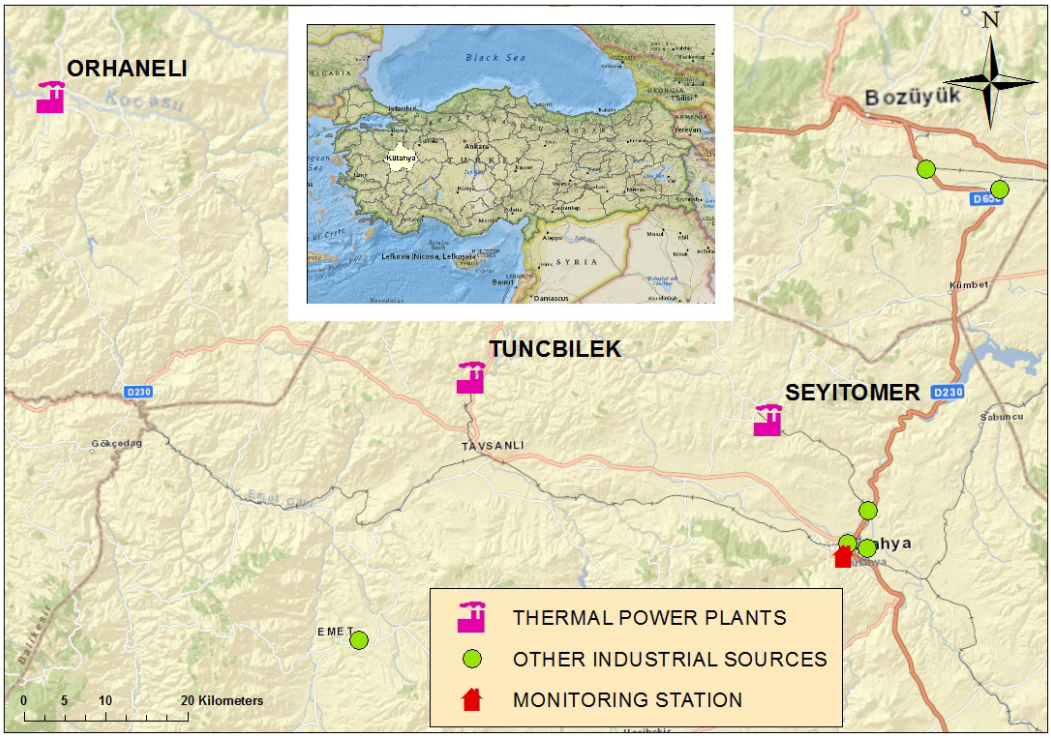


Fig. 1. Potential pollutant sources in Kütahya.

constitute unfavorable conditions because of the complex topography with mountains on the Northwest-Southeast of Kütahya plain and the effective climatic factors. For these reasons, air pollution in the city reached a critical level, due to residential heating in winter period and industrial emissions through the year (Keser, 2002).

MCDM Methodology

MCDM is a dynamic research method that uses several evaluation criteria for the selection, classification and ranking of different alternatives. Some of the MCDM techniques are: AHP, Analytical Network Process (ANP), ELECTRE and Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE).

In this study, two multi criteria decision making methods (MCDM) were used: AHP and ELECTRE III. ELECTRE and AHP methods are among the most reliable and user friendly MCDM methods. ELECTRE III and AHP were considered in this study because of their different viewpoints. The AHP method is a multiobjective analytical tool and it decomposes a complex decision problem into smaller sections, called a hierarchical tree. The AHP algorithm consists of 4 phases: (1) construction of the hierarchical structure of the decision problem, (2) definition of the preferential information (relative weights) and calculation of the absolute weights, (3) coherence analysis and (4) construction of the final ranking. All variants are ranked based on their utilities (Zak, 2005).

In the AHP method, pairwise comparisons are made with the grades ranging from 1–9 and reciprocal matrix for each criterion and alternatives are obtained. For instance, a 3 by 3 reciprocal matrix is obtained for a problem with 3 criteria. Then, the sums of each column of the reciprocal matrix are taken. Each entry in the column is then divided by the column sum to yield its normalized score. The sum of each column is 1. Hence, the normalized principal Eigen vector can be obtained by averaging across the rows. The normalized principal Eigen vector is also called the priority vector. Finally, the priority vector and the criteria weight are multiplied for the final ranking.

ELECTRE III, is one of the multiobjective ranking methods based on outranking relations. Indifference, weak preference, strong preference, and incomparability are used for the extended model of the decision makers' (DMs) local preferences in ELECTRE III. For instance, if the difference between the evaluations of two variants a and b (i.e., the difference between f(a) and f(b)) is too small to help the DM make a distinction between them, these two variants are considered indifferent. In addition, variant a is strongly preferred against variant b if the difference between their evaluations f(a) and f(b) on a specific criterion is substantial to the DM and the decision maker is convinced that a is preferred to b (Fierek and Zak, 2012). The ELECTRE method algorithm is composed of 4 phases: construction of the performance matrix (alternatives and criteria), determination of criteria weights and thresholds, calculation of the credibility and concordance index, and final ranking.

