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From traditional density to compaction index: the example of Van province

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ABSTRACT

Due to the spread of epidemic diseases such as Covid 19, through the mobility and interaction of infected people, rates of transmission, infection and death are even higher in urban areas with higher density. Density is a measurement obtained by dividing the number of people by the area; we can call it "Traditional Density". However, traditional density alone is not enough for cities that are growing and developing day by day and becoming increasingly complex. In the study, the average compaction index for Van province was calculated as 3788.67 person/km^2 (one person in Van province lives with 3788.67 persons in one square kilometer). According to the traditional population density, there are 57.69 people per square kilometer in Van throughout the province. While the traditional density for the city center of Van is 1368.39 person/km^2, this value is 7164.92 person/km^2 according to the compaction index. The Compaction Index, weighted density by population, is an alternative to the traditional density scale, which is the total population divided by the total area. The compaction index is the average of the densities of the subareas of a larger area weighted by the populations of the subareas. Urban sprawl is directly related to compaction, and the selection of the appropriate density scale is crucial for a developing city. Although both types of density are positively related to the size of urban areas, the compaction index takes a different density aspect compared to conventional density. Compaction index; It is a scale that should be considered in situations such as health, transportation, urban life, education, fire, natural disaster management and coordination. Therefore, it is a useful alternative in most cases.

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1 Introduction

Population Density is one of the most fundamental characteristics for an urban area. The basic idea of Population Density refers to the number of people per area. Traditional Density is a measurement obtained by dividing the number of people by the area. However, traditional density alone is not sufficient for cities that are growing and developing day by day and becoming increasingly complex. Population-weighted density is more explanatory and guiding in expressing the compaction of an urban area. The Compaction Index is an alternative density scale, commonly referred to as population-weighted density, which is an alternative to the traditional density, consisting of the average of the densities of small sub-areas weighted by the populations of the whole subregional areas. It is a scale that reflects the average density of urban area populations, whose densities are weighted according to sub-area populations, within their own sub-areas. Population-weighted density has been used in a variety of ways. The simplest is that it is often used as a descriptive intensity scale compared to conventional intensity.

Craig [7] examined the conventional density and compaction index (including the geometric mean) for the whole of Great Britain using sub-areas of different sizes. In a subsequent article, he compared traditional and population-weighted densities in regions and counties of England and Wales according to Craig [8].

Dorling and Atkins [11] presented more detailed and up-to-date results on the subject.

Coombes and Raybould [6] evaluated the metrics of settlement patterns used to allocate funds to local authorities in England in the context of policymaking. They then evaluated additional measures, including population-weighted

density, looking for relationships to improve their proposed indexes.

Barnes [2] used both population- and employment-weighted densities as scales of land use when examining the impact on various aspects of travel behavior in the United States, taking into account studies of transportation and the environment. In this study, the author defined the population-weighted density scale as a "new" scale, which he named "perceived density".
Castro [5] evaluated both traditional and population-weighted density relationships, taking into account regional income convergence in Europe. He examined how economic factors affect crowding.

Lee and Lee [15] showed in their study that higher population-weighted density is associated with larger reductions in carbon dioxide greenhouse gas emissions from domestic travel and residential energy use in the one hundred and twenty-five largest urbanized regions of the United States. In addition, population-weighted density was calculated using block group data. "We use this alternative measure because it better captures the population density that typical residents of an urban area experience in their daily lives than traditional density measures," the authors explained.
Bradford [4] and Davies [9] view the traditional density scale as an "irrational" scale of density.

According to Avent [1], Bradford [4], the compaction Index is a more meaningful or informative density scale than traditional density.

According to Florida Richard [13], the Compaction Index is the best way to measure density.

The compaction index is a valid alternative to traditional density, which captures aspects that the other scale does not [16].

Since the population shapes the economic, social, health and physical conditions of a city, the most important element that makes up the city is the demographic element [10].

According to Başer [3], Pandemics are spread through the movement of infected people and the interaction between them, and these interactions occur more frequently where the Compaction index is high. As such, it has been associated with higher rates of transmission, infection and death in urban areas where density is higher during pandemics such as Covid-19. According to the traditional density, while there are 109 people per square kilometer in Turkey, this value rises to 3,868 people according to the compaction index. On average, a person in Turkey lives with 3,868 people in one square kilometer.

