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COMPARISON OF INTERPOLATION METHODS IN THE SPATIAL DISTRIBUTION OF MONTHLY PRECIPITATION DATA IN KONYA CLOSED BASIN

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Highlights

- The performance of deterministic and geostatistical interpolation methods in the spatial distribution of monthly total precipitation in the Konya Closed Basin (KCB) was investigated.
- The effect of both the number of stations and the observation period on the prediction performance was evaluated.
- Inverse Distance Weighted Interpolation Method (IDW), Regularized Spline (Sp-R) and Tension Spline (Sp-T) were used as deterministic methods, while Ordinary Kriging (OK) and Universal Kriging (UK) were used as geostatistical methods.

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ABSTRACT: Interpolation methods are used as an effective tool in determining the spatial distribution of precipitation. In this study, the performance of deterministic and geostatistical interpolation methods in estimating the spatial distribution of monthly total precipitation in the Konya Closed Basin (KCB) was investigated. In the study, the effect of both the number of stations and the observation period on the prediction performance was evaluated. While 11 stations were used in the long period (1971-2019), 34 stations were used in the short period (2014-2019). Spatial forecasts were performed by deterministic methods such as Inverse Distance Weighted Interpolation (IDW), Regularized Spline (Sp-R), and Tension Spline (Sp-T) and geostatistical methods such as Ordinary Kriging (OK) and Universal Kriging (UK). spherical (S), gaussian (G), circular (C), and exponential (E) were used as semivariogram methods in the OK method. According to Nash Sutcliffe efficiency coefficient (NSE), the most successful interpolation methods for the long period (1971-2019) were Sp-T (NSE=0.721) at Cihanbeyli station, Sp-R (NSE=0.561) at Seydişehir station, and OK-G (NSE=0.704) at Karapınar station. In the short period (2014-2019), the highest prediction success among the 10 test stations was obtained from Seydişehir station (IDW_{NSE}=0.843), and the lowest prediction success was obtained from Sultanhanı station ($OK\text{-}G_{NSE}$=0.533).

Keywords: Deterministic, Geostatistics, IDW, Interpolation, Kriging, Precipitation, Spline

1. INTRODUCTION

Climate parameters are used in many different fields such as hydrology, meteorology, geology, agriculture, forest management, and ecology. Precipitation is among the climate parameters that play a key role in modeling hydrological processes [1]. Analysis of spatial and temporal variability in precipitation data is quite important for the management of water resources systems, the management of floods and droughts, landslide management, and management of agricultural activities [2-3]. Precipitation, which is the main input data for modeling hydrological processes, is measured pointwise at meteorological stations or determined by satellites and weather radars, as with most climatological parameters, [4]. Satellite and radar data, which are often used in hydrological studies, need to be verified and corrected before use [2]. Therefore, the most reliable measurement method is a rain gauge. Since precipitation is the climate element with the most variation over time and location, denser network of measuring stations is needed to measure precipitation data compared to other climate elements [5]. Due to economic and geographical difficulties around the world, the land measurement network is insufficient to represent the spatial variability of precipitation. Therefore, spatial interpolation techniques based on point measurements are used as alternative tools for precipitation estimation [6]. Interpolation methods are generally categorized into two groups: deterministic and stochastic (geostatistical) methods. Geostatistical interpolation methods quantify point or spatial correlation based on the distance between sampling points, and take into account the spatial configuration of sampling points around the estimation points [7-8]. Deterministic interpolation methods create surfaces from sample points using mathematical functions [9-10]. The interpolation methods used have different advantages and disadvantages. For this reason, there is no valid and appropriate interpolation method that can be used in all conditions [11]. This

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is mainly because the performance of interpolation techniques is controlled by many factors, such as data density, spatial distribution of data, data clustering, surface type, data variance, grid size or resolution, the quality of the supporting information to be used, and the interactions between these factors [12]. Therefore, it is important to make a comparative assessment of different interpolation methods for a specific study area.

