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What is the best spatial interpolation technique for evaluating droughts?

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Abstract

Drought is a destructive phenomenon that negatively impacts the environment and socioeconomic aspects. Drought can be evaluated temporarily and spatially based on drought indices, such as Standardized Precipitation Index (SPI). Spatial evaluation of drought has been conducted in the literature using many spatial interpolation methods without mentioning the difference between these methods and their accuracy. This research paper aims to find the accuracy of using Inverse Distance Weighted (IDW) and Kriging methods in evaluating drought based on SPI. Monthly precipitation data from 21 stations in Istanbul were used, 16 stations were used for interpolation, and 5 stations were used for validation. The results showed that the IDW method has more extreme drought values, which means more conservative regarding drought analysis and monitoring than the Kriging method. However, IDW and Kriging have approximately the same correlation coefficient (0.6) with observed values. Also, the correlation between IDW and Kriging was about 0.8. Generally, for drought analysis and monitoring, IDW is more conservative and gives more extreme drought values. Subsequently, validating and using the most suitable method and more research about using interpolation methods in drought are suggested before using any interpolation method.

1. Introduction

Drought is a complicated phenomenon with many definitions, such as an environmental and ecological catastrophe, and has been monitored and evaluated by environmentalists, agriculturists, and hydrologists. Drought has a hugely destructive impact on the environment and socioeconomic aspects. Also, drought occurs in any climate and area and is related to a precipitation deficit in a specific period (Wilhite 2016). Drought is classified into four types. One of the most common droughts is metrological drought. The most crucial variable in this type of drought is precipitation, and to avoid and prevent the negative impacts of droughts, a comprehensive understanding of drought and its characteristics has a leading role. Subsequently, the first step is using drought indices for drought assessment and monitoring (Van Loon 2015).

Several drought indices have been developed, and each one of them has its methodology and variables. Some of these indices are the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al. 2010) and the Actual Precipitation Index (API) (Şen 2021). SPI is the most used drought index worldwide because of its simplicity. SPI depends only on one variable, which is precipitation. SPI is calculated for each metrological station (for a specific point), and the obtained results are used for a specific metrological station. Spatial interpolation is used to calculate and evaluate the spatial distribution of the SPI values over a specific study area like a city, country, or continent. Using spatial interpolation helps us measure the unknown values, produce maps, and improve the methodologies by validating data. The term interpolation estimates the unknown and non-observed values using the measurements of observed values at specific locations within the same location and area. Spatial interpolation converts the point observed data into surface data. The most common spatial interpolation techniques are: 1) Inverse distance weighted (IDW) and Kriging (Esri 2012).

In the literature, many articles evaluated the spatial distribution of drought indices using several methods without mentioning the accuracy and difference between these methods. Considering the importance of drought, and spatial evaluation of drought, this research is done to calculate the accuracy of IDW and Kriging methods. Also, to compare these spatial interpolation methods regarding drought analysis based on SPI. Istanbul is an ideal area for this research because of its large database (21 metrological stations), and covers considerable variations in terrain.

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2. Method

2.1. Data

To investigate the accuracy and compare the Kriging and IDW spatial methods in evaluating droughts based on SPI, the application is conducted for the monthly precipitation records between 2014 and 2020 from 21 metrological stations in Istanbul (MGM). 15 metrological stations were used to get the drought map, and 6 metrological stations were used as observed data to validate the obtaining results from spatial interpolation. All monthly precipitation data were checked for consistency and continuity. Table 1 summarizes the main information about metrological stations.

2.2. Standardized precipitation index (SPI):

The SPI method was developed in 1993 by Mc Kee et al. The precipitation data is fitted to a suitable probability density function (PDF), and the goodness-of-fit tests are controlled and checked by Kolmogorov-Simirnov and Chi-Square (Stephens 1970). The last step is the standardization of probabilities into normal PDFs. More information about SPI can be found in (McKee et al. 1993).

2.3. Spatial interpolation

Inverse Distance Weighted (IDW) is a non-statistical and spatial interpolation method. In the IDW method, the unknown values are calculated and affected more by observed points near the unknown points than points far away. The original / observed data are placed on a surface-distributed grid, and the interpolation procedure is done on this regular grid to generate a spatial map. The simplest form of IDW interpolation is linear interpolation. The quality of the resulting map depends on the validated input points.

Kriging is a geostatistical interpolation method. It estimates the unknown values using the known values and semivariograms. The Kriging procedure incorporates error measures and uncertainty while determining the unknown values (Loquin and Dubois 2010). Depending on the semivariogram, optimal weights are given to known values to calculate unknown values.