After performance values, weights and thresholds have been obtained, a concordance index [C(a, b)] is computed for each pair of alternatives. The concordance index varies from 0 to 1. If 'a' equals 1, it shows that alternative 'a' is better than alternative 'b' for all criteria and if 'a' equals 0, it shows that alternative 'a' is worse than alternative 'b'. This index is calculated based on a weighted comparison of the performances over each criterion and can be expressed as in Eq. (1):

$$C(a,\ b) = \frac{1}{W}\sum_{j=1}^{n} w_j c_j(a,b),\ W = \sum_{j=1}^{n} w_j \tag{1}$$

where w_j (j = 1, …, n) is the weight of each criterion. The complete set of concordance indices form the concordance matrix which measures the strength of the assertion that *a* is at least as good as *b*. Each comparison index c_j (a, b) for each criterion is formulated as in Eq. (2):

$$c_j(a,b) = \begin{cases} 1, & if \quad g_j(a) + q_j \geq g_j(b) \\ 0, & if \quad g_j(a) + p_j \leq g_j(b), j = 1.2,....r \\ \dfrac{p_j + g_j(a) - g_j(b)}{p_j - q_j}, & otherwise \end{cases} \tag{2}$$

where q_j and p_j denote the indifference and preference thresholds on criterion j, respectively, and $g_j(a)$ and $g_j(b)$ are the assessments for the jth criterion of alternatives *a* and *b*.

In MCDM studies, it is very important to define the DMs. A DM may be a person or a group of people (e.g., a committee), who carries out a final choice among the alternatives. DM should have sufficient knowledge and experience to apply the decisions (Özkan, 2013). In this study, several experts on air quality from different Turkish universities (Anadolu University, Dokuz Eylul University and Middle East Technical University) were considered as DMs.

The alternatives and criteria – which were the same in both cases – are set out initially, followed by the multi criteria decision making methods. The flow diagram of the study is given in Fig. 2. Each step is discussed in the following sections.

Air Quality Modeling

The aim was to locate the air quality monitoring stations at appropriate places to quantify the contribution of thermal power plants' (TPPs) emissions to the city and province air quality. Wind direction and emissions of power plants need to be known prior to the selection of possible locations for the monitoring stations. One of the considerations in the location of the monitoring stations is the winds which transport power plant emissions to the monitoring stations. Local meteorology data were used to investigate the wind pattern. The wind rose was also plotted for the year of 2013 (Fig. 3). Northerly winds are prevalent during a year. The wind roses were plotted for the year 2013 since the year chosen for the air quality modelling was also 2013. In

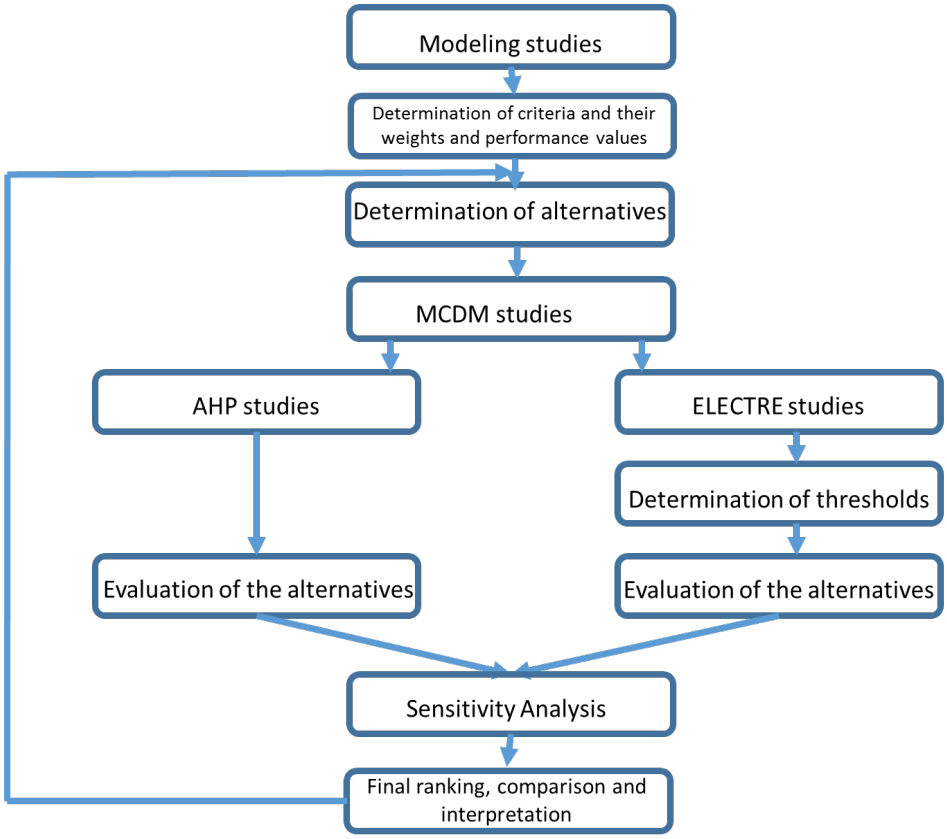


Fig. 2. The flow diagram of the study.

the official meteorological reports, long term records also show that the prevailing wind direction has been north, owing to the topography of the region (MEUP, 2014).

Within the scope of the air quality modeling study; inventory of emissions from TPPs was prepared. Fuel consumption, heating value of the fuels and emission factors (EFs) were used to prepare the emission inventory for the thermal power plants (EEA, 2009; Özkan *et al.*, 2013).

The dispersions of SO_2, PM_{10}, NO_x and CO from Tunçbilek and Seyitömer TPPs have been revealed after taking into consideration the topography and the meteorological conditions of the region by using an air quality dispersion model (AERMOD) (USEPA, 2004). Thus, the current situation has been identified with air quality modeling studies.

By using air quality modeling results, distribution maps of pollutants emitted from power plants were prepared. Annual average concentrations of SO_2 is shown in Fig. 3. Hotspot points are near the Tunçbilek TPP and the west of the city center. According to these results, the urban station was planned to be established at the city center and the rural station was planned to be established at a location to monitor the effects of the Tunçbilek and Seyitömer TPPs. With the help of the air quality maps and wind roses, several spots were visited and coordinates of alternative sites were determined to be evaluated in the MCDM methods. The objective was to establish the urban and rural stations at places under the influence of the power plant emissions. Locations to the south of the Tunçbilek TPP, which may receive concentrations of both TPPs in different time periods, have been found to be appropriate for the rural station. Location of urban station was selected in terms of the criteria of dominant wind directions and population exposure in the city.