The literature contains numerous studies that use interpolation methods to estimate precipitation parameter [2], [9], [13-24]. Katipoğlu [9] obtained maps showing the spatial distribution of seasonal precipitation in the Euphrates Basin by using several interpolation techniques. The most effective interpolation techniques were found to be ordinary Kriging for autumn precipitation, ordinary CoKriging for winter and spring precipitation, and local polynomial interpolation for summer precipitation in the study that used precipitation data from 21 stations for the period 1966-2017. Antal et al. [14] estimated the average annual precipitation using seven interpolation methods. For this purpose, data of 128 stations in Portugal for the period 1991-2000 were used, and it was determined that the empirical Bayesian kriging regression (EBKR) interpolation method showed the most successful spatial distribution. Liu et al. [20] found that hybrid methods such as Trend Surfaces and Regression-Ordinary Kriging (TSA-OK) and Bayesian Model Averaging (BMA) between sparse and relatively dense gauge stations for different time scales (daily, monthly, and yearly) performed best at all time scales for spatial precipitation estimation in the Changjiang River Basin. In another study, Fung et al. [22] investigated the temporal-spatial variation of rainfall patterns (number of wet days, monthly rainfall, and maximum daily rainfall) in Peninsular Malaysia using four interpolation methods. The performance of multivariate interpolation (geographical weighted regression—GWR, multiscale geographical weighted regression—MGWR) and univariate interpolation (Ordinary Kriging and IDW) methods were compared. The results show that MGWR has better prediction performance in general among the interpolation methods.

Interpolation techniques are also utilized in the spatial distribution of other meteorological data such as temperature [25], evapotranspiration [26-27], groundwater level [28-29], and drought [30-31].

In this study, the applicability of stochastic and deterministic interpolation methods in the spatial precipitation distribution of the Konya Closed Basin (KCB) was investigated. For this purpose, deterministic methods such as Inverse Distance Weighting (IDW), Regularized Spline (Sp-R), and Tension Spline (Sp-T), as well as geostatistical methods Ordinary Kriging (OK) and Universal Kriging (UK), were applied. For the OK method, spherical (S), gaussian (G), circular (C), and exponential (E) semivariogram models, which are the most used in the literature, were applied. In the UK method, predictions were made with the Stable semivariogram model. KCB has quite an important place in terms of agricultural production in our country. Most of the water potential in the basin is used in agriculture. It is of great importance to analyze the spatial variation of precipitation in KCB, which is the driest and water-limited basin of Turkey.

2. STUDY AREA and DATA

The Konya Closed Basin (KCB), which was used as the study area, is located between 36°51' - 39°29' north latitude and 31°36' - 34°52' east longitude. The basin covers an area of 49805.34 km², corresponding to 7% of Türkiye's surface area. The KCB is bordered by the Sakarya and Kızılırmak Basins to the north, the Kızılırmak and Seyhan Basins to the east, the Eastern Mediterranean Basin to the south, and the Akarçay and Antalya Basins to the west. KCB is among the basins with the lowest rainfall in Türkiye. The average annual precipitation is around 300-350 mm. While the least precipitation falls in the central parts of the basin, the most precipitation falls in the western part. Due to the irregularity of precipitation in the basin, river regimes are also irregular. KCB is among the most important regions of Türkiye in terms of agricultural production.

Two different periods were taken into consideration in the spatial distribution of precipitation data: long period (1971-2019) and short period (2014-2019). The data from 11 meteorological observation stations were used for the long period, and 34 meteorological observation stations were used for the short period. Information about the meteorological observation stations used in the study is given in Table 1.