2.4. Validation data

One of the main objectives of this research is to find the accuracy of IDW and Kriging spatial interpolation methods, and it is done by using 6 metrological stations as observed data to validate and check the accuracy of resulting data. These stations are distributed over the study area and indicated with a star (*) in Table 1. The validation process is done using Pearson correlation analysis. Figure 1 shows the location of the metrological and validation stations in Istanbul.

3. Results

Drought was analyzed using SPI at a 3-month timescale. SPI was calculated between 2014 and 2020 over Istanbul using 16 metrological stations. The results showed that there is a huge variation in SPI values within this period. Moderate drought (-1.50 ≤ SPI ≤ -0.99), Severe drought (-2.00 ≤ SPI ≤ -1.49), and extreme drought (-2.00 > SPI) were noticed within the 7 years in the study area. Figure 2 shows the temporal evaluation of SPI3 from 2014 to 2020 using the average value of the stations for each month.

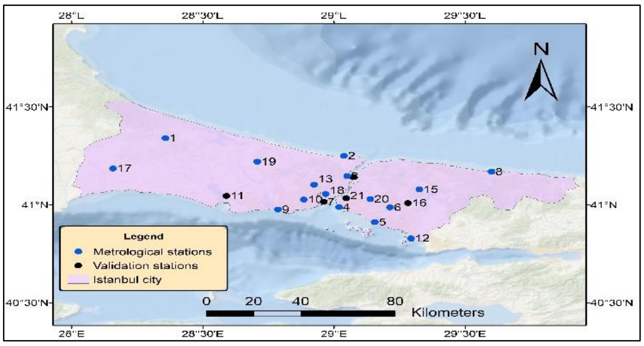

Figure 1. Location of metrological stations in Istanbul

Table 1. Geographical information of the metrological stations

#	Code	Name	Lat (N)	Long (E)
1	17047	ÇATALCA RADAR	41.34	28.36
2	17059	SARIYER/KUMKÖY	41.25	29.04
3	17061	SARIYER	41.15	29.05
4	17062	KADIKÖY RIHTIM	40.99	29.02
5	17064	İSTANBUL BÖLGE	40.91	29.16
6	17065	SAMANDIRA	40.99	29.21
7	17603	FATİH *	41.02	28.96
8	17610	ŞİLE	41.17	29.60
9	17636	FLORYA	40.98	28.79
10	17814	GÜNGÖREN	41.03	28.89
11	18099	BÜYÜKÇEKMECE *	41.05	28.59
12	18100	TUZLA	40.83	29.29
13	18101	EYÜPSULTAN	41.10	28.92
14	18396	BEYKOZ *	41.14	29.07
15	18397	ÇEKMEKÖY	41.08	29.33
16	18399	SANCAKTEPE *	41.01	29.28
17	18400	SİLİVRİ	41.19	28.16
18	18401	ŞİŞLİ	41.05	28.97
19	18402	ARNAVUTKÖY	41.22	28.71
20	18403	ÜMRANİYE	41.03	29.14
21	18404	ÜSKÜDAR *	41.03	29.05

* is the stations used as observed data to validate the results.

The calculated SPI3 values were used as Z values in the IDW and Kriging spatial interpolation methods. The interpolation was done for 4 selected months in 2020 (the last year of the period): March, June, September, and December, using the ArcMap program. Figure 3-Figure ***10*** show the SPI3 maps using IDW and Kriging methods for Mar, Jun, Sep, and Dec 2020.

The first result is that IDW has more extreme values than Kriging. For the same month and same data, the max. extreme value, according to IDW, is more than obtained from Kriging. For example, the most extreme value of SPI3 in Mar. 2020 based on IDW is -2.00, but based on Kriging, the SPI3 was -0.97. This can be attributed to the main concept of each method. IDW uses and keeps the observed values; otherwise, the Kriging method is a geostatistical method that changes the values regarding the created model. For all resulting maps, the

IDW gave more extreme SPI3 values. In literature, both IDW and Kriging were used as interpolation methods without mentioning the effect of using these methods on the resulting spatial maps.