The Organization for Economic Cooperation and Development (OECD), which has been working on rural areas since 1988, defines rural areas according to arithmetic population density criteria by emphasizing the human-space relationship. The OECD has defined the amount of population per square kilometer as a determining criterion, and if this amount is less than 150 people, it defines that settlement as rural. The European Union (EU) uses this criterion to facilitate comparisons between countries [17].

An incorrect perception has been created that the geographical area of the metropolitan municipalities within the borders of the provinces they are located in is entirely the city area and that rural areas are not included in this area.

Rural areas; These are areas with a unique lifestyle, where economic activities such as agriculture, animal husbandry, hunting, and forestry make a living, the population is low, and natural geographical conditions are dominant, apart from urban settlements. The European Commission advocates that rural areas should not be evaluated with one-dimensional criteria such as population density, agriculture and natural resources [14].

In this study, all neighborhoods of Van province were specified in accordance with both various satellite maps (Google Earth) images and international density criteria used in the determination of urban and rural areas in order to obtain better results and to minimize the impact of the compaction index on vacant lands far from the living area.

1.1. Van province

Van Province is located in the Eastern Anatolia Region and is the 19th province of Turkey, the largest in this region in terms of population. As of the end of 2020, its population is 1 149 342 people (TUIK, 2020). It is bordered by Ağrı in the north, Bitlis in the west, Siirt in the southwest, Hakkari provinces in the south, and Iran in the east. On the shores of Lake Van, the largest closed basin of Anatolia; It is a settlement center with fertile soils, abundant streams and very favorable climatic conditions. It is one of the oldest inhabited cities in the world.

Figure 1. *Van province and districts map [12].*

As of the end of 2020, the total area of Van (areas of 691 neighborhoods) with a population of 1 149 342 people is 19 922 square kilometers. While the population growth rate is

1.11% compared to the previous year, the traditional population density is 58. The districts with the highest and lowest population growth rates are İpekyolu (2.60%) and Bahçesaray (-2.19%).

1.2. Districts of Van province

According to the data of the Turkish Statistical Institute (TUIK) [18] on February 04, 2021, there are 13 districts of the province of Van and a total of 691 neighborhoods in these districts. Of the 13 districts, İpekyolu, Edremit and Tusba are central districts and the others are provincial districts.

Table 1. *Numerical information about the population of Van province and its districts [18]*

District	Population 2019	Population 2020	Difference	P.Growth (%)	Num. of Neigh.	Area (km^2)	Density (D)
Bahçesaray	14 701	14 379	-322	-2.19	20	372	39
Başkale	48 838	49 850	1.012	2.07	68	2618	19
Çaldıran	62 530	63 133	603	0.96	70	1384	46
Çatak	20 592	20 337	-255	-1.24	33	1844	11
Edremit	127 505	128 557	1 052	0.83	30	353	364
Erciş	175 108	176 680	1 572	0.9	101	1854	95
Gevaş	28 235	28 242	7	0.02	40	1475	19
Gürpınar	34 393	34 956	563	1.64	79	3845	9
İpekyolu	326 007	334 470	8 463	2.6	50	970	345
Muradiye	50 206	50 247	41	0.08	48	918	55
Özalp	65 296	65 495	199	0.3	58	1417	46
Saray	20 498	20 843	345	1.68	27	917	23
Tuşba	162 848	162 153	-695	-0.43	67	1956	83
Van	1 136 757	1 149 342	12 585	1.11	691	19 922	58

2. Materials and methods

In this study, it is aimed to arrive at the concept of Compaction Index from agglomerations in sub-areas by defining densities and showing that the compaction index is an alternative to the traditional density. The Compaction Index is an indicator of the Compaction of a settlement and shows how many people actively interact with a person in a square kilometer area. For this reason, it offers very different values from the traditional population density.

TurkStat presents the population data of the provinces that have been granted metropolitan status after 2012, at the neighborhood level, within the scope of the Address Based Population Registration System (ADNKS). In this study, firstly, the population data of Van province for the year 2020 were obtained from TUIK at the neighborhood level. Likewise, the surface measurements of all neighborhoods were taken from the relevant institutions (Municipalities) and various websites using Google Earth. Traditional population densities were calculated for each district and neighborhood in Van. Then, the density indices of the settlements were calculated with the traditional population density data.