Table 1. Meteorological observation stations used in the study

Station Code	Station Name	Station Number	Latitude	Longitude
S1	**Aksaray**[xx]	17192	38°22'13.80"N	33°59'55.32"E
S2	**Niğde**[xx]	17250	37°57'30.60"N	34°40'46.20"E
S3	**Çumra**[xx]	17900	37°33'56.88"N	32°47'24.00"E
S4	**Beyşehir**[xx]	17242	37°40'39.72"N	31°44'46.68"E
S5	**Kulu**[xx]	17754	39° 4'43.68"N	33° 3'56.52"E
S6	**Konya Havalimanı**[xx]	17244	37°59'1.32"N	32°34'26.40"E
S7	**Ereğli**[xx]	17248	37°31'31.80"N	34° 2'54.60"E
S8	**Karaman**[xx]	17246	37°11'35.5"N	33°13'12.7"E
S9	**Seydişehir/Alacabel**[x]	18212	37°14'03.1"N	31°55'00.8"E
S10	**Akören**[x]	18487	37°27'06.1"N	32°22'49.1"E
S11	**Ahırlı**[x]	18486	37°14'25.1"N	32°06'52.9"E
S12	**Güneysınır**[x]	18495	37°16'04.8"N	32°43'14.9"E
S13	**Altınekin**[x]	18488	38°17'56.0"N	32°52'45.1"E
S14	**Hüyük**[x]	18497	37°57'55.1"N	31°35'47.0"E
S15	**Yalıhüyük**[x]	18500	37°17'31.9"N	32°06'43.9"E
S16	**Derebucak**[x]	18492	37°23'30.8"N	31°30'51.8"E
S17	**Emirgazi**[x]	18494	37°53'33.0"N	33°50'28.0"E
S18	**Bozkır/Sorkun**[x]	18591	37°09'06.1"N	32°05'35.2"E
S19	**Derbent**[x]	18491	38°00'59.0"N	32°01'01.9"E
S20	**Güzelyurt**[x]	18116	38°16'14.9"N	34°22'19.9"E
S21	**Eskil**[x]	18481	38°18'31.0"N	33°21'33.1"E
S22	**Altunhisar**[x]	18501	38°00'05.4"N	34°21'31.7"E
S23	**Çiftlik**[x]	18503	38°08'35.2"N	34°27'42.8"E
S24	**Ayrancı**[x]	18211	37°20'13.9"N	33°43'16.0"E
S25	**Seydişehir**[yy]	17898	37°25'36.12"N	31°50'56.40"E
S26	**Cihanbeyli**[yy]	17191	38°39'2.08"N	32°55'18.70"E
S27	**Karapınar**[yy]	17902	37°42'58.72"N	33°31'33.60"E
S28	**Karatay TAGEM**[y]	18213	37°51'38.2"N	32°35'02.0"E
S29	**Bozkır**[y]	18489	37°10'59.9"N	32°14'46.0"E
S30	**Halkapınar/İvriz**[y]	18496	37°26'29.0"N	34°09'06.8"E
S31	**Sultanhanı**[y]	18117	38°11'58.9"N	33°31'00.8"E
S32	**Gülağaç**[y]	18482	38°24'32.0"N	34°20'37.0"E
S33	**Bor**[y]	18502	37°55'17.0"N	34°33'10.1"E
S34	**Kazımkarabekir**[y]	18484	37°1307.0″N	32°5723.0″E

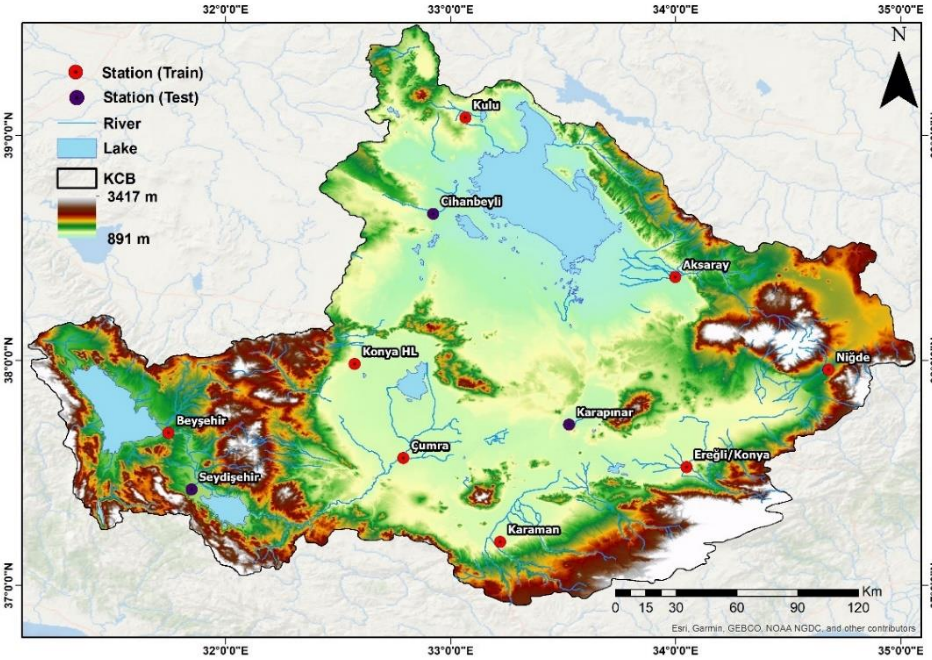
xx : Meteorological stations used in spatial distribution in the long period (1971-2019)

yy : Test stations used in the long period (1971-2019)

