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Research Article

Identification of the priority regions in the customer water meters replacement using the AHP and ELECTRE methods

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ABSTRACT

The aim of this study is to determine the priority areas in the meter replacement or rehabilitation by using an integrated methodology combining the AHP and ELECTRE I methods to reduce the non-revenue water. For this, a total of 7 criteria such as the Water Consumption Rate, Mean Meter Age, Faulty Water Meter Ratio, Region Population Rate, Customer Loyalty Percentage, Average Operating Pressure and Calibrated Age were considered. The AHP method was applied to calculate the weights of the criteria and then a model based on weights of criteria was developed using the ELECTRE I method. The model based on AHP and ELECTRE I methods was applied by taking into account the field data records for 7 criteria and the priority regions in water meter replacement were determined. This study will make significant contributions in the scope of minimizing the losses caused by the meters, reducing the costs in meter management and making the most benefit in meter replacement.

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INTRODUCTION

In water distribution systems (WDSs), faults in customer water meters occur according to various reasons. Apparent losses consist of some components such as authorized unbilled consumption or unauthorized unbilled consumption (water thief, illegal connections) and water meter inaccuracies [1, 2]. The rate of non-revenue water called "*Apparent Losses*" increase according to the ratio of these faults that occurs in the water meters. The water and sewerage administrations follow generally the way to replace the meters, which are generally 10 years old, in order to reduce the non-revenue water (NRW) rate caused by the meters. While these meters are being replaced, a certain number of monthly or yearly random change policies are applied

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instead of identifying and changing the ones that are defective. This strategy leads to the replacement of non-defective meters and to an increase in the initial investment cost for the Utilities. In addition, since the meter can measure correctly even if it is in 10 years old, the replacement policy which is monitored according to the meter age only, can reveal uneconomical results for the Administrations. In the literature, various methods have been applied related to analysis of water meter faults, evaluation of the effect of these faults on NRW rate and reduction of apparent losses. Davis [3] investigated the NRW ratio resulting from the incorrect measurement of customer meters, one of the key components of the International Water Association (IWA) water balance. Authors stated that there are no specific standards in meter replacement and it is generally replaced between 10 and 20 years. Experiments were carried out in three different flow rates (low, medium and high) to determine the economic meter change ages for each flow regime. Alegre et al. [4] stated that every water volume transmitted, consumed by customers and unbilled was a very significant cause for the Utilities. As a result, they pointed out that the leakage component is directly related to customer service management and that the measurement errors are directly related to the selection of the meters at the right type and size. Criminisi et al. [5] analyzed two main criteria such as water meter age and individual water tanks in the buildings affecting apparent losses in WDSs. For this aim, a total of 180 authorized water meters with a range 0–45 years were taken into consideration. As a result of the study, it was emphasized that the apparent losses increased due to the meter age. Vairavamoorthy [6] analyzed the criteria causing apparent losses by considering the measurements carried out at the site and operating data. The results showed that water meter accuracy plays an important role on water consumption. Stoker [7] conducted a study to investigate the criteria affecting the correctness and deterioration of the meters used in the houses and stated that faults in customer water meters are a function of criteria such as degradation, water quality, water velocity, and volume and installation type. Arregui [8] aimed to assess measurement errors in water meters in residential areas and investigated the impact of water consumption characteristics on apparent losses. The measurement error is a function of the customer meter type and the user characteristics. Mbabazi [9] analyzed the deterioration rates of two different meter types (volume and velocity based) with the same system and water consumption characteristics. They proposed that the degradation rates can be used to change the water meters. Multi-criteria decision making can be described as an approach that considers all the criteria considered to be effective in the problem being addressed. In literature, various methods such as Analytical Hierarchy Process (AHP), Elimination and Choice Translating Reality (ELECTRE), The Technique For Order Preference By Similarity To Ideal Solution (TOPSIS) have been proposed and used in multi-criteria decision analysis [10, 11, 12–19, 20]. Al-Barqawi and Zayed [21] used the artificial neural networks and AHP methods to estimate and assess the performance of the main pipes in WDSs. As a result, it was stated that the developed model will provide significant gains in the planning and rehabilitation of drinking water pipes by practitioners, decision makers and consulting agencies. Tanyimbob and Kalungi [22] applied the AHP method to decide the most appropriate alternative for the design, rehabilitation and improvement of drinking water distribution systems. Carriço et al. [23] applied the methods of ELECTRE TR1 and ELECTRE III based on criteria such as risk, performance and cost for defining the priority areas in rehabilitation in drainage systems. Kessili and Benmamar [24] aimed to identify priority projects in the rehabilitation of wastewater drainage systems. For this aim, 47 projects with 12 criteria were considered and AHP-PROMETHEE II methods known as multi-criteria decision methods were applied together.

As can be seen in the literature, inaccuracies in customer water meters lead to an increase in apparent losses. These inaccuracies lead to an increase in the authorized unbilled losses that mean direct loss of income for the administrations. For this reason, these losses should be minimized and managed systematically. Generally, water meters over 10 years old are changed in Utilities. However, the material and workmanship quality, age, technology and usage method of the meter are very effective on its economic life. For this reason, it is necessary to consider the factors affecting meter errors and to define the risks in meter management. In order to achieve this, it is necessary to monitor the meter and customer information, to determine the error rates annually, to define the most risky areas in terms of water and economy, and to develop a renewal strategy.

Moreover, *t* is very important to change the meters in a certain systematic and program framework and strategy for reducing NRW ratio resulting from the meters. In addition to the water meter age, criteria such as faulty meter ratio, the number of total meters, water consumption rate etc. in the region should be taken into account in the meter replacement policy to be developed. The aim of this study is to determine the priority areas in the meter replacement or rehabilitation by using an integrated methodology combining the AHP and ELECTRE I methods to reduce the NRW ratio and to increase the economic gains. For this aim, a total of 7 criteria such as water consumption rate, average meter age, faulty meter rate, customer loyalty percentage, average operating pressure and meter calibration age were taken into consideration and the developed model was applied for 20 sub-regions. In determining the priority areas, firstly, the AHP method was applied to calculate the weights of the criteria. Then, with the determined weight coefficients and real field data of 7 criteria in 20 sub-regions, the priority areas in water meter changing were determined by applying the ELECTRE method.