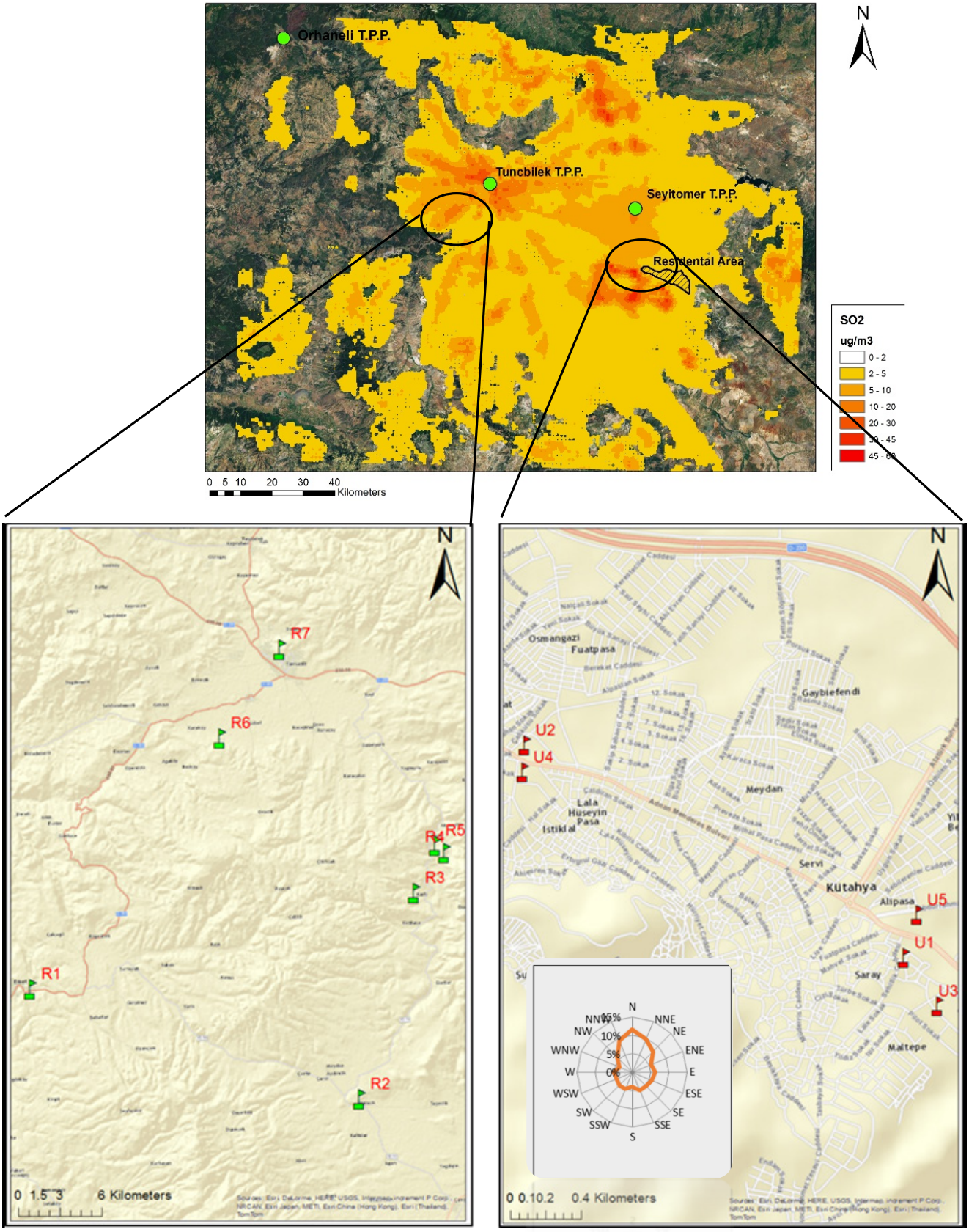
Criteria

The assessment in this study was based on seven criteria for both rural and urban stations and their weightings. These criteria, weightings and their ascending order can be seen in Table 1. The same criteria were determined for AHP and ELECTRE III. Possible important obstructions like nearby buildings that might affect the air flow, trees, crowded traffic junction points, small industrial facilities were also evaluated and avoided during site selection.

Alternatives

In the study, location alternatives of air quality monitoring stations are discussed in two sections; rural and urban areas. Two institutions (Kütahya Provincial Directorate of Environmental and Urban Planning and Kütahya Provincial Directorate of Forestry) were visited to determine potential sites for both stations by discussing the criteria to be met for an air quality monitoring station.

This study was part of a broader air quality assessment study for Kütahya, which is still ongoing. One of the main objectives was to assess the dominant sources of air pollution. The motivation of the study was the fact that the pollution levels did not decrease as much as expected after



Rural station alternatives

Urban station alternatives

Fig. 3. Potential alternatives for rural and urban air quality monitoring stations (annual wind rose is also shown).

Table 1. The criteria of AHP and ELECTRE studies.