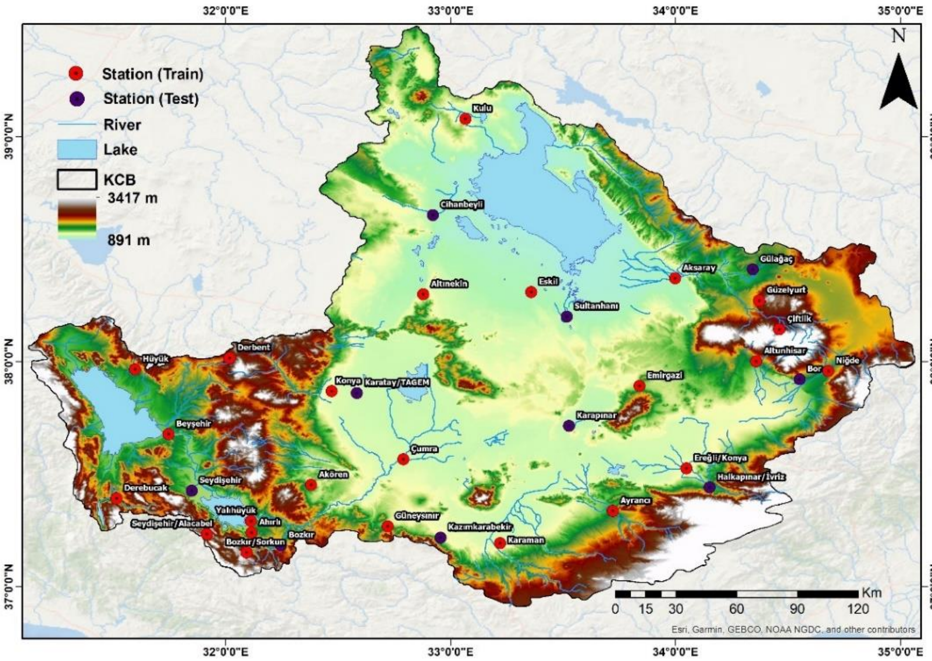
x ve xx : Meteorological stations used in the spatial distribution in the short period (2014-2019)

y ve yy : Test stations used in the short period (2014-2019)

The interpolation methods applied to the monthly total precipitation data were tested with 3 stations in the long period and 10 stations in the short period, and the methods were compared. The locations of the meteorological observation stations utilized for the long and short periods are presented in Figure 1a and Figure 1b, respectively.



(a)



(b)

Figure 1. Location of the meteorological observation stations used in the spatial distribution and for testing purposes in KCB **a)** Long period (1971-2019), **b)** Short period (2014-2019)

In the long period (1971-2019), Seydişehir, Cihanbeyli, and Karapınar stations were utilized for testing, whereas Aksaray, Niğde, Çumra, Beyşehir, Kulu, Konya, Ereğli, and Karaman stations were used for spatial distribution (Figure 1a). In the short period (2014-2019), 10 stations (Seydişehir, Cihanbeyli, Karapınar, Karatay-Tagem, Bozkır, Halkapınar/İvriz, Sultanhanı, Gülağaç, Bor and Kazımkarabekir) were used for testing, while the remaining 24 stations, which are shown in Table 1, were used for spatial distribution (Figure 1b).

For geostatistical analyses to yield useful findings, details about the statistical distribution, outliers, and kurtosis of the analyzed data set are crucial [32]. Statistical characteristics of annual total precipitation data from the stations for the long period (2014-2019) and short period (2014-2019) are given in Table 2 and Table 3, respectively.