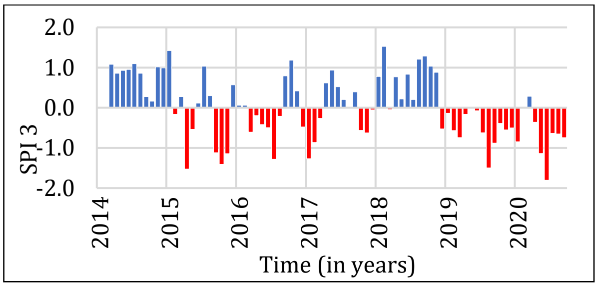

Figure 2. Temporal evaluation of SPI3 using the average value for all stations

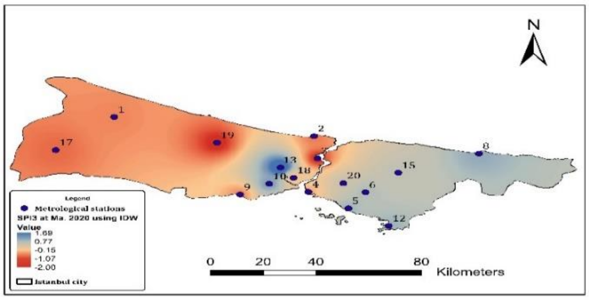

Figure 3. SPI3 in March 2020 using the IDW method

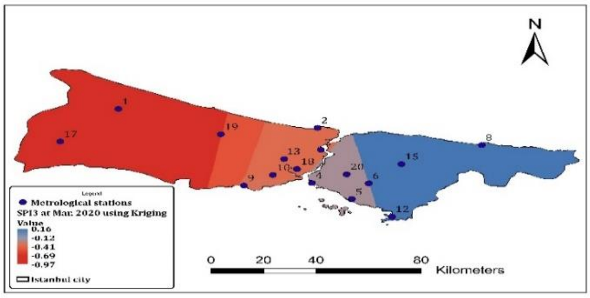

Figure 4. SPI3 in March 2020 using the Kriging method

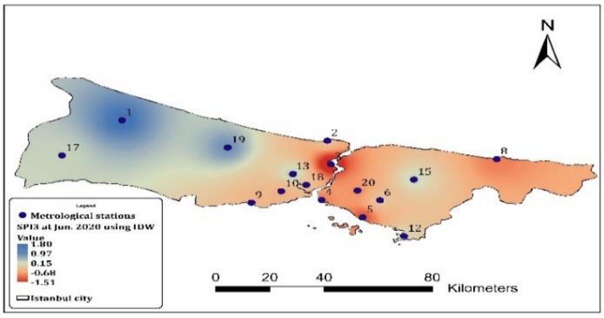

Figure 5. SPI3 in June 2020 using the IDW method

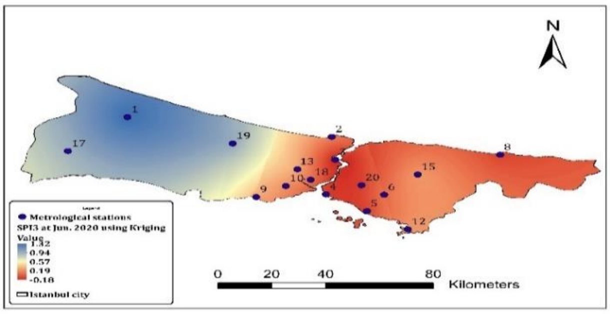

Figure 6. SPI3 in June 2020 using the Kriging method

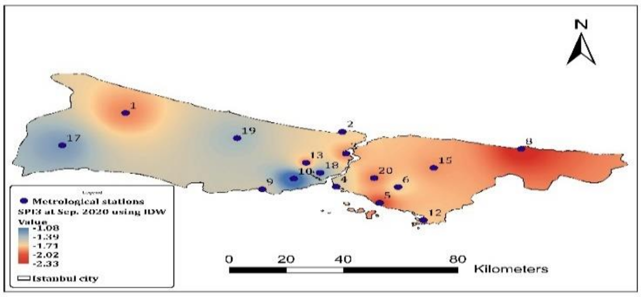

Figure 7. SPI3 in September 2020 using the IDW method

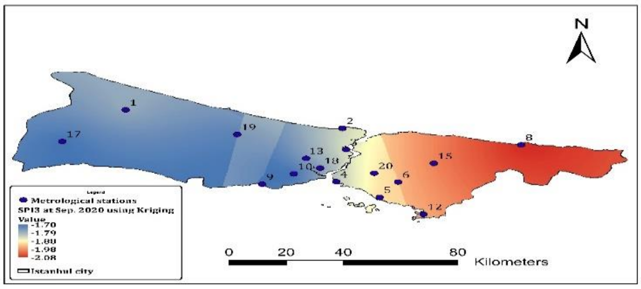

Figure 8. SPI3 in September 2020 using the Kriging method

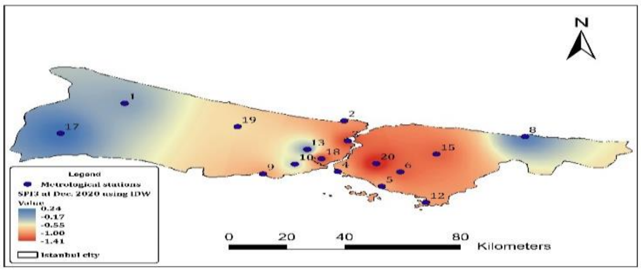

Figure 9. SPI3 in December 2020 using the IDW method

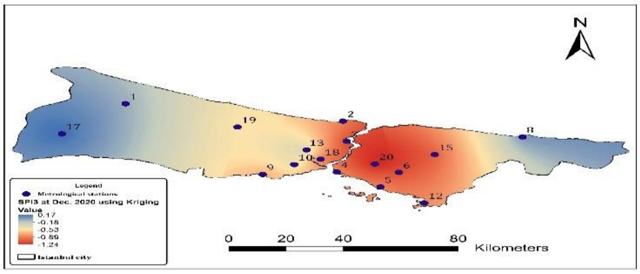

Figure 10. SPI3 in December 2020 using the Kriging method

To find the accuracy of the IDW and Kriging methods, 5 metrological stations were used as observed stations. Then, the Pearson correlation (R) was conducted between the interpolated values obtained from IDW and Kriging and observed values. Figure 11 shows the correlation between interpolated values from Kriging and observed values. The R was 0.6, which is a moderate positive relationship (Irhoumah et al. 2017). However, Figure 12 shows the correlation between interpolated values from IDW and observed values with R equal to 0.57, which is also a moderate positive relation.

Another novelty of this research paper is finding the difference between IDW and Kriging methods in evaluating droughts. Figure 13 shows the correlation between IDW and Kriging methods for drought analysis. The R was 0.8, which is a fairly strong positive relationship.

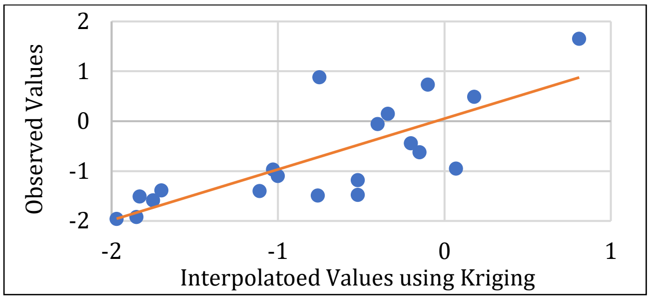

Figure 11. Correlation between Interpolated values using Kriging and the observed data

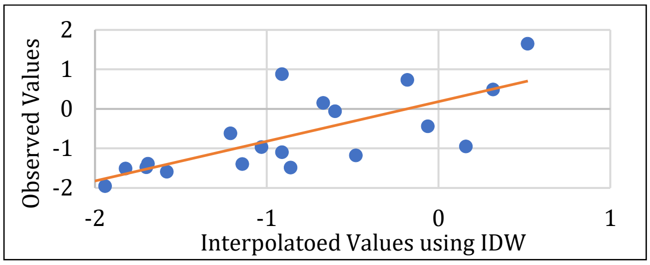