Criteria No	Name of Criteria	Unit ascending order (for ELECTRE)	Weighting of Criteria (%)	Explanations
g1	Pollution levels	Score (1–9) decreasing/increasing	30	Pollution levels in urban and rural air quality monitoring stations are expected to change according to wind direction and sources thus pollution level should change increasingly for urban station and decreasingly for rural station.
g2	Security	Score (1–9) increasing	20	Security of the stations is an important criteria due to the high costs of equipments and apparatus. The station should be located in a safe site to prevent any danger outside, apparatus being stolen and/or damaged.
g3	Availability of electricity	Score (1–9) increasing	10	Possibilities of the lamppost, distance and location of places that could be used to run electrical wires close to the station are considered.
g4	Collaborations	Score (1–9) increasing	10	This criterion is important because the location to be chosen for the station is discussed with competent authorities. The establishment is important for being able to make a bilateral agreement with partners.
g5	Staff support	Score (1–9) increasing	10	Once the stations are installed, staff support is needed for the control of all air quality monitoring equipments and immediate interventions.
g6	Easy access	Score (1–9) increasing	10	During the installation and operations of the stations transportation via vehicles will be needed, therefore access to the region should be easy. Regions with a rough way, without road, or hard to access should not be preferred.
g7	Distance	km decreasing	10	The distance between the station and Anadolu University (Eskişehir) is an important criteria because the visits are to be made at regular intervals during one year.

the partial switch to natural gas for residential heating. The same practice had exhibited decrease in pollution levels at other cities. One possibility for the different condition is the presence of two coal-fired power plants. Therefore, the decision of establishing two monitoring stations was that one would be more under the effect of urban sources and one with more rural characteristics. For more detailed information on the spatial distribution of the pollutants, short term saturation monitoring using passive samplers (2 weeks in each season) was also included in the project. However, continuos monitoring at two sites is still crucial considering the time resolution of the measurements and the fact that the effect of some sources might be missed or underestimated during short term measurements.

Seven alternatives for rural air monitoring station and 5 alternative sites for urban air monitoring station were determined by visits to those locations. The wind direction was an inherent criterion and none of the alternatives were upwind of the power plants, since they are supposed to be influenced by the plants for certain time periods of the year. All alternatives were public property because of security measures and because of frequent visits planned. Potential alternatives are shown in Fig. 3.

Seven alternative sites for rural station and site characteristics are given below:

a. **R1:** It is considered as one of the suitable alternatives for the rural air quality in the region. On the other hand, high dust concentrations are observed around the Forestry Management Administration and a boron manufacturing plant also is located at a close distance.
b. **R2:** According to the modeling results, it is considered as one of the appropriate points. The area is controlled by the Örencik Municipality and it is a bit troublesome in terms of vehicle transport.
c. **R3:** It is located within Karlı village and is controlled by the headman of the village. It is a bit problematic in terms of security and vehicle transport. The transportation is seen difficult during winter conditions.
d. **R4:** Location of R4 is excellent considering pollution distribution maps. On the other hand, qualified personnel assistance will not be available for 24 hours to collect samples.

e. **R5:** This Water Treatment Plant (WTP) facility belongs to the Municipality of Tavşanlı. There are two people at the facility permanently. It is safe and guarded, pollution is expected to be at background levels. The modeling studies estimated low concentrations of pollutants reaching the region.
f. **R6:** This site was recommended by Tavşanlı Municipality and located near the Spa facilities managed by the municipality. It is located 15–20 km south of the Tunçbilek TPP and is expected to be under the effect of the plant, depending on the wind direction.
g. **R7:** It is located on a hill, near the State Hospital on the side of the radio receiver. It is a weak alternative in terms of transportation, support and bilateral agreements.

As for the rural station, the criteria for the urban station were determined after field trips with the help of the officers from Kütahya Provincial Directorate of Environmental and Urban Planning that have good knowledge of the region. The alternative locations are mostly public buildings/ locations, considering the readily available security. The five urban station site alternatives assessed are as follows:

a. **U1:** It is a location far from the direct effect of traffic. It might be affected from domestic heating in winter period since it is located in a settlement area.
b. **U2:** The location is subject to traffic related pollutants, being at the crossroad at the city exit towards Tavşanlı town. It does not seem to represent the pollution transported from the power plants. However, it looks favorable in terms of security, bilateral agreements and staff support.
c. **U3:** This location, suggested because of continuous security measures, is close to U1. It seems to be problematic in terms of staff support and the availability of electricity. Another problem is the dense presence of trees that might create obstacles for representative sampling.
d. **U4:** It does not seem to very suitable because of a tall building in front of it. The location may also not serve adequate space for the station and the equipment. However, it was still considered due to the availability of personnel and security.
e. **U5:** This location next to the stadium at the very city center is exposed to small amounts of traffic-related pollutants. Staff support seems to be problematic. Possible particulate resuspension before and after the matches and games should also be considered.

RESULTS AND DISCUSSION

ELECTRE Studies for Rural and Urban Stations

Performance matrices were prepared based on DM preferences both for rural and urban stations and given in Table 2 for ELECTRE III.

The factors for score/values of criteria for rural station are explained below:

g1 (Pollution levels): The rural air quality monitoring station is supposed to be situated at a location to represent different levels of pollution and the effect of different sources at different times, depending on the wind direction. The rankings were assigned according to descending order. Therefore the assigned points are 5 for R3 and R6 that have low pollution; 6 for R4, R5 and R7; and 8 for R1 and R2 that have higher pollution levels.

g2 (Security): Security is an important criterion. The assessment of this criterion depended on the views of the people living in the vicinity of the points. R5 and R6, that are operated by the Municipality and are under continuous protection, were assigned 8 points. R1, R2 and R3 were assigned moderate points since they are under non-continuous security protection. R4 and R7 were regarded as points with low security.

g3 (Availability of electricity): The assessment was done according to the presence of electric poles or the distance, position and usability of potential points of power

Table 2. Performance matrices for rural and urban stations.