METHODS

Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a multi-criteria decision-making method that has gained widespread use after it was developed by Wind and Saaty [25]. All the criteria that are effective on the problem studied in this method are considered and the superiority of each factor are taken as basis. The process steps of the AHP method can be basically given as [25]:

Step 1: Defining the Criteria

The model should fully represent the problem, the most appropriate criteria and / or sub-criteria should be selected by analyzing the problem in detail.

Step 2: Establishing the Pairwise Comparison Matrices

The criteria and sub-criteria are scored by experts based on the scoring scale given in Table 1 and pairwise comparison matrices are constructed [25].

Step 3: Calculation of the Weights

The weight coefficients of each factor is calculated by the following equations (1–3) using the pairwise comparison matrices constructed according to expert opinions [25]. In addition, preference matrix is created by dividing each cell in each column by the sum of that column (equation (4)).

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad (1)$$

Table 1. Scoring Scale

Importance Degree	Relative Importance
1	Equal importance
3	Moderate importance
5	High importance
7	Very High importance
9	Strongly High importance
2,4,6,8	Scale Values

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (2)$$

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{n} \quad (3)$$

$$W = \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix} \quad (4)$$

Where, A is the basic matrix, W is the preference matrix, a_{ij} is the each element of the pairwise comparison matrix, b_{ij} is the each element of the preference matrix, w_i is the elements of preference matrix.

Step 4: Consistency Analysis

Consistency is a method applied to check the appropriateness of weight coefficients. Therefore, the consistency ratio (CR) is calculated and the suitability of the pairwise comparison matrices is checked. Moreover, the matrix D is obtained by the matrix multiplication of the weights of each factor with the pairwise comparison matrices. In addition, the elements of this matrix are divided by the weight coefficients to obtain the E column matrix, which is the basic value of each factor. ƛ basic value is obtained by calculating the arithmetic average of the total value of the E column matrix found for each factor. The consistency indicator (CI) is calculated based on the number of criteria in the base value by using equation (5) [26].

$$CI = \frac{ƛ - n}{n-1}, (i = 1,2,3,\dots n) \quad (5)$$

Calculation of Consistency Ratio (CR)

After the consistency analysis, the consistency rate is determined using equation (6). For this, the regulation coefficients (RI) proposed by [25] are determined by factor numbers (Table 2) [26].

The consistency of factor weights is verified via this analysis and the critical values of consistency ratio proposed by [25, 27] can be given as; (i) If CR is greater than

Table 2. The regulation coefficients (RI)

N (Number of factors)	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56

0.10, pairwise comparison matrix and weights of criteria are recalculated by reconsidering the opinions of experts and practitioners, (ii) If CR is equal or smaller than 0.10, then the results are assumed as valid.

$$CR = \frac{CI}{RI} \tag{6}$$

Electre

The combination of ELECTRE I and AHP methods was used to determine the priority areas in the meter replacement or rehabilitation. The ELECTRE family was introduced by Benayoun et al. [28] and later was developed by Roy [29, 30]. The ELECTRE I can be expressed as a method of comparing superiority relations (outranking relations) by comparing each alternative in a comprehensive way [31, 32]. In the ELECTRE I method, the process steps are basically given as:

Step 1: Creating the Decision Matrix (A)

The decision matrix is defined as a basic matrix which is dimensioned according to decision point and criteria numbers (n), evaluates decision points (m) according to all criteria and is calculated by using the equation (7).

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \tag{7}$$

Step 2: Calculation of the Normalized Decision Matrix

The decision matrix is normalized by equation (8a) and the normalized decision matrix is obtained as in equation (8b) [33].

$$x_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}^2}} \tag{8a}$$

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{8b}$$

A_{ij} is the decision matrix, $i = 1,2,...m$, $j = 1,2,\ldots n$, m is the number of alternatives in decision matrix, n is the number of criteria in decision matrix, X_{ij} is the normalized decision matrix, r_{ij} is the elements of the decision matrix, x_{ij} is the elements of the normalized decision matrix.

Step 3: Calculation of the Weighted Normalized Decision Matrix

The weighted normalized decision matrix (Yij) given in Eq. (9) is calculated by multiplying the weights determined by the AHP method and the normalized decision matrix (Xij matrix).

$$Y_{ij} = \begin{bmatrix} x_{11}.w_1 & x_{12}.w_2 & \cdots & x_{1n}.w_n \\ x_{21}.w_1 & x_{21}.w_2 & \cdots & x_{2n}.w_n \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ x_{m1}.w_1 & x_{m2}.w_2 & \cdots & x_{mn}.w_n \end{bmatrix} \tag{9}$$

Y_{ij} is the weighted normalized decision matrix, w_i is the criteria weight calculated by AHP method, $i = 1,2,...m$, $j = 1,2,\ldots n$.

Step 4: Determination of Concordance and Discordance Sets

The data in weighted normalized decision matrix is compared for each pair by creating pairs between any two decision points. If the decision point is equal to or better than the other decision point compared, the (C) Concordance Set given in equation (10) is defined (1 if provided, 0 if not). If the decision point is worse than the other in which the comparison is made, the set of Discordance (D) given in Eq. (11) is defined.

$$C(p,q) = \{j,\ Y_{pj} \geq Y_{qj}\} \tag{10}$$

$$D(p,q) = \{j,\ Y_{pj} < Y_{qj}\} = j - C(p,q) \tag{11}$$

Step 5: Calculation of the Concordance and Discordance Matrices

The concordance index shows the superior of the decision points and is obtained using equation (12). The matrix of discordance shows the value of inconsistency when one of the two decision points is preferred and is calculated as in equation (13) [34]. The discordance matrix with the mxm dimensional is obtained by calculating the inconsistency criterion for all decision point pairs by the equation (14).