The data collected by the above methods were written using the Microsoft Office program “Microsoft Excel” software, and the neighborhood population was written in one column and the neighborhood areas in the other column for each district. Data were transferred using the same program and traditional population densities and compaction indices of the neighborhoods were calculated.

2.1. Traditional population density

The density (D) of an urban area (referred to as "conventional density" to distinguish it from population-weighted density) is calculated by dividing the total population (P) by the total area (A) in Eqn. 2.1.

$$D = \frac{P}{A} \tag{2.1}$$

However, this generally does not give an ideal result for urban sprawl or urban compaction as it does not take into account unused land. Since the traditional density is not affected by the sub-areas, that is, it takes the average directly without distinguishing the most congested and rarest neighborhoods.

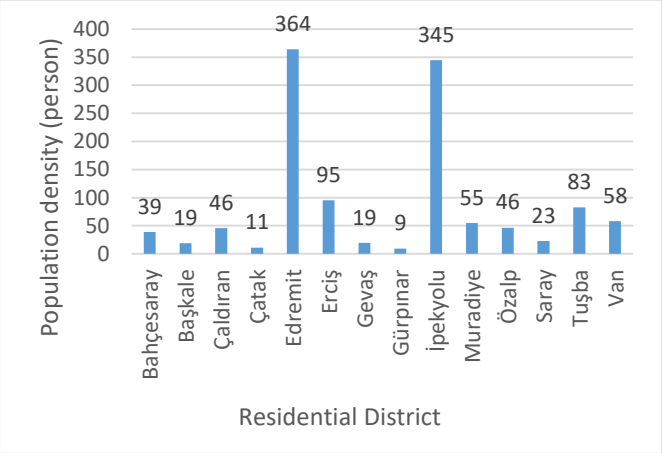

Figure 2. *Traditional population densities of Van province districts*

As can be seen from the above, the district with the highest traditional population density is Edremit, while the district with the lowest density is Gürpınar. It is clear that Edremit and İpekyolu districts are very dense compared to other districts.

2.2. Compaction index

The size and configuration of the subdomains used in calculating the compaction index have important implications for the values obtained and their interpretation. The result is

to show what the 'Compaction Index' reached means for urban development.

This section presents the origin of the relationship between the Compaction index and conventional density. The density of an urban area is found by dividing the traditional density (D) by the total population (P) by the total area (A) as in Eqn. 2.2:

$$D = \frac{P}{A} \tag{2.2}$$

By definition, total population and total census area (or other sub-area) of area are population and areas:

$$P = \sum Pi \tag{2.3}$$

$$A = \sum ai \tag{2.4}$$

Pi is the population of region *i* and *ai* is the area of region *i*. *di* is the traditional population density of region *i*. The traditional population density of any region *i* is given in Eqn. 2.5.

$$d_i = \frac{P_i}{a_i} \tag{2.5}$$

The conventional density, which also applies to comparisons with the compaction index, is the average of the densities of the census regions (or other sub-areas) weighted by area, as shown in Eqn. 2.6.

$$D = \frac{1}{A}\sum a_i\, d_i = \frac{1}{A}\sum p_i = \frac{P}{A} \tag{2.6}$$

Therefore, conventional density is area-weighted density as opposed to compaction index.

The compaction index C_i is the average of the census densities weighted by the population of the areas. The compaction index is calculated as in Eqn. 2.7.

$$C_i = \frac{1}{P}\sum p_i\, d_i \tag{2.7}$$

We can now show that the difference between the Compaction index and conventional density is a function of the density variance between census areas and conventional density.

Calculating variance requires the average density across areas. In order to calculate both the average density and the traditional density variance, it is necessary to weigh the regions according to their areas as in Eqn. 2.8.

$$\bar{D} = \frac{1}{A}\sum a_i d_i = \frac{1}{A}\sum p_i = D \tag{2.8}$$

Density variance S_D^2 is the weighted sum of the squares of the difference of the area densities and the mean intensity divided by the total area and is given as in Eqn. 2.9.

$$S_D^2 = \frac{1}{A}\sum di\ (d_i - \bar{D})^2 \tag{2.9}$$

We should note that we do not need to do the equivalent of (n - 1) correction for the weighted variance, since we have information about all domains and not just one sample.