RURAL STATION							
	g1	g2	g3	g4	g5	g6	g7
R1	8	6	5	7	6	3	173
R2	8	4	3	4	4	1	141
R3	5	5	3	3	3	2	132
R4	6	1	1	3	2	1	129
R5	6	8	7	7	9	2	127
R6	5	8	9	9	8	6	134
R7	6	2	1	2	3	3	140
URBAN STATION							
	g1	g2	g3	g4	g5	g6	g7
U1	2	9	7	8	8	7	81
U2	8	7	4	7	6	7	88
U3	3	5	3	4	1	5	84
U4	8	6	4	3	2	7	88
U5	4	6	4	2	2	6	85

* Non numerical values were scaled from 1 to 9 where Excellent = 9; Very good = 8; Good = 7; More or less good = 6; Indifferent = 5; Somewhat bad = 4; Bad = 3; Very bad = 2; Awful = 1 for increasing ascending order and Excellent = 1; Very good = 2; Good = 3; More or less good = 4; Indifferent = 5; Somewhat bad = 6; Bad = 7; Very bad = 8; Awful = 9 for descending order.

connection. The distance to the electric pole is an important factor determining the cost of the line to be constructed. R6 was assigned 9 points for the availability of electricity, R5 was assigned 7 points according to the distance to the electric pole and R4 and R7 with the most difficult access to electricity were assigned 1 point. Opportunities or options like remote electronic connectivity of stations or wireless connections were not considered because of their high expenditures and additional investment costs.

g4 (Collaborations): The views of the governing authorities, whether in villages or small and big towns, are important in the selection of the site. Depending on the effect of the services of the related authorities on the sustainability of the study, R6 was assigned full points, R1 and R5 were assigned 5 points and R7, for which an authority body to collaborate with was not available, was assigned 2 points.

g5 (Staff Support): After the establishment of the air quality stations, staff support for the control and routine operation of the various equipment is an important criterion for site selection. R5 was assigned 9 points since qualified staff on environmental issues is available at the nearby water treatment plant. R6 was assigned 8 points since there is continuous staff that can help in the operation after short tutorials. R1, R2, R3, R4 and R7 were assigned 6, 4, 3, 2 and 3, respectively.

g6 (Easy Access): Easy transport to the station by vehicles is important. Easy access to the location was preferred in the first place. Rural station alternatives were commonly far from asphalt roads and relatively obsolescent districts. Human activities, traffic and domestic heating activities are all minimum, and also fugitive dust emissions from unpaved roads are minimum because of rare traffic. In spite of its not-perfect conditions, R6 was still the best alternative and assigned 6 points. It is followed by R1 and R7 with 3 points assigned.

g7 (Distance): Since the station should be visited systematically within the one-year project, the distance to Anadolu University in Eskisehir (the institution leading the project) is an important criterion. R5 is the most advantageous location with 127 km distance. The distances to R4, R3, R6, R7 and R2 are 129, 132, 134, 140 and 141, respectively. The farthest location is R1 with 173 km.

The factors for score/values of criteria for urban station are explained below:

g1 (Pollution levels): The urban air quality monitoring station is supposed to be situated at a location to represent different levels of pollution depending on the wind direction. The rankings were assigned according to ascending order. The urban station, being at the city center, will continuously be exposed to pollution. Since the most important local source, residential heating, will not be active during summer, pollution form TPPs is expected to be transported to this station when the station is downwind of the plants. According to this consideration, the assigned points were 2 for U1, 3 for U3, 4 for U5 and 8 for U2 and U4.

g2 (Security): Considering security, U1 was assigned 9 points since it is inside the yard of the Directorate of Meteorology that provides continuous protection. U2 in the yard of the Directorate of Agriculture was assigned 7 points. U3, U4 and U5 with moderate security were assigned 5, 6 and 6 points, respectively.

g3 (Availability of electricity): U1 with readily available electricity was assigned 7 points. U2, U3, U4 and U5 that are located relatively further to electric poles were assigned 4, 3, 4 and 4 points, respectively.

g4 (Collaborations): With reasons similar to the those of the rural station, assigned points for U1, U2, U3, U4 and U5 were 8,7, 4,3 and 2, respectively.

g5 (Staff Support): The assessment is similar to that of the rural station. The presence of experts at the Directorate of Meteorology lead to an assigning of 8 points for U1, less qualified staff at the Directorate of Agriculture (U2) lead to an assigning of 6 points. U3, U4 and U5 with no or little possible support were assigned 1, 2 and 2 points, respectively.

g6 (Easy Access): U1, U2 and U4 are the best alternatives with 7 points assigned. They are followed by U3 and U5 with 5 and 6 points, respectively.

g7 (Distance): U1 is the most advantageous location with 81 km distance to Anadolu University. The distances of U3, U5, U2 and U4 are 84, 85, 88 and 88, respectively.

To use ELECTRE III, preference, indifference and veto thresholds and importance weights must be defined by decision makers for all criteria. These thresholds produce outranking relations with an allowance for data uncertainty. Considering the thresholds as a function of performance; $[\alpha \times gj(a) + \beta]$; where α equals 0 and β equals the corresponding value in Table 3, β is expressed in the same units as the performance scale. The weights that are determined by DMs for each criterion, indifference and preference thresholds for rural and urban stations are given in Table 3. In this study, DM stated that there is no alternative that can be vetoed. Hence, the veto threshold was not used in this study, and the discordance matrix was not considered. The DM was asked to assign the weighting of criteria such that the sum of these values would be 100.

Credibility matrices have been obtained from ELECTRE III for the rural and urban station through the use of an Excel Worksheet, which was developed by the researchers for similar MCDM problems. The credibility matrix that gives the outranking degree is equal to the concordance matrix if the discordance matrix is not used. So, credibility and concordance matrix for rural and urban station site selection are used for the ranking.