$$C_{pq} = \sum_j W_j \tag{12}$$

$$D_{pq} = \frac{\left(\sum_{j^o} \left|Y_{pj^o} - Y_{qj^o}\right|\right)}{\left(\sum_j \left|Y_{pj} - Y_{qj}\right|\right)} \tag{13}$$

$$D = \begin{bmatrix} - & d_{12} & d & \dots & d_{1m} \\ d_{21} & - & d_{23} & \dots & d_{2m} \\ . & & - & & . \\ . & & & - & . \\ . & & & & . \\ d_{m1} & d_{m2} & d_{m3} & \dots & - \end{bmatrix} \quad (14)$$

C(p,q) is the concordance cluster, *D* is the discordance matrix, *D(p,q)* is the discordance cluster, *p* and *q* refer to pairs created between any two decision points, $p = 1,2\dots m$, $q = 1,2,\dots m$ and $p \neq q$, Y_{pj} refers the *p* point in *j*th column in weighted normalized decision matrix, Y_{qj} refers the *q* point in *j*th column in weighted normalized decision matrix, m is the number of alternatives in decision matrix.

Step 6: Establishment of the concordance-superiority and the discordance-superiority matrices

The concordance-superiority matrix is obtained by comparing the concordance threshold with the elements of the concordance matrix [28]. As a result of these comparisons, the matrix F of size mxm and consisting of values 0 and 1 is calculated [35]. The discordance-superiority matrix (called G matrix) is obtained in a manner similar to the concordance-superiority matrix (called F matrix). The discordance index ($\overline{d}$) is calculated by equation (17) [34].

$$\overline{c} = \frac{1}{m(m-1)} \sum_{p=1}^{m} \sum_{q=1}^{m} C_{pq} \quad (15)$$

$$f_{pq} = \begin{pmatrix} 0, & c_{pq} \geq \overline{c} \\ 1, & c_{pq} < \overline{c} \end{pmatrix} \quad (16)$$

$$\overline{d} = \frac{1}{m(m-1)} \sum_{p=1}^{m} \sum_{q=1}^{m} D_{pq} \quad (17)$$

$$g_{pq} = \begin{pmatrix} 0, & d_{pq} \geq \overline{d} \\ 1, & d_{pq} < \overline{d} \end{pmatrix} \quad (18)$$

$\overline{c}$ is the concordance index, f_{pq} is the elements of concordance-superiority matrix, $\overline{d}$ is the discordance index, g_{pq} is the elements of the discordance-superiority matrix.

Step 7: Calculation of Net Concordance and Discordance Matrices

The net concordance and discordance values are calculated to rank the decision points. Where C_p represents the largest or most risky value among all decision points, and D_p represents the lowest value between decision points [36].

$$C_{net} = \sum_{\substack{q=1 \\ q \neq p}}^{m} C_{pq} - \sum_{\substack{q=1 \\ q \neq p}}^{m} C_{qp} \quad (19)$$

$$D_{net} = \sum_{\substack{q=1 \\ q \neq p}}^{m} D_{pq} - \sum_{\substack{q=1 \\ q \neq p}}^{m} D_{qp} \quad (20)$$

Step 8: Calculation of Overall Concordance Matrix (E)

The overall concordance matrix (E) is calculated by multiplying the concordance-superiority matrix (F) by each cell of the discordance-superiority matrix (G) matrices [33]. In matrix E, a value of 1 indicates the superiority between two decision points, whereas a value of 0 indicates that the two decision points are neutral. The matrix E is used to rank the decision points according to their superiority to each other.

$$e_{pq} = f_{pq} \times g_{pq} \quad (21)$$

Cnet is the net value of concordance, *Dnet* is the the net value of discordance C_{pq} and C_{qp} are the elements of concordance matrix, D_{pq} and D_{qp} are the elements of concordance matrix, e_{pq} *is* the elements of general concordance matrix, f_{pq} *is* the elements of the concordance-superiority matrix.

Study Area

In this study, Malatya city was chosen as the study area in order to determine the priority areas in the customer water meters replacement. The total population of Malatya in year 2016 is 781305. The study area covers Battalgazi and Yeşilyurt regions which are the central towns. These central towns were grouped according to similar characteristics that are population density information, average operational pressures, average annual water consumption amounts, average water meter ages, and water meter weighted error rates and a total of 20 sub-regions were obtained (Figure 1). Analyzes in the following sections were conducted for these 20 sub-regions.

ANALYSIS AND RESULTS

Defining the Criteria and Data

As mentioned earlier, the rate of non-revenue water for the Water Utilities is increasing according to the error rate in the meters. Therefore, the water meters in a certain systematic and program framework should be replaced and long term strategy should be defined to reduce the non-revenue water ratio resulting from the meters. In this part of the study, after the weights of the criteria were determined by the AHP method, the ELECTRE I method was applied considering these weight coefficients and field data of 7 criteria such as water consumption rate, average meter age, faulty meter rate, customer loyalty percentage, average operating pressure and meter calibration age in 20 sub-regions.

In order to ensure the efficiency of the system, the costs arising from the meter replacement should turn into a benefit as soon as possible. Factors such as meter errors, meter age, and calibration status are generally very effective in increasing costs arising from meters in a region.