Table 2. Annual total precipitation statistics for the period 1971-2019

Station Name	Station Number	Avg. (mm)	Max (mm)	Min (mm)	Std Dev (mm)	Skewness	Kurtosis
Aksaray	17192	346.77	506.20	228.80	70.51	0.30	-0.53
Beyşehir	17242	490.45	656.90	317.10	90.12	-0.45	-0.72
Çumra	17900	322.19	502.10	176.50	70.31	0.16	-0.43
Ereğli	17248	304.64	438.50	140.00	57.69	-0.17	0.51
Kulu	17754	376.29	547.80	218.70	71.65	-0.04	-0.01
Niğde	17250	336.87	484.00	192.90	70.22	0.02	-0.24
Karaman	17246	333.97	513.40	212.60	70.66	0.41	-0.15
Konya	17244	326.53	523.90	176.10	73.80	0.14	0.18
Seydişehir	17898	752.65	1202.00	474.90	154.61	0.46	0.46
Cihanbeyli	17191	323.57	499.80	184.60	70.86	0.11	-0.40
Karapınar	17902	291.05	412.90	171.60	57.72	0.22	-0.43

Table 3. Annual total precipitation statistics for the period 2014-2019

Station Name	Station Number	Avg. (mm)	Max (mm)	Min (mm)	Std Dev (mm)	Skewness	Kurtosis
Aksaray	**17192**	358.72	434.60	298.90	46.89	0.27	-0.76
Beyşehir	**17242**	526.68	593.40	463.50	47.01	0.08	-2.08
Çumra	**17900**	355.40	443.60	245.20	68.51	-0.54	-0.99
Ereğli	**17248**	318.03	353.90	274.80	32.09	-0.47	-2.20
Kulu	**17754**	386.07	459.20	328.80	48.38	0.20	-1.84
Niğde	**17250**	350.72	463.80	246.50	71.08	0.18	-0.52
Karaman	**17246**	393.68	477.60	287.10	64.63	-0.33	-0.64
Konya	**17244**	371.52	523.90	283.70	75.96	1.38	2.68
Seydişehir Alacabel	**18212**	1152.35	1475.00	884.10	194.31	0.29	-0.33
Akören	**18487**	465.48	566.60	376.00	62.54	0.09	-0.34
Ahırlı	**18486**	543.42	641.00	428.30	90.01	-0.30	-2.55
Güneysınır	**18495**	503.75	553.40	408.70	60.71	-0.98	-1.65
Hüyük	**18497**	490.73	571.00	329.90	75.77	-1.88	4.27
Yalıhüyük	**18500**	538.85	645.00	425.40	67.95	-0.17	0.51
Derebucak	**18492**	854.67	1073.30	593.80	142.38	-0.57	1.94
Emirgazi	**18494**	325.47	379.40	211.00	55.92	-1.66	2.84
Bozkır/Sorkun	**18591**	699.52	928.70	331.90	211.91	-1.08	0.60
Derbent	**18491**	553.82	633.30	474.20	64.39	0.00	-2.93
Altınekin	**18488**	373.17	442.30	262.00	59.77	-0.96	0.75
Güzelyurt	**18116**	435.97	487.40	351.20	48.47	-0.88	-0.45
Eskil	**18481**	287.93	347.70	250.90	38.57	0.88	-1.67
Altunhisar	**18501**	328.40	390.90	299.70	31.40	1.51	1.97
Çiftlik	**18503**	557.25	670.80	440.40	69.75	-0.11	1.05
Ayrancı	**18211**	308.68	374.80	253.00	41.54	0.37	-0.93
Seydişehir	**17898**	772.23	935.80	696.40	85.60	1.35	0.88
Cihanbeyli	**17191**	347.83	446.50	270.20	76.25	0.25	-2.72
Karapınar	**17902**	327.90	391.80	260.20	41.75	-0.02	0.09
Bozkır	**18489**	553.10	630.00	443.60	68.77	-0.57	-1.42
Kazımkarabekir	**18484**	446.13	533.40	326.90	64.66	-0.87	1.09
Halkapınar/İvriz	**18496**	362.52	476.40	293.00	67.08	0.82	-0.82
Karatay(TAGEM)	**18213**	280.62	409.50	177.10	68.19	0.73	2.54
Sultanhanı	**18117**	298.72	340.90	255.40	32.47	-0.16	-1.81
Bor	**18502**	374.17	460.40	272.40	67.04	0.13	-1.00
Gülağaç	**18482**	337.03	367.20	303.50	21.95	-0.44	-1.11