Calculation of variance is done by squaring the binomial term in Parenthesis in Eqn. 2.9, dividing the sum, factoring the constants from the sums, and substituting the conventional density for the average density:

$$S_D^2 = \frac{1}{A}\left(\sum a_i\ d_i^2 - 2D\sum a_i d_i + D^2\sum a_i\right) \tag{2.10}$$

In Eqn. 2.10, the sum of the region's area multiplied by the density in the second term is the sum of the region's populations, the total population P equals the area times the density, A*D. Transforming this result together with the total area for the sum of the regional areas in the third term gives Eqn. 2.11.

$$S_D^2 = \frac{1}{A}\left(\sum a_i d_i^2 - 2AD^2 + AD^2\right) = \frac{1}{A}\left(\sum a_i d_i^2 - AD^2\right) = \frac{1}{A}\sum a_i d_i^2 - D^2 \tag{2.11}$$

To show that this operation is related to the difference between the Compression index and density if we substitute $p_i/a_i = d_i$ for a d_i in the first term in Eqn. 2.11, we get 'Eq. 2.12'.

$$S_D^2 = \frac{1}{A}\sum a_i d_i\ \left(\frac{P_i}{a_i}\right) - D^2 = \frac{1}{A}\sum d_i p_i - D^2 \tag{2.12}$$

We can multiply the first term in Eqn. 2.13 by D/(D) and substitute P for AD,

$$S_D^2 = \frac{D}{AD}\sum d_i p_i - D^2 = \frac{D}{P}\sum d_i p_i\ D^2 \tag{2.13}$$

If factor D is taken from both terms, Eqn. 2.14 is obtained.

$$S_D^2 = D\left(\frac{1}{P}\sum d_i p_i - D\right) \tag{2.14}$$

The first term in parentheses is the formula for the Compaction index, this term is replaced by C_i to get Eqn. 2.15.

$$S_D^2 = D(C_i - D) \tag{2.15}$$

Thus, as seen in Eqn. 2.15, the variance in density is the difference between the compaction index and the conventional density multiplied by the conventional density. Therefore, the difference between compaction index density and conventional density is shown as in. 2.16.

$$C_i - D = \frac{S_D^2}{D} \tag{2.16}$$

This is obtained by dividing the density variance by the conventional density. As a result, the compaction index is the

sum of the traditional density and the ratio of the variance to the conventional density, as shown in Eqn. 2.17.

$$C_i = D + \frac{S_D^2}{D} \quad (2.17)$$

3. Results

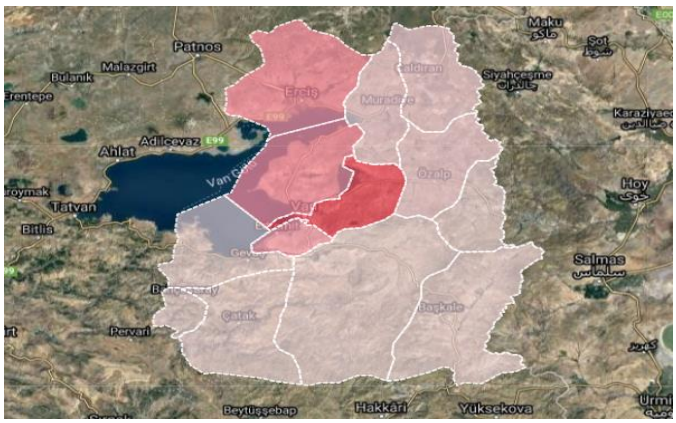

Figure 3. *District boundaries of Van province [12].*

The total population of Van province is 1 149 340 and its total area is 19 921.41 square kilometers. 63% of its population resides in urban areas and 37% in rural areas. The urban area constitutes 4% of the total area. While the most populous district of Van is the central İpekyolu district with 334 470 people, the district with the least population is Bahçesaray with 14 401 people.