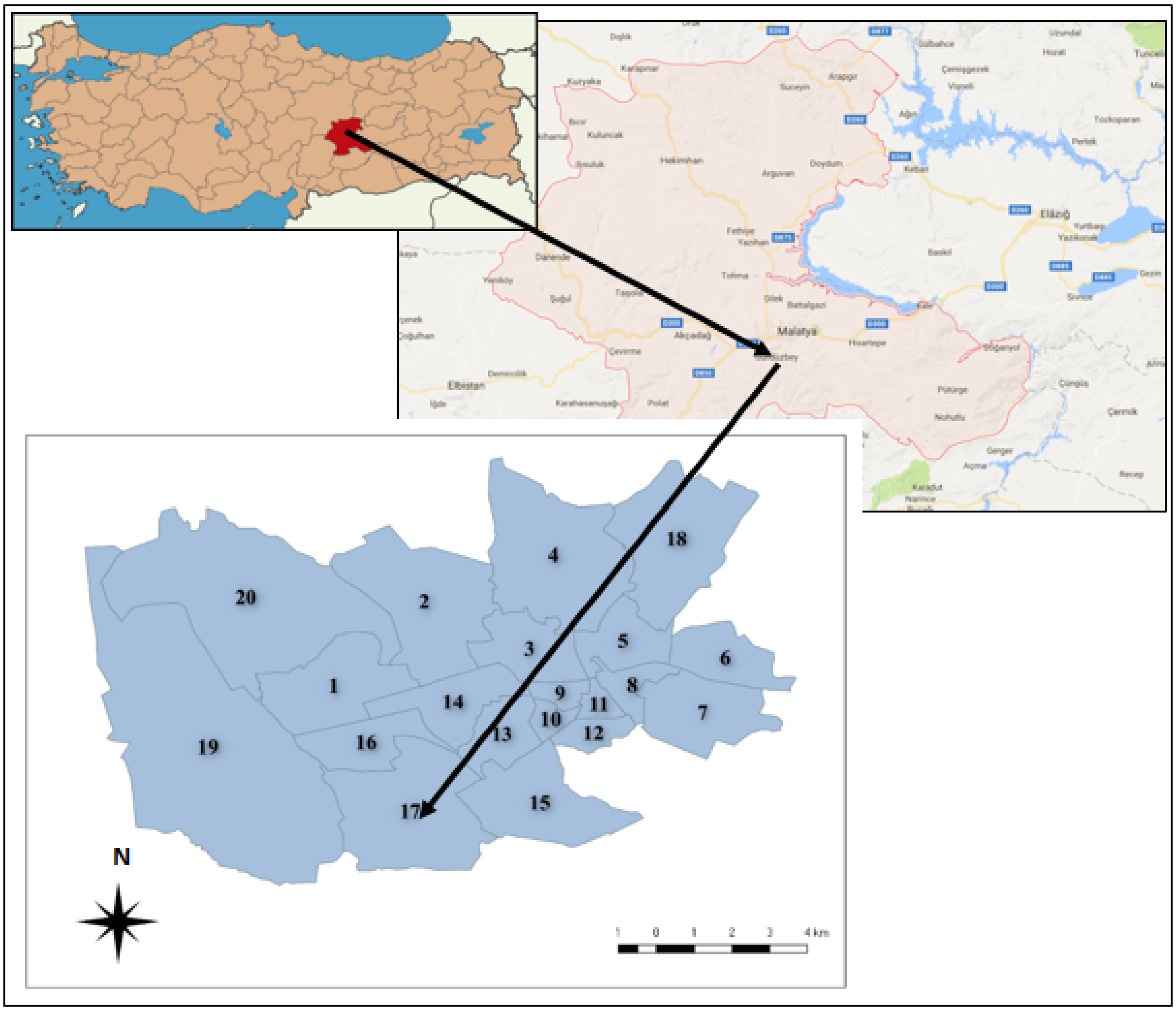


Figure 1. Study area.

On the other hand, factors such as meter age, calibration status and system pressure are effective on meter errors. In places where meter error rates are high, losses due to meter errors (in volume) increase depending on the population and consumption rate, and direct income loss occurs for the administration. For this reason, it is very important to determine the priority areas in meter replacement by considering these factors. Therefore, in this study, these factors, which have an effect on meter errors and cause increased revenue loss for the administration, are taken into account. Although it is possible to increase the number of these factors, the availability and applicability of the data is very important. The details of these criteria are given below.

Population and authorized customers

The 20 sub-regions in the application area cover 170363 authorized customers and 452759 people in total, and the distribution of the population and the authorized customers according to regions is shown in Figure 2.

It is seen that population density and number of customers in the application area are predominantly in Regions 7 and 13, population in regions 1, 2 and 4 is lower than the other regions (Figure 2). The regions 7 and 13 are located in the city center and contain old settlements.

System operating pressure

The system operating pressure is the one of the important criteria affecting meter errors. The high pressure and fluctuations in system pressure disrupt the mechanical structure of the meters and cause missing or incorrect measurement. The pressure distribution in the study area is measured and the variation according to the zones is given in Figure 2. It is seen that in regions 4, 16 and 17, the pressure is higher than the other regions. In addition, regions 2 and 20 have been identified as regions with the lowest pressures (Figure 2c). The reason for this low pressure may be due to the topographic features of the zone, as well as the high losses in the existing distribution network in the region.