AHP Studies and Comparison with ELECTRE

The general idea in the AHP method is to make the pairwise comparisons of the alternatives with respect to the criteria and criteria with respect to themselves to estimate the criteria weights. The DMs are asked to make pairwise comparisons of the criteria using a nine point scale suggested by Saaty in AHP studies (Saaty, 1980 and 1994). It was pointed out that the consistency ratios (CR) were less than 0.1 due to the nature of the method; a self-evident fact. For CR values larger than 0.1, the judgments are untrustworthy and it is necessary to revise them (Zafarani *et al.*, 2014). The top level of the diagram shows the overall goal of the hierarchy, "Site selection for urban air quality station". The

Table 3. Threshold and weights of criteria for ELECTRE III.

Criteria no	rural			urban		
	β_q [a]	β_p [b]	W[c]	β_q [a]	β_p [b]	W[c]
g1	1	2	30	1	2	30
g2	1	2	20	1	2	20
g3	1	3	10	1	3	10
g4	1	3	10	1	3	10
g5	1	2	10	1	2	10
g6	1	2	10	1	2	10
g7	6	10	10	3	5	10

[a] β_q: Coefficient for indifference threshold;
[b] β_p: Coefficient for preference threshold;
[c] W: Weights of criteria.

second level lists the criteria for evaluation of the alternatives. The last level is one node for each alternative with multiple lines connecting the alternatives and the criteria. According to this diagram, the criteria were pairwise compared against the goal for importance and the alternatives were pairwise compared against each of the criteria for preference.

Comparison results of alternatives for each criterion, inconsistency values and weightings for rural and urban station are shown in Figs. 4(a) and 4(b), respectively. According to the figure, inconsistency ratios of the comparisons were calculated smaller than 0.1. The criterion "pollution level" has the highest value (30.8 and 30.6%) by means of criteria weighting. The highest ranking values for each criterion are shown in bold. According to these values, R6 (Göbel spa facilities) is the most suitable rural station alternative in terms of the criteria except "availability of electricity" and U1 (Kütahya Meteorological Station Building) is the most suitable urban station alternative in terms of the criteria.

Ranking results of ELECTRE and AHP are shown in Table 4. As seen from Table 4, in both methods, the most suitable rural station alternative is R6 (Göbel Spa facilities). R5 (Tavşanlı Municipality water treatment plant) has the second highest ranking. R2 (Örencik water storage) and R7 (State Hospital) alternatives have the lowest rankings in both methods. As seen from Table 4, the most suitable urban station alternative is U1 (front yard of the meteorological station) with a much higher ranking than other alternatives. Other alternatives, in terms of weighting and ranking in both methods also seem to be quite close to each other.

Sensitivity Analysis

The ranking of alternatives remains dependent on the values of the various thresholds and the weights of importance. Sensitivity analysis shows the influence of the possible changes of values according to the changes in DM's preferences. The sensitivity analysis in this study could be done in three different ways. These are;

- Changes in point values of non-numerical criteria,
- Changes in the weights of criteria,
- Changes in threshold

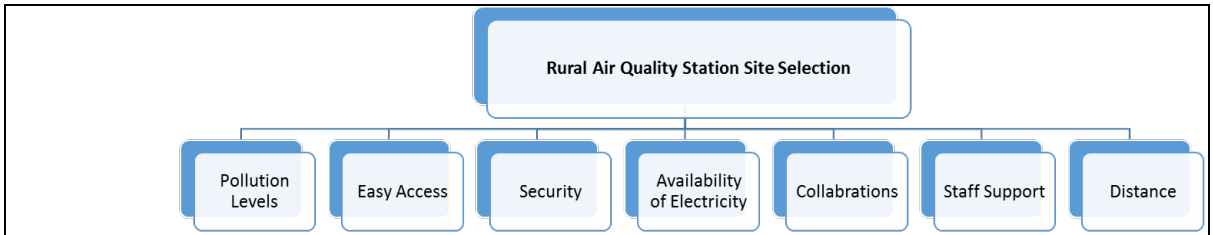
A sensitivity analysis was recommended to highlight which priority order was convincingly justified by the model in spite of all the elements of inclusive arbitrariness. The sensitivity analysis results obtained from AHP for rural and urban station are shown in Figs. 5(a) and 5(b). Results as percentage, the weights (0–1) and the criteria are shown in first y-axis, secondary y-axis and x-axis, respectively. The new values of the criteria weights are shown as bar diagrams. The lines show the ranking results of the alternatives for each criterion and overall results. The final ranking results can be seen at the "overall" label in x-axis, first y-axis and the lines. The changes in the weights of criteria are given in Table 5 for rural and urban stations. Same changes were done in AHP as the ELECTRE sensitivity analysis.

Pollution level, easy access and distance criteria were decreased and at the same time security, availability of electricity and staff support criteria were increased to see the effect of different scenarios. As seen in Table 5, the collaboration criterion was not changed because of the bilateral agreements with the partners. It was seen that there was no change in the final ranking. There are only some small amounts changes in the numerical results.

For ELECTRE sensitivity analysis, three types of changes were done. For the first type; three criteria were changed because of their high weights and it was seen that there was no change in the first-three ranking in final result. In the second approach, 100 points were distributed to 7 criteria, weights of criteria except collaborations were changed. In the last approach, changes were conducted in two ways such as; changes only in preference thresholds and only in indifference threshold. The changes are given in Table 5 for rural and urban stations.