3. METHODOLOGY

3.1. Interpolation Methods

By utilizing measured point data, estimates can be made for unmeasured regions. To achieve spatial estimations, a variety of interpolation methods are employed. To perform spatial estimations and mapping of precipitation data in this study, interpolation methods were implemented in ArcGIS 10.7.1 software utilizing the Spatial Analyst Tools and Geostatistical Analyst module. As interpolations, IDW, Sp-R, and Sp-T from deterministic methods and OK and UK from geostatistical methods were applied. For OK methods, applications were performed with the most frequently used semivariogram models in the literature. These are spherical (S), gaussian (G), circular (C), and exponential (E) semivariogram models. In the UK interpolation method, the stable semivariogram model was used. The workflow diagram of the deterministic and geostatistical analysis applications in this study is given in Figure 2.

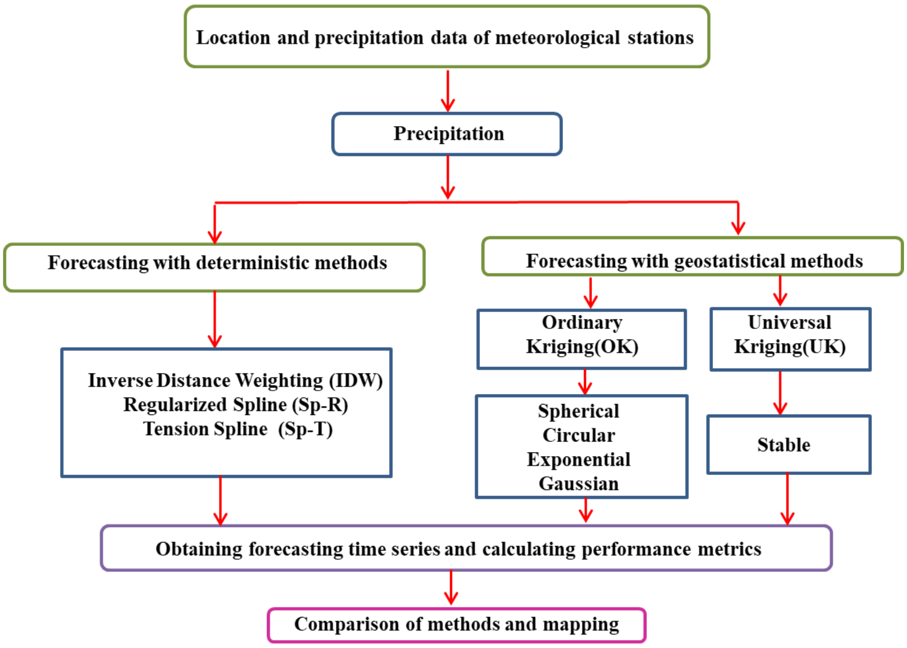


Figure 2. Workflow diagram of deterministic and geostatistical analysis applications

3.1.1. Inverse Distance Weighting (IDW)

IDW is one of the widely used deterministic interpolation methods. IDW is a local interpolation method since it produces estimates only from neighboring points [22], [25]. IDW is based on the principle that nearby points on the surface to be interpolated have more weight than distant points. As the distance from the point to be interpolated increases, the importance and influence on the cell to be estimated decreases [18], [22], [25], [33]. This technique uses the mathematical functions in Equations 1, 2, and 3 [34].

$$F(x, y) = \sum_{i=1}^{n} wifi \quad (1)$$

$$w_i = \frac{h_i^{-p}}{\sum_{j=1}^{n} h_i^{-p}} \quad (2)$$

$$\sum_{i=1}^{n} wi = 1 \quad (3)$$

In the above equations, *p is the* force parameter, h_i is the spatial distance between sample points and the interpolated points, and w_i is the weights [33]. In the weight function, the power parameter is expressed as the exponent of the distance inversely proportional to the distance. If the power parameter p *is* 0, no weighting can be done in relation to the distance. p can be given ≥1 values [32].

3.1.2. Spline (Sp)

Spline is a deterministic interpolation method that interpolates by passing the minimum curvature surface through points of known value (input values). Spline interpolation is not suitable for data with large variations over short horizontal distances [35].