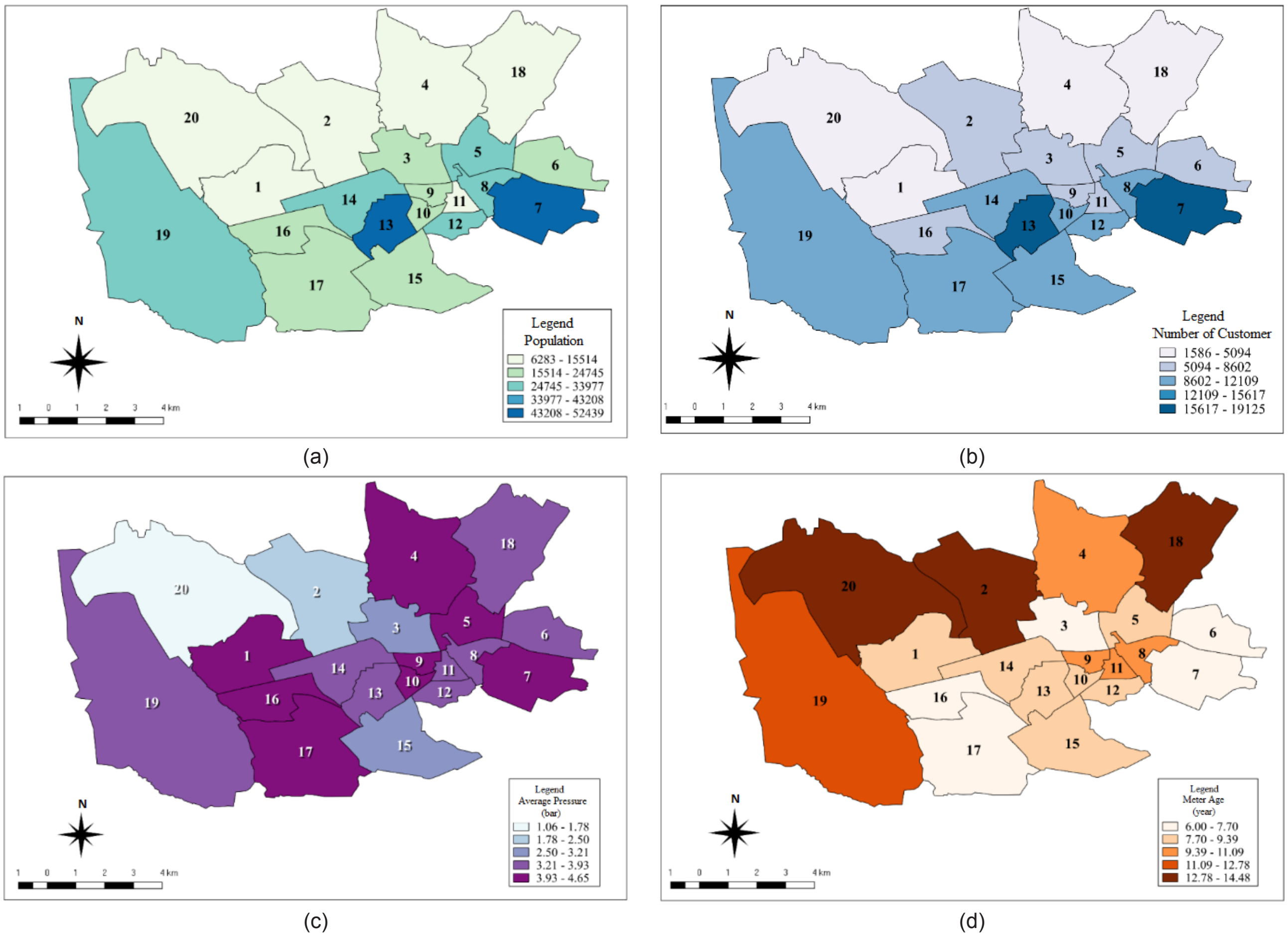


Figure 2. a) The Population b) The number of Customers in regions c) The system operating pressure d) The water meter age variation.

Water meter details (meter calibration, meter age and ratio of faulty meters)

In this study, field data of a total of 181370 authorized customer's meters in the application area were collected. In order to make general evaluation, the water meters were analyzed according to various characteristics. The water age is another factor that causes the errors in water meters. The useful life of the customer water meters ranges from 10 to 15 years on ideal conditions, provided that it is calibrated every 2 years. In water meter with high ages the error rate in the measurements increase. The average age of the meters in the 20 sub-regions is shown in Figure 3. Moreover, the variation of the ratio of faulty water meters are given in Figure 4.

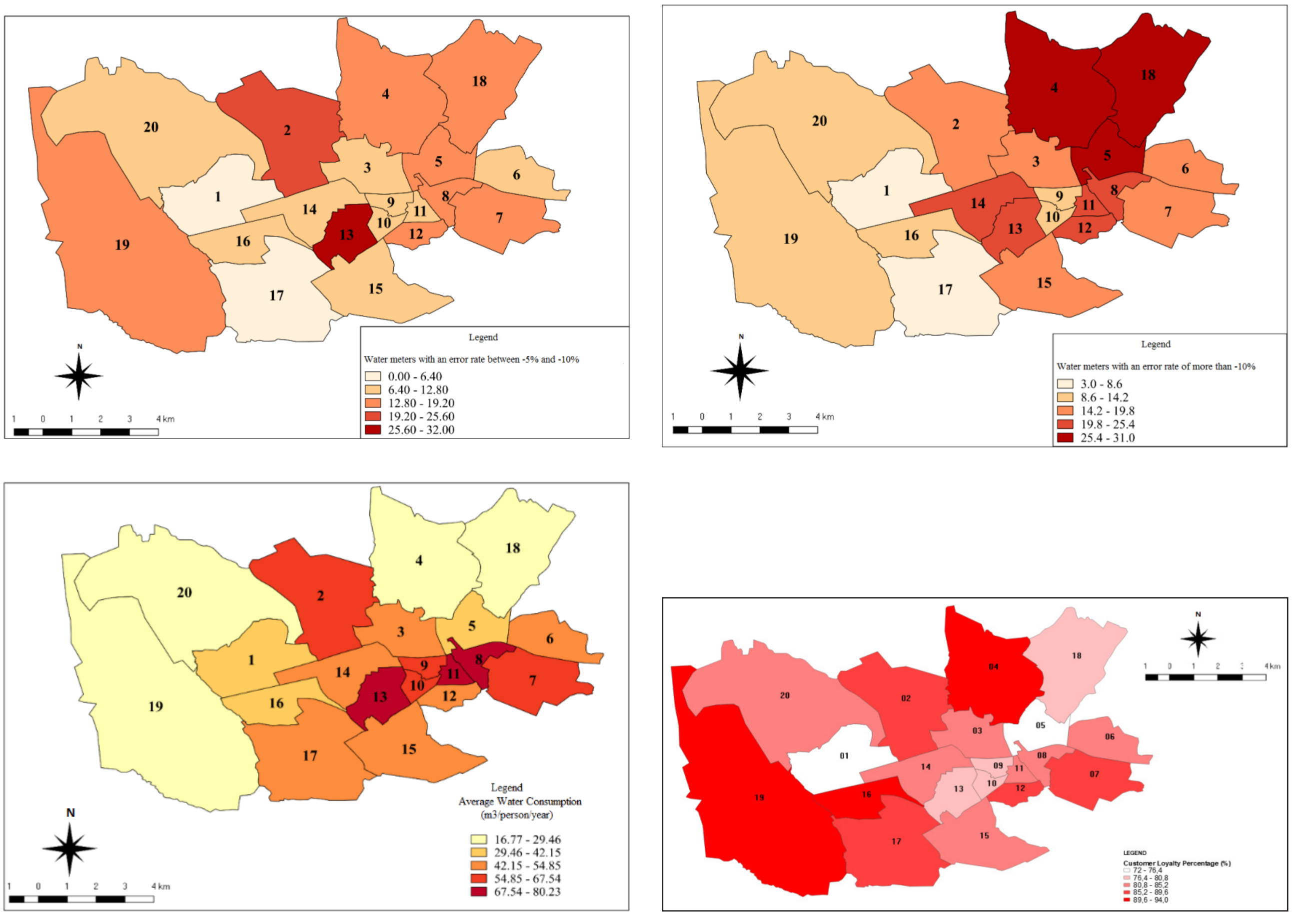
The average meter age is 9.25 in regions. The region with the highest average age is in the region 18 with 14.48 years, while the region with the lowest average age (6.00) is the region 17. It can be said that this region 17 is in better condition than other regions in terms of meter age because of having relatively new settlement areas.