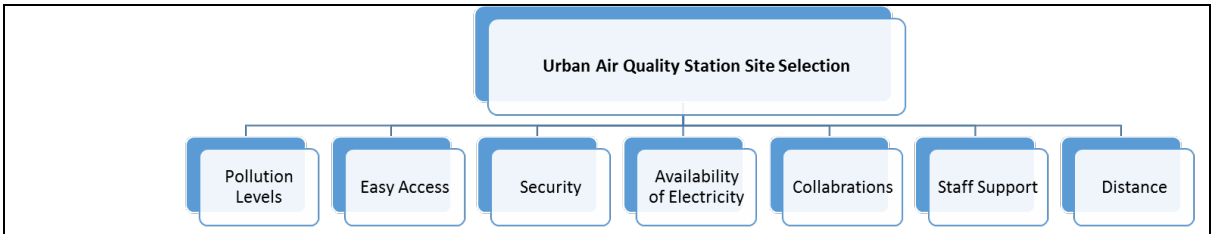
CONCLUSION

In the site selection of an air quality monitoring station, the DMs should consider various parameters. At this point, the Multi-Criteria Decision-Making procedure would be a helpful tool for DMs in solving this complex problem. In the present study, AHP and ELECTRE III, which are two well-known MCDM techniques, were used for the first time to select the best location of the air quality monitoring stations according to different criteria (pollution levels, security, availability of electricity, collaborations, staff support, easy access, distance). According to the evaluations, similar results were obtained using both techniques to find the appropriate



R1	0.149	0.119	0.122	0.113	0.128	0.171	0.036
R2	0.053	0.108	0.069	0.058	0.046	0.044	0.082
R3	0.036	0.054	0.039	0.048	0.041	0.043	0.139
R4	0.101	0.100	0.078	0.088	0.088	0.077	0.184
R5	0.213	0.179	0.270	**0.330**	0.295	0.294	0.227
R6	**0.419**	**0.404**	**0.389**	0.329	**0.369**	**0.339**	**0.240**
R7	0.28	0.036	0.033	0.034	0.032	0.032	0.093
Inconsistency	0.05	0.05	0.08	0.09	0.08	0.04	0.04
Weighting	0.308	0.098	0.203	0.098	0.106	0.098	0.090

(a)



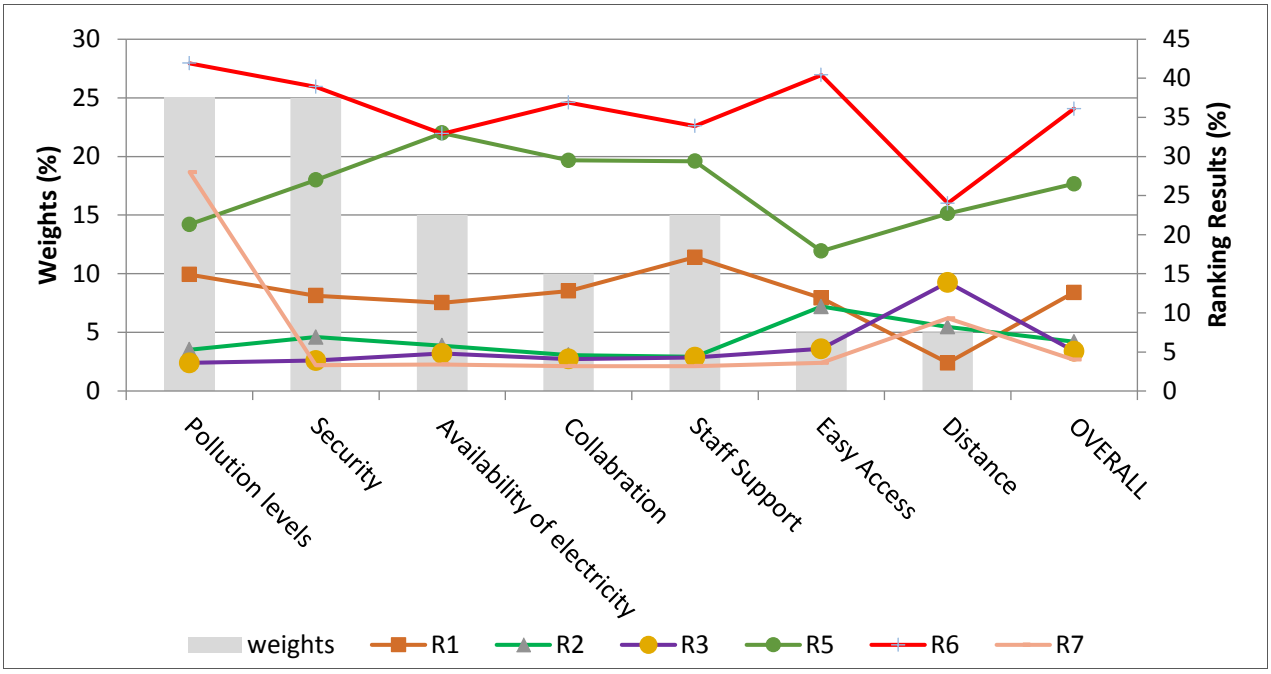
U1	**0.361**	**0.366**	**0.518**	**0.449**	**0.349**	**0.421**	**0.327**
U2	0.065	0.084	0.228	0.204	0.245	0.181	0.094
U3	0.192	0.241	0.099	0.074	0.086	0.075	0.290
U4	0.059	0.073	0.045	0.167	0.228	0.236	0.097
U5	0.323	0.236	0.110	0.106	0.092	0.087	0.192
Inconsistency	0.01	0.02	0.08	0.07	0.04	0.03	0.02
Weighting	0.306	0.097	0.201	0.097	0.104	0.106	0.089

(b)