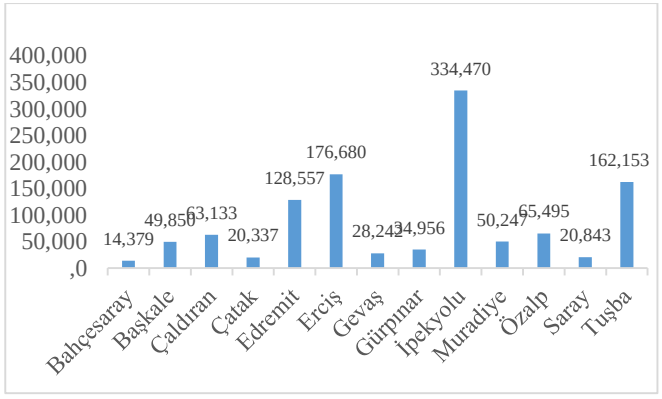

Figure 4. *The population of districts of Van province [18] (2020).*

While it is 57.69 per square kilometer throughout the province of Van, this value decreases to 3 788.67 per square kilometer with compaction.

The 3 central districts within the city center are İpekyolu, Edremit and Tusba districts. The total number of these three central neighborhoods is 548,590, and their area is 400.90 square kilometers.

There is a provincial town where 10 people outside the central districts of Van province are known. These districts are Bahçesaray, Başkale, Çaldıran, Çatak, Erciş, Gevaş, Gürpınar, Muradiye, Özalp and Saray districts.

Table 2. Traditional density and compaction indices of Van province and its districts

District	Traditional Density	Compaction Index	Population	Area(km^2)	Ci/D Ratio
Bahçesaray	39	55.82	14 379	372	1,43
Başkale	19	176.03	49 850	2618	9,26
Çaldıran	46	188.55	63 133	1384	9,26
Çatak	11	288.25	20 337	1844	4,10
Edremit	364	2 078.33	128 557	353	26,20
Erciş	95	1 894.41	176 680	1854	19,94
Gevaş	19	268.96	28 242	1475	14,16
Gürpınar	9	50.33	34 956	3845	5,59
İpekyolu	345	9350.78	334 470	970	27,10
Muradiye	55	257.55	50 247	918	4,68
Özalp	46	431.86	65 495	1417	9,39
Saray	23	79.05	20 843	917	3,44
Tuşba	83	3 363.86	162 153	1956	40,53
Van	58	3788.67	1 149 342	19 922	65,32

İpekyolu district, which is one of the central districts of Van, is both the most crowded and the most congested district of the city. According to the traditional population density in İpekyolu district, 344.81 people per square kilometer area, while according to the compaction index of the district, an average person lives with 9 350 people in a square kilometer area.
The total population of Tusba district is 162 151 and its area is 1955. 90 square kilometers.

According to the traditional population density in Tusba district, 82.90 people per square kilometer area, while according to the compaction index, one person in Tusba district lives with 3 363.86 people per square kilometer.

Edremit is the third crowded and last central district of Van. The total population of Edremit district is 128 557 people and its area is 353.17 square kilometers. According to the traditional population density in Edremit district, while 364.01 people per square kilometer area, this value shows that there are 2 078.33 people per square kilometer according to the compaction index. Its total population is 14 379 people and its area is 370.98 square kilometers. According to the traditional population density of the district, 38.76 people per square kilometer area, while according to the compaction index, there are 55.82 people per square kilometer throughout the county.

The population of Başkale district, which ranks second among the provincial districts of Van province in terms of surface area, is 49 850 people, and its area is 2 618.3 square kilometers. While

the traditional population density of Başkale district is 19.04 people per square kilometer area. According to this value compaction index, one person per square kilometer corresponds to 176.03 people.

The total population of Çaldıran District, which is a provincial district of Van province, is 63 133 and its area is 1384.37 square kilometers. The traditional population density of Çaldıran; while there are 45.60 people per square kilometer area, according to the compaction index, 1 person lives with 188.55 people in a square kilometer area.

Çatak district is a small town with a narrow settlement area on the river bed. The total population is 20 337 people and its total area is 1 843.65 square kilometers. The traditional population density of the Çatak district; while there are 11.03 people per square kilometer, according to the compaction index, one person lives with 288.25 people per square kilometer.

Erciş, the most populous district of the provincial districts of Van, has a total population of 176 680 people and an area of 1853,949 square kilometers. According to the traditional population density, 95.30 people per square kilometer in Erciş district, according to the central compaction index, one person lives with 1894.41 people.