Water consumptions

Annual per capita water consumption of the authorized customers in the study area is analyzed and shown in Figure 4. The highest per capita consumption is in the region 13 with 80.23 m^3 / person / year consumption. Moreover, per capita water consumption ratios are lower in the regions 18, 19 and 20 where the meter age is high compared to the other regions. The low per capita consumption in these regions can be interpreted as follows: the sociocultural structure of the region is different, the differences in lost and leaked rates, the incomplete measurement due to the large part of the elderly meter etc.

Customer loyalty percentage

Customer loyalty percentage is expressed as the ratio of the amount of money paid to the total billed for the authorized consumptions in the regions. In water distribution systems, the authorized consumptions are billed however a certain part of these billed consumptions are not paid. If the in the regions where the customer loyalty percentage



(a) (b)

Figure 3. a) The variation of ratio of faulty water meters and the average water consumptions b) The variation of customer loyalty percentages.

is high, the loss of income for the Water Utilities will be higher. In other words, if the rate of loss of water from the customer meters is reduced in regions where the percentage of customer loyalty is high, the amount of water generating income for Water Utilities will be increased. The variation of the Customer loyalty percentage is given in Figure 3.

Determination of Weights of Criteria by AHP

The weights of the criteria are determined by the AHP method. As detailed above, a total of 7 criteria such as the Water Consumption Rate (D1), Mean Meter Age (D2), Faulty Water Meter Ratio (D3), Region Population Rate (D4), Customer Loyalty Percentage (D5), Average Operating Pressure (D6) and Calibrated Age (D7) were considered. For the composing the pairwise comparison matrices given in Table 3, the criteria were scored by experts consisting of managers and engineers working in the field of water management, network and leaking management and field applications in Water Utilities based on standard relative importance values proposed by [27]. Based on this pairwise comparison matrices, mean and result matrices are determined (Table 3). In addition, preference and average matrices were obtained for the result matrix (Table 4).

Consistency analysis was performed with the help of the equations given in Section 3 for the result matrix generated from the results of the expert opinion. As a result of the consistency analysis, the CI value was 0.0003 and the CR

Table 3. The pairwise comparison matrix

Criteria	D1	D2	D3	D4	D5	D6	D7
D1	1	1/2	1/2	3	1	1	1
D2	2	1	1/2	2	3	4	1/4
D3	2	2	1	3	3	2	3
D4	1/3	1/2	1/3	1	4	1/2	1
D5	1	1/3	1/3	1/4	1	2	1/2
D6	1	1/4	1/2	2	1/2	1	3
D7	1	4	1/3	1	2	1/3	1

value was 0.0002 which are in the range of the limit values. The weight coefficients determined by the AHP method are given in Table 5.

The highest value of the weight coefficient was obtained for the factor D3 (Faulty Meter Ratio) with a value of 0.242. Also, the second highest value of the weight coefficient was calculated for factor D2 (Mean Meter Age) factor. On the other hand, the weighting coefficient calculated for factor D5 (Percent of Customer Loyalty) has the lowest value. The customer water meters that make missing or inaccurate or non-measuring meters increase the non-revenue water ratio. In addition, it is known that the increase in meter age has a significant effect on the meter error rate. By considering these two points, it can be said that the weight coefficients calculated for the Faulty Meter Ratio and Mean Meter Age criteria have the highest values, and the results of the AHP analysis are similar to the physical conditions of the problem.

Table 4. The preference matrix

Factor	D 1	D 2	D 3	D 4	D 5	D 6	D 7
D 1	1/8	1/9	1/8	1/8	1/8	1/8	1/9
D 2	1/5	1/6	1/6	1/5	1/6	1/5	1/6
D 3	1/4	1/4	1/4	1/4	1/4	1/4	1/4
D 4	0	0	1/9	1/9	1/9	0	0
D 5	0	0	0	0	0	0	0
D 6	1/8	1/8	1/8	1/8	1/8	1/8	1/8
D 7	1/7	1/7	1/7	1/7	1/7	1/7	1/7

Table 5. The weights for factors

D1	D2	D3	D4	D5	D6	D7
0.118	0.183	0.242	0.1	0.084	0.127	0.147

Criteria	W	D	E	
D1	0.118	0.83	7.0	
D2	0.183	1.28	7.0	
D3	0.242	1.69	7.0	λ = 7.0019
D4	0.1	0.70	7.0	CI = 0.0003
D5	0.084	0.59	7.0	CR = 0.0002
D6	0.127	0.89	7.0	
D7	0.147	1.03	7.0	

Determination of the Priority Regions by ELECTRE

The ELECTRE I method was applied to determine the priority areas in the water meters replacement by considering the factor weights determined by the AHP method in the previous section. The field data for 7 criteria were collected in 20 sub-regions in the study area and the decision matrix was generated. The decision matrix was normalized using equation (8a). Each element of the normalized decision matrix was multiplied by the weight coefficients calculated with AHP and the weighted normalized decision matrix was obtained. Then the matrices such as the concordance matrix (called C matrix), the discordance matrix (called D matrix), the concordance-superiority matrix (called F matrix), the discordance- superiority matrix (called G matrix) and the overall-concordance matrix (called E matrix) were determined. After obtaining these matrices, the regions are ranked and shown in Table 6 and Figure 4.