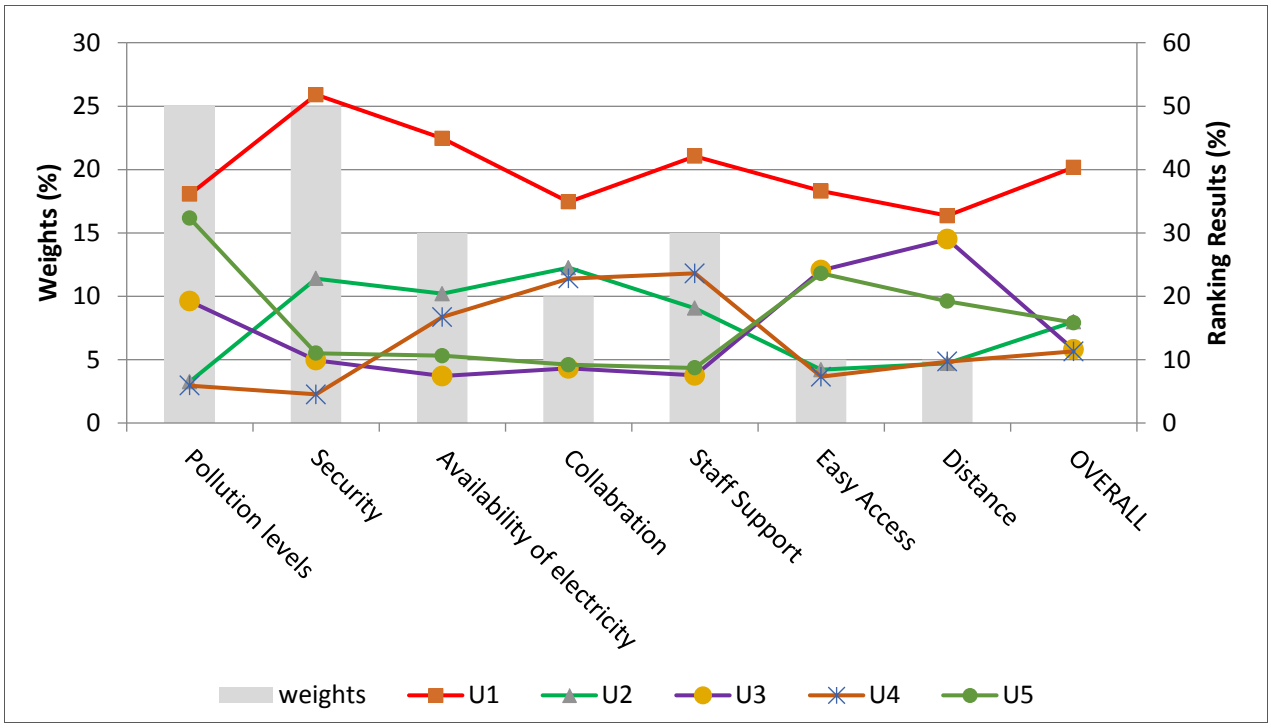
Fig. 4. Results of AHP for site selection of (a) rural and (b) urban air quality station.

Table 4. Ranking results of ELECTRE and AHP.

Rural stations			Urban stations		
	ELECTRE, ranking	AHP, ranking (%)		ELECTRE, ranking	AHP, ranking (%)
R1	4	3 (12.2)	**U1**	**1**	**1 (39.4)**
R2	6	5 (6.4)	U2	2	4 (14.0)
R3	3	6 (5.5)	U3	2	3 (15.9)
R4	5	4 (10.3)	U4	3	5 (10.9)
R5	2	2 (25.2)	U5	2	2 (19.8)
R6	**1**	**1 (36.4)**			
R7	5	7 (4.0)			



(a)



(b)

Fig. 5. Sensitivity Analysis Results for (a) rural and (b) urban station.

location of the urban and rural station. The results of the two methods validated each other as well as sensitivity results since the same locations were determined as the best alternatives by both methods and this indicates the robustness of the methods.

According to the results, in both MCDM methods, the most suitable rural station alternative is R6 (Göbel Spa facilities) and it is planned to be established at this point to directly see the effects of the Tunçbilek and Seyitömer TPPs. The most suitable urban station alternative is U1 (front yard of the meteorological station) with much higher ranking than other alternatives. Other alternatives, in terms of weighting and ranking in both methods also seem to be quite close to each other and the urban station is planned to be established at this point at the city center to represent the air quality of the city center.

Table 5. Result of sensitivity analysis for rural and urban stations.

Changed parameters	Initial values	Final values	Changes in results
Rural stations			
Changes in point values of non-numerical criteria			
Pollution levels (C1)	8,8,5,6,6,5,6	7,6,4,5,4,4,8	R6 > R5 > R3 > R1 > R2 > R4 > R7
Security (C2)	6,4,5,1,8,8,2	8,3,3,1,9,8,1	R6 > R5 > R3 > R1 > R4 = R7 > R2
Easy Access (C6)	3,1,2,1,2,6,3	6,2,2,4,4,6,1	R6 > R5 > R3 > R1 = R4 > R7 = R2
Changes in the weights of criteria			
weights of criteria	30;20;10;10; 10;10;10	25;25;15;10; 15;5;5	No change in the final ranking although credibility and concordance matrices were changed in small amounts.
Changes in threshold			
only in preference thresholds	2,2,3,3,2,2,10	2,3,3,3,3,4,15	No change in final ranking
only in indifference threshold	1,1,1,1,1,1,6	1,1,1,1,1,1,8	No change in final ranking
Urban stations			
Changes in point values of non-numerical criteria			
Availability of electricity (C3)	7,4,3,4,4	7,7,3,6,4	U1 > U5 = U2 > U3 > U4
Easy Access (C6)	7,7,5,7,6	7,8,7,5,7	No change in the final ranking.
Pollution levels (C1)	2,8,3,8,4	3,5,7,5,3	U1 > U5 = U2 > U4 > U3
Changes in the weights of criteria			
weights of criteria	30;20;10;10; 10;10;10	30;25;10;10; 15;5;5	U1 > U5 = U2 > U4 > U3 Credibility and concordance matrix were changed in small amounts.
Changes in threshold			
only in preference thresholds	2,2,3,3,2,2,5	2,3,3,3,3,3,4	no change in final ranking
only in indifference threshold	1,1,1,1,1,1,3	1,1,2,2,1,1,1	no change in final ranking

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