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Applying the Hierarchical Gray Relational Clustering Method to Municipal Water Use in Turkey

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ABSTRACT

This study aims to compare the municipal water distribution performance and classify the municipal water distribution systems in the provinces of Turkey using the Gray Relational Hierarchical clustering method for both 2006 and 2016. A correlation analysis was used to determine the variables affecting the distributed water. The Hierarchical gray clusters and the changes during the decade are presented with spatial distribution maps using statistically significant variables. Consequently, the findings reveal that the municipalities of Istanbul, Izmir, Bursa, Gaziantep, and Kocaeli managed water distribution effectively, whereas the municipalities of Konya, Şanlıurfa, Diyarbakır, Samsun, Trabzon, and Sakarya managed it poorly.

Keywords: Climate change, municipal water use, water management, sustainability.

1. INTRODUCTION

The importance of water distribution systems has increased gradually in recent years due to direct or indirect factors such as increasing population, water consumption, industrialization, seasonal conditions, and climate change [1, 2]. Currently, a critical concern is to ensure urban water sustainability and to improve the decision-making processes for sustainable development planning [3]. Water distribution modelling is used to predict what the future water consumption and requirements depend on, based on various socio-economic and

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climatic factors that affect water use. Domestic water consumption is the most significant component of municipal water use, and precise estimation techniques are required to accurately predict future water needs with appropriate methodologies [4].

Gray Relational Analysis (GRA) is a method that has been used recently in cases where the data set is small and contains insufficient information. Missing and insufficient information is very common in hydrological data in water research [5]. GRA was initially developed to be used for interval analysis in cases of insufficient information [6, 7]. Deng [8-10], on the other hand, produced the gray system theory, which can formally deal with small samples using fuzziness. GRA and its simple concept can be observed in many analyses that exhibit excellent performance when there is a small sample and insufficient information. In this study, Hierarchical Gray Relation Clustering (HGRC), a combination of GRA and Hierarchical Cluster Analysis, is applied to the distribution water model.

This study aims to compare the water distribution performance of the municipalities for 2006 and 2016 and to classify the provinces using HGRC. One of the main goals of the study is to use the HGRC method to determine the variables and regions that affect municipal water distribution.

This study is structured as follows. First, the scientific literature on water distribution systems and the basis of applying the method to municipal water distribution models is reviewed. Then, the study area and data are presented, followed by a discussion of the calculation procedure for hierarchical relation gray clustering analysis. Next, HGRC is applied to the variables that explain the distributed water, and the results are visualized with three spatial distribution maps. The cluster results in this study are then discussed, and the changes in the variables affecting the water distribution during the decade of study are determined. Additionally, the contribution of this analysis to water distribution management is discussed. Finally, suggestions are made for future steps by determining the levels of water management for the provinces and regions.

2. STUDY AREA AND DATA

Turkey is a country with a total geographical area of 780,000 km², comprising 81 provinces. Its municipalities are units with a population of over 2000. According to UN estimates, Turkey has a population of about 84 million, and 75.7% of its population lives in urban centers. Municipal water statistics are published by Turkstat [11] every two years and cover Turkey and its provinces. Therefore, instead of using a time series method, data from this source are analyzed separately for both 2006 and 2016 to illustrate changes, and the variables used are presented in Table 1. Municipal water statistics have been published in Turkey since 2003 (biennially after 2004) and the two years with complete data are 2006 and 2016. The study includes the annual data for 81 provinces.

Previous studies have shown that streamflow has a significant effect on the main variables (river, dam, lake, well, etc.) affecting water distribution [12, 13]. The streamflow is not included in this study due to the lack of data and discontinuities.

The variables used in the study and their correlations are presented in Table 1. The analysis in this study was concluded on the basis of 81 provinces, reflecting the general characteristics of the data, and the total values for Turkey are displayed in Table 1.

The amount of distributed water is the most convenient variable to represent the municipal water distribution system in Turkey. Therefore, the aspects that explain the amount of distributed water are also described in the water distribution system. Existing literature has revealed that there are many variables that directly or indirectly affect the amount of water distributed [14-16]. Correlation analysis was thus used to determine whether all the data received from Turkstat [11] are related to the amount of water distributed. These variables, their definitions, and the correlation table are presented in Table 1. As can be observed in this table, the variables that have a significant correlation with the amount of water distributed are TNM, RPSD, NS, WIN, TAWA, LAKE, RIV, DAM, WAPC, NTP, TC, and AWT, while the variables whose correlations with the AWD are insignificant are TNM, SPR, and WELL. The variables that were not significant in the correlation analysis were removed, and only the significant variables were used in the HGRC analysis.