Priority regions in the customer water meters replacement were determined as Region 13, 18, 4 and 20, respectively, where the meter age is the highest, the water consumption rate per capita is the lowest. One of the most important reasons of this situation is considered to be the water meter inaccuracies. The fact that the meter error rates are higher than the other regions in these regions further strengthens this evaluation. This strategy raises the first investment cost due to the renewal of the meter, especially in the regions where the number of customers is high and the rate of faulty counter is low, and thus leads to an uneconomic way. Water Utilities usually replace the customer water meters which have completed 10 years. This strategy increases the number of customers and the first investment cost due to the water meter replacement in the regions where there are fewer measurement errors. Therefore, in addition to meter age, factors such as faulty rate of the water meters, total number of meters, water consumption rate should be taken into consideration in decision-making policy decision-making. On the other hand, the best regions according to 7 criteria were obtained as Region 1,3,17 and 6, respectively, where the water consumption rates and the rates of the water meter errors are the lower than other regions.

CONCLUSIONS

In this study, a methodology by integrating the AHP and ELECTRE I methods was applied to determine the priority areas in the customer water replacement or rehabilitation to

Table 6. The final ranking of the regions

Region	B13	B18	B4	B20	B2	B11	B9	B15	B7	B14
Final Ranking	1	2	3	4	5	6	8	8	9	10
Region	**B12**	**B8**	**B5**	**B19**	**B10**	**B16**	**B6**	**B17**	**B3**	**B1**
Final Ranking	11	12	13	14	15	16	17	18	19	20

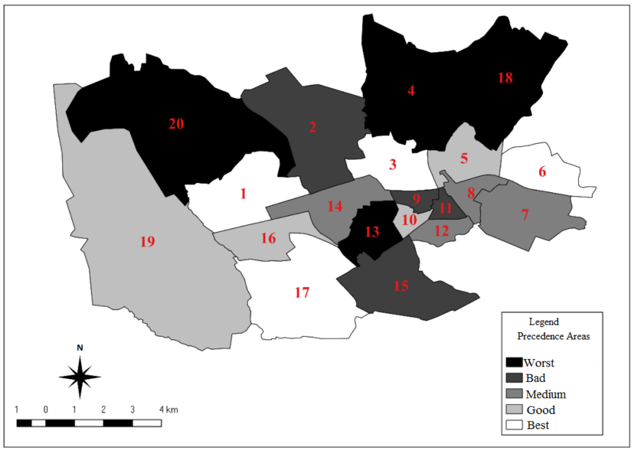


Figure 4. The final ranking of the regions.

reduce the non-revenue water ratio from water meter errors and to increase the economic gains. For this, a total of 7 criteria were determined and their weight coefficients were calculated by applying the AHP method. The highest value of the weight coefficient was obtained for the D3 (Faulty Meter Ratio) factor with a value of 0.242. Also, according to the results in the table, it was seen that the second highest value of the weight coefficient is calculated for D2 (Mean Meter Age) factor. Meters that make missing or inaccurate or non-measuring meters increase the non-revenue water ratio. In addition, it can be said that the increase in meter age has a significant effect on the meter error rate. Taking these two points into consideration, it can be said that the weight coefficients calculated for the Faulty Meter Ratio and Mean Meter Age criteria have the highest values, and the results of the AHP analysis are similar to the physical conditions of the problem. The ELECTRE I method was applied to determine the priority areas in changing the water meters by taking into consideration the weights determined by the AHP method. Priority rankings were set as regions 13-18-4-20 in the evaluations made by setting the priority areas for water meter change.

Determination of priority regions contributes significantly to the development of long-term and economical meter management plan. However, the most important problem encountered in making such analyzes is obtaining data from the field. It is very difficult to perform analyzes especially in systems where meter information and calibration data are missing and subscriber information is not up to date. Since the losses occurred by meter errors cause direct loss of revenue for the administration, the error rates should be systematically determined annually. Meter information (age, mark, class) and customer information should be kept up to date (residential, commercial) in order to define inaccuracy rates correctly. It is very important to integrate these data with GIS in order to use them in analysis and to make regional evaluations. In order to achieve this, databases should be updated regularly, field calibrations should be performed and a relationship should be established between each other. Thus, it is possible to analyze the temporal and spatial changes of meter information, consumption changes, losses and their economic effects. Based on these data and evaluations, determining priority areas for meter replacement will contribute to reducing the initial investment costs and shortening the return time. In addition, an asset management plan should be created in order to extend the economic life of meters and increase their efficiency. Thus, it will be possible to carry out activities such as calibration, testing, change, maintenance and repair systematically.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Farley M. Non Revenue Water – International Best Practice for Assessment, Monitoring and Control. 12th Annu CWWA Water, Wastewater, 2003. p. 1–18.
[2] Lambert A. Assessing non-revenue water and its components : a practical approach. Water Res 2003;21:50–1.
[3] Davis SE. Residential water meter replacement economics. Conference Proceedings. Leakage 2005.

[4] Alegre H, Baptista JM, Cabrera J, Cubillo F, Duarte P, Hirner W, et al. Performance Indicators for Water Supply Services. London: IWA Publishing; 2006.

[5] Criminisi A, Fontanazza CM, Freni G, Loggia GL. Evaluation of the apparent losses caused by water meter under-registration in intermittent water supply. Water Sci Technol 2009;60:2373–83. [CrossRef]

[6] Mutikanga HE, Sharma SK, Vairavamoorthy K. Multi-criteria decision analysis: a strategic planning tool for water loss management. Water Res Manag 2011;101:3947–969. [CrossRef]

[7] Stoker DM, Barfuss SL, Johnson MC. Flow measurement accuracies of in-service residential water meters. J Am Water Work Assoc 2012;104:637–42. [CrossRef]

[8] Arregui F, Balaguer M, Soriano J. Quantifying measuring errors of new residential water meters considering different customer consumption patterns. Urban Water J 2015;12:1–13. [CrossRef]

[9] Mbabazi D, Banadda N, Kiggundu N. Determination of domestic water meter accuracy degradation rates in Uganda. J. Water Supply Res Technol 2015;64:486–93. [CrossRef]

[10] Fares HA. Evaluating the risk of water main failure using a hierarchical fuzzy expert system. Master thesis. Concordia University Gina Cody School of Engineering and Computer Science Building, Civil and Environmental Engineering, Montreal, 2008.