Gevaş, a provincial town on the edge of Lake Van, has a population of 28242 people and an area of 1 474.88 square kilometers. Traditional population density of Gevaş district; 19.15 people per square kilometer area. According to the compaction index, one person in a square kilometer area in Gevaş district lives with 268.96 people.

The population of Gürpınar, the provincial district with the largest area in Turkey, is 34 956 people and this area is 3 844.69 square kilometers. The traditional population density of Gürpınar district; There are 9.09 people per square kilometer area. According to this value compaction index, one person lives with 50.33 people per square kilometer.

The total population of Muradiye district is 50 247 people and its total area is 917.51 square kilometers. While the traditional population density of Muradiye district is 54.76 people per square kilometer, this value is 257.55 people per square kilometer according to the compaction index.

The total population of Özalp district is 65 495 people and its total area is 1417.46 square kilometers. In Özalp district, according to the traditional population density, 46.21 people per square kilometer area, while this value is 431.86 people per square kilometer according to the compaction index.

The population of Saray district is 20 843 people. Its total area is 916.53 square kilometers. According to the traditional population density of Saray district, 22.74 people per square kilometer area, while this value increases to 79.05 people according to the compaction index.

4. Results and discussion

Table 3. *Traditional population densities of Van province by years (2007-2020)*

2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
51	52	53	54	53	55	55	56	57	57	57	58	59	60

Mean = 55

The Compaction Index is a Different, alternative density scale. As shown, population-weighted density is equal to the conventional density and the density variance in the sub-areas used for its calculation, divided by the conventional density, which is simply the total population divided by the total area. Conventional density is also equivalent to the area-weighted density calculated across any sub-area set.

Table 4. *Comparison of compaction index, population and population density values*

District	Compaction Index	Population Ranking	Popilation Density Ranking
İpekyolu	9 350.78	2	2
Van (overall)	3 788.67	1	5
Tuşba	3 363.86	4	4
Edremit	2 078.33	5	1
Erciş	1 894.41	3	3
Özalp	431.86	6	7
Çatak	288.25	13	13
Gevaş	268.96	11	11
Muradiye	257.55	8	6
Çaldıran	188.55	7	8
Başkale	176.83	9	12
Saray	79.05	12	10
Bahçesaray	55.82	14	9
Gürpınar	50.33	10	14

While 57.69 people per 1 square kilometer area in Van province, the density generally applied throughout the province of Van, 3 788.67 people live in a square kilometer area according to the compaction zone. While the population census for the city center of Van is 1 368.39/km^2, this value is 7 164.92/km^2 according to the compaction data.

Ipekyolu district, which is in the 2nd place according to both the population amount and the population census, has been the most congested district of Van province. Edremit district ranks 5th in terms of compaction from a dense district until the census. We can better understand that the Çatak district is

in the last place with the 13th place in terms of both the population amount and the census, and the compaction demonstrations in the 6th place of the collision in the settlement. Preliminary preparations are made in the planning of all urban light contents.

It is located in an area that is a favorite of the crowds, gamers and closer than the eyes for its urban scales. This point of view is generally applied in general terms. Jam; related to health, life in education, education, fire, designing natural disasters. Although both types of density are positively correlated with the size of urban areas, the compaction index is more highly correlated than conventional density. The compaction index is not only related to the current size of an urban area, but also the size of the urban growth going back to past years.

To emphasize the point made in the introduction, the Compaction index takes a different density aspect compared to conventional density, it is a better density scale. For these reasons, it is a useful alternative in most situations.
According to the data obtained from TURKSTAT below [18], it is seen that the average population growth rate in Van province between 2007 and 2020 is 1.23% per year. According to these values, with the increase in the population of Van province, the compaction index will increase in the coming years.

Table 5. *Annual population growth rates in Van province by years (%) (2007-2020) [18]*

2007-2008	2008-2009	2009- 2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020
2.49	1.77	1.27	-1.25	2.84	1.71	1.43	1.00	0.35	0.61	1.51	1.15	1.10

Mean = %1.23

To other researchers; it can be suggested that they determine the relationship between the population growth rate and the compaction index, and make studies on the estimation and effects of the compaction index for the coming years.

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