Table 1 - Variables used in the study (with descriptives for 2006 and 2016) and their correlations.

Municipal Water Use Indicators, 2006-2016																
Variable Codes		Definition of Variables						2006				2016				
AWD		Amount of water distributed (m³)						2375043				3732875				
TNM		Total number of municipalities						3225				1397				
TMP		Total municipal population						58581515				74911343				
RPSD		Rate of the population served by drinking water treatment plants in total municipal population (%)						41				55				
NS		Number of subscribers						19358951				27486201				
WIN		Water income (Turkish Lira)						3096377755				14217798093				
TAWA		Total amount of water abstracted (Thousand m³)						5163500				5838561				
SPR		Spring (Thousand m³)						1380057				1000205				
LAKE		Lake (Thousand m³)						232621				104354				
RIV		River (Thousand m³)						305271				552624				
DAM		Dam (Thousand m³)						1843736				2618225				
WELL		Well (Thousand m³)						1401815				1563154				
WAPC		Water abstraction per capita in municipalities (liters/capita-day)						245				217				
NTP		Total number of treatment plants						139				519				
TC		Total capacity						3994060				6592863				
AWT		The total amount of water treated						2426639				3350389				
Source: Turkish Statistical Institute [21]																
AWD		TN M	TM P	RPS D	NS	WI N	TAW A	SPR	LAK E	RIV	DA M	WELL	WAP C	NT P	TC	AW T
	Correlation Coefficient	0.20	0.99	0.37	0.99	0.91	0.98	0.01	0.44	0.84	0.92	0.25	-0.11	0.41	0.90	0.95
	P - Value	p ≤ 0.05	p > 0.05					p ≤ 0.05	p > 0.05			p ≤ 0.05	p > 0.05			

HGRC analysis was then applied to examine the municipal water distribution system and yearly changing state of water management for all provinces in Turkey. Excel for HGRC was used to perform the analysis. Variables found to be significant through the correlation analysis in explaining the amount of water distributed were used in HGRC, and their spatial distribution maps are presented with the help of maps.

3. METHODS

3.1. Hierarchical Gray Relational Clustering

Deng [17] first proposed the gray system theory in 1982. Gray means that a system provides partially known and partially unknown information; thus, it basically is an attempt to model uncertainty. Gray systems theory is used to examine systems that analyze relationships between systems, make predictions and decisions, and create models [18]. In 1987, Deng [19] first proposed gray cluster analysis (GCA). A new method has been developed known as gray relational clustering (GRC), which combines gray relational analysis and clustering to capture the complex factors and mixed structure in gray cluster analysis. The GRC method cannot use a tree diagram for classification without recalculation [20]. Hence, Wu et al. [20] combined the GRC method with hierarchical cluster analysis.

The calculation procedure for hierarchical gray relation clustering analysis proceeds as follows for the data set used in our study.

Let x_{jk} specify the k th coordinate axis of the j th province, and let x_j represent the indices for the j th province. It may be written as follows:

$$x_j = (x_{j1}, x_{j2}) \quad (1)$$

Step 1. Compute the difference series:

$$\Delta_{ij}(k) = |x_i(k) - x_j(k)| \quad (2)$$

Step 2. Compute the minimum and maximum of the difference series:

$$\begin{aligned} \Delta_{\max} &= \max_{\forall j \in I} \max_{\forall k} |x_i(k) - x_j(k)| \\ \Delta_{\min} &= \min_{\forall j \in I} \min_{\forall k} |x_i(k) - x_j(k)| \end{aligned} \quad (3)$$

Step 3. Compute the gray relation coefficient:

$$\gamma(x_i(k), x_j(k)) = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_{ij}(k) + \zeta \Delta_{\max}} \quad \zeta = 0.1 \quad i = 1, 2, \dots, m, \quad (4)$$

The value of ζ is used to expand or compress the range of the gray relation coefficient; it is called the distinguishing coefficient and represents the significance of Δ_{\max} [21, 22]. If the

difference between the analyzed data is large, the ζ value should be determined to be close to 0 [23]. Therefore, the value of ζ is taken as 0.1.