[11] Shahata K, Zayed T. Integrated decision-support framework for municipal infrastructure asset. ASCE Pipelines Proc 2010;514:1492–502. [CrossRef]

[12] Achillas C, Vlachokostas C, Moussiopoulos N, Banias G. Prioritize strategies to confront environmental deterioration in urban areas: Multicriteria assessment of public opinion and experts. Views Cities 2011;28:414–423. [CrossRef]

[13] Francisque A, Shahriar A, Islam N, Betrie G, Siddiqui RB, Tesfamariam S, Sadiq R. A decision support tool for water mains renewal for small to medium sized utilities: a risk index approach. J Water Supply Res Technol – AQUA 2014;63:281–302. [CrossRef]

[14] Scholten L, Scheidegger A, Reichert P, Mauer M, Lienert J. Strategic rehabilitation planning of piped water networks using multi-criteria decision analysis. Water Res Manag 2014;49:124–43. [CrossRef]

[15] Zhao J, Jin J, Zhu J, Xu J, Hang Q, Chen Y, et al. Water resources risk assessment model based on the subjective and objective combination weighting methods. water resour. Water Res Manag 2016;30:3027–3042. [CrossRef]

[16] Yan W, Li J, Liu M, Bai X, Shao H. Data-based multiple criteria decision-making model and visualized monitoring of urban drinking water quality. Soft Comput 2017;21:6031–41. [CrossRef]

[17] Volmer D, Pribadi DO, Remondi F, Rustiadi E, Gret-Regamey A. Prioritizing ecosystem services in rapidly urbanizing river basins: A spatial multi-criteria analytic approach. Sustain Cities Soc 2017;20:237–52. [CrossRef]

[18] Zinatizadeh S, Azmi A, Monavari SM, Sobhanardakani S. Evaluation and prediction of sustainability of urban areas: a case study for Kermanshah city, Iran. Cities 2017;66:1–9. [CrossRef]

[19] Kilinç Y, Özdemir Ö, Orhan C, Firat M. Evaluation of technical performance of pipes in water distribution systems by analytic hierarchy process. Sustain Cities Soc 2018;42:13–21. [CrossRef]

[20] Wu Y, Zhang B, Xu C, Li L. Site selection decision framework using fuzzy ANP-VIKOR for large commercial rooftop PV system based on sustainability perspective. Sustain Cities Soc 2018;40:454–70. [CrossRef]

[21] Al-Barqawi H, Zayed T. Infrastructure management: integrated AHP/ANN model to evaluate municipal water mains' performance. J Infrastruct Syst 2008;14:305. [CrossRef]

[22] Tanyimboh T, Kalungi P. Multicriteria assessment of optimal design, rehabilitation and upgrading schemes for water distribution networks. Civ Eng Environ Syst 2009;26:117–40. [CrossRef]

[23] Carriço N, Covas IC, Ceu Almeida M, Leitao JP, Alegre H. Prioritization of rehabilitation interventions for urban water assets using multiple criteria decision-aid methods. Water Sci Technol 2012;66:1007–14. [CrossRef]

[24] Kessili A, Benmamar S. Prioritizing sewer rehabilitation projects using AHP-PROMETHEE II ranking method. Water Sci Technol 2016;73,283–91. [CrossRef]

[25] Wind Y, Saaty T. Marketing applications of the analytic hierarchy process. Manage Sci 1980:641–58. [CrossRef]

[26] Lamata T, Alonso J. Consistency in the analytıc hıerarchy process: a new approach. Int J Uncertainty Fuzziness Knowledge-Based Syst 2006;14:445. [CrossRef]

[27] Saaty TL. The Analytic Hierarchy Process. New York: McGraw-Hill; 1980. [CrossRef]

[28] Benayoun R, Roy B, Sussman B. Electre: Une méthode pour guider le choix en présence de points de vue multiples. Note de travail 1996;49.

[29] Roy B. No classament et choix en presence de points de vue multiples. Int J Uncertainty Fuzziness Knowledge-Based Syst 1968;1:57–75. [CrossRef]

[30] Govindan K, Shankar M, Kannan D. Application of fuzzy analytic network process for barrier evaluation in automotive parts remanufacturing towards cleaner production. J Clean Prod 2016;114:199–213. [CrossRef]

[31] Farhadinia B. Information measures for hesitant fuzzy sets and interval-valued hesitant fuzzy sets. Inf Sci (Ny) 2013;240:129–144. [CrossRef]

[32] Mousavi S, Bahreininejad A, Musa N, Yusof F. A modified particle swarm optimization for solving the integrated location and inventory control problems in a two-echelon supply chain network. J Intell Manuf 2017;28:191–206. [CrossRef]

[33] Tille M, Dumont A. Methods of multicriteria decision analysis within the road projects like an element of the sustainability. Swiss Transport Research Conference, Monte Verità / Ascona, March 19–21, 2003. p. 1–49.

[34] Roy B. Multicriteria Methodology Goes Decision Aiding. Berlin: Kluwer Academic Publishers; 1996. [CrossRef]

[35] Vami, B. Proiect opportunity study on integrated use of the razgah nepheline ores. Iran by metallurgical processing into Alumina Cement, sodium carbonate and potash, final report , Volume, general explanatory note,1992.

[36] Afshari F, Zentenno T, Ronquillo L, Wiebbe S. Surgical outcomes in lesional and non-lesional epilepsy: A systematic review and meta-analysis. Epilepsy Res 2010;89:310–8. [CrossRef]