Figure 12. Correlation between Interpolated values using IDW and the observed data

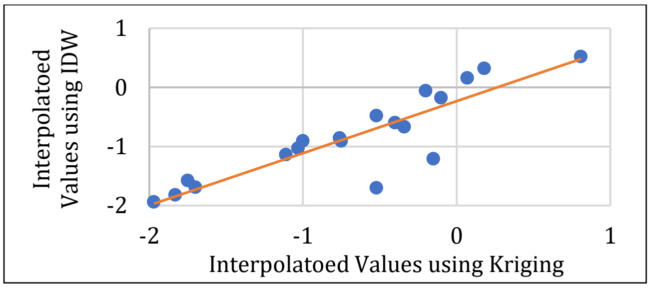

Figure 13. Correlation between Interpolated values using Kriging and IDW

4. Discussion

Generally, according to the drought analysis, IDW gives more conservative results. Due to the geostatistical method used, the origin data may be changed, which makes the Kriging interpolation method unsuitable for drought analysis. Both IDW and Kriging have approximately the same correlation coefficient regarding observed data.

5. Conclusion

Because of the importance of drought analysis and the vital role of spatial interpolation in creating drought maps, this research has two main objectives: to find the accuracy of using IDW and Kriging spatial interpolation methods and to investigate the difference between IDW and Kriging in evaluating drought.

It can be concluded that using the IDW method is more conservative and gives high and more extreme drought values. Regarding the observed data, IDW and Kriging have approximately the same R (0.6), which is a moderately positive relationship. Furthermore, the correlation between IDW and Kriging was 0.8, which is fairly strong.

It can be concluded that using the IDW method is more conservative and gives high and more extreme drought values. Regarding the observed data, both IDW and Kriging have approximately the same R (0.6), which is a moderately positive relationship. Furthermore, the correlation between IDW and Kriging was 0.8, which is fairly strong.

It is complex and impossible to find and evaluate the drought analysis at each point, and it is very complicated to put a metrological station at each meter or kilometer, so spatial interpolation is vital in studying the drought analysis and its negative impacts. The results are significant and useful for the water authorities and decision-makers.

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