Step 4. Compute the gray relation grade to develop the matrix $R(R=(\Gamma_{ij}), i, j=1, 2, \dots, m)$:

$$\Gamma_{ij} = \frac{1}{k} \sum_{k=1}^k \gamma(x_i(k), x_j(k)) \quad i=1, 2, \dots, m, j \in i, k=1, 2 \quad (5)$$

Step 5. Develop the matrix $G(g_{ij} = (\Gamma_{ij} + \Gamma_{ij}) / 2)$ (known as the gray similar matrix, this is the crucial output for gray relational clustering):

$$G = [g_{ij}], \quad i, j = 1, 2, \dots, m \quad (6)$$

Step 6. Determine the two points (province) of the most near.

Step 7. Repeat steps 1–6 until all data are in one cluster [20].

4. RESULTS AND DISCUSSION

4.1. Hierarchical Gray Relational Clustering for 2006 and 2016 and Changes during the Ten-Year Period

In this study, the distances of the cluster centers to each other are calculated. Provinces are then divided into five classes to demonstrate the data's general structure and facilitate interpretation. As a result of the evaluations made based on the variables, clusters are named according to their characteristics from very poor to very high for both 2006 and 2016.

When the results of the HGRC analysis were evaluated for 2006 (Figure 2), Istanbul, which is Turkey's most populous city, emerged as the city with the best water management. Furthermore, it is notable that the provinces neighboring Istanbul were at poor and very poor levels. While the capital Ankara had medium-level management, the water management level of Izmir, which is another high-population province, was very poor. It was observed that Konya, Eskişehir, and Antalya followed a well-distributed water policy for 2006 in the Central Anatolia region. The provinces in the eastern and southeastern regions apart from Şanlıurfa and Diyarbakır showed a poor level, and only the province of Balıkesir performed well in the Aegean region.

Turning to 2016 (Figure 3), while Istanbul maintains a well-distributed water management system, it may be observed that Ankara, the capital city, remained at the same level. Contrary to its poor level in 2006, Izmir improved to a medium level in 2016, while its surrounding provinces dropped to a very poor level. It can be clearly seen from Figure 3 that there were severe problems in distributed water management system in the Mediterranean and Black Sea coastal regions. While Gaziantep continued to have a high standard of water management approach, the management approach of the other municipalities in the Southeastern Anatolia region in 2016 had deteriorated. It was determined that the distributed water management of Turkey had deteriorated in 2016 compared to 2006.

Figure 4 shows how the management of the distributed water changed over 10 years. This figure illustrates the general structure of the long-term change result of the HGRC spatial distribution maps depicted earlier in Figures 2 and 3. It demonstrates that Izmir, Bursa, Kocaeli, and Gaziantep Provinces displayed positive developments in distributed water management over the decade. The Aegean region, on the other hand, is the region where water management generally worsened. It was also determined that in the Central Anatolia region, Eskişehir and Konya managed to distribute water poorly. Figure 4 shows that in the Eastern Anatolian region, water distribution in Erzurum, Şanlıurfa, and Diyarbakır has deteriorated. On the other hand, the provinces colored white showed no change in distributed water management level between 2006 and 2016.



Figure 2 - Municipal water distribution model results for 2006 according to Hierarchical Gray Relational Clustering



Figure 3 - Municipal water distribution model results for 2016 according to Hierarchical Gray Relational Clustering

Migration was one of the factors in Şanlıurfa's deterioration in 2016, which had a good water management system in 2006. A reverse trend can be observed in Gaziantep [26]. Additionally, the province of Konya was one of the municipalities that witnessed the greatest groundwater withdrawal, which was responsible for the formation of a large number of sinkholes and the disappearance of groundwater resources [27]. For the surrounding provinces and the Central Anatolian region, this problem raises the problem of water scarcity, and this problem will worsen in the future if the distributed water is not managed well.

Most importantly, this study revealed that the distributed water management system was in a poor condition and that the number of provinces showing deterioration have been increasing.

From the study results, we note that the efficient management of the municipal water distribution is highly dependent on the environmental policy of the distributed water management, and this dependence reveals the necessity for an integrated water management system. Provinces sharing the same water basin and its source should thus follow a common distributed water policy. The results of this study will have a significant impact on research and analysis of distributed water system management in Turkey, which is an important contribution, due to the use of the Gray Relational Hierarchical clustering method.

Conflicts of Interest

The authors declare no conflicts of interest.

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