Two types of Spline versions are used in this study: Regularized Spline (Sp-R) and Tension Spline (Sp-T). Compared to the Sp-R method, the Sp-T method produces a more closed and uniform data set that is bounded by the sample data range [28], [36-37]. A general mathematical function is used for the Spline method (Equation 4). Equations 5-6 are the mathematical functions for the Sp-T method, and Equations 7-8 are the mathematical functions for the Sp-R method [28].

$$S(x,y) = T(x,y) + \sum_{j=1}^{N} \lambda j R(r_j) \tag{4}$$

$$T(x,y) = a_1 \tag{5}$$

$$R(r) = \frac{1}{2\pi\varphi^2}\left[ln\left(\frac{r\varphi}{2}\right) + c + K_{.}(r\varphi)\right] \tag{6}$$

$$T(x,y) = a_1 + a_2 x + a_3 y \tag{7}$$

$$R(r) = \frac{1}{2\pi}\left\{\frac{r^2}{4}\left[ln\left(\frac{r}{2\pi}\right) + c - 1\right] + \tau^2\left[K_{.}\left(\frac{r}{\tau}\right) + c + ln\left(\frac{r}{2\pi}\right)\right]\right\} \tag{8}$$

In the above equations; N: Number of points, λj: Coefficients found by solving the system of linear equations, r_j: Distance between point (x, y) and point j. a_1: Coefficients found by solving the system of linear equations, φ^2 and τ^2: Weight parameters, C = 0.0577215, r: Distance between point and sample, K: modified Bessel function.

3.1.3. Kriging Interpolation

Kriging is a geostatistical estimation method developed for spatial estimation [38]. This method is defined as the best linear unbiased estimator or calculator known as collocation in mathematical geodesy [39]. The Kriging method does not only depend on the distance between the measurement points and the estimation points as in the IDW method. It also depends on the overall spatial regularization between the measurement points. In the Kriging method, weights are determined by the semivariogram model developed according to the spatial location of the data. Kriging is an interpolation method that has proven its popularity in geostatistics and many other fields [35].

The variogram, which measures the spatial correlation between two points, is the most crucial in this interpolation technique. The major advantage of the Kriging method is that, in addition to the estimated surface, it also provides a measure of the error or uncertainty of the estimated surface [32], [40]. Its disadvantage is that it requires more computational time and input compared to IDW and Spline methods [28].

To know the properties of the regional parameters and to estimate the values at points where the measured values are not known, it is necessary to know the semivariogram values of each point. This is achieved by fitting a mathematical function to the experimental semivariogram values. This model is called the theoretical semivariogram model or semivariogram model [41]. The mathematical functions of the semivariogram model are shown in Table 4.

Table 4. Semivariogram models

Semivariogram Model	Mathematical Function
Spherical	$\gamma(h) = C_0 + C\left(\frac{3h}{2a} - \frac{h^3}{2a^3}\right), \quad 0 \le h \le a$
Gaussian	$\gamma(h) = C_0 + C\left(1 - exp\left(\frac{-h^2}{a^2}\right)\right), \quad h \ge 0$
Circular	$\gamma(h) = C_0 + C\left(1 - \frac{2}{\pi}cos^{-1}\left(\frac{h}{a}\right) + \sqrt{1 - \frac{h^2}{a^2}}\right), \quad 0 \le h \le a$
Exponential	$\gamma(h) = C_0 + C\left(1 - exp\left(\frac{-h}{a}\right)\right), \quad h \ge 0$

In the equations given in Table 4, *a is the* impact distance, *C is the* threshold value, and C_0 is the nugget effect.

The Stable model is a model that balances between Gaussian and Exponential semivariogram models. This model produces results by approximating Gaussian and Exponential semivariogram models [32], [42]. The general formulation of the kriging technique is known as the OK method [43]. OK is the most widely used type of kriging [44]. The analysis of the Kriging system by taking into account the presence of trends in the data is called the UK method [38]. In this study, OK (with 4 different semivariogram versions) and the UK method are Kriging methods used as geostatistical methods. More information about the Kriging method is available in Webster and Oliver [44].

3.2. Performance Metrics

The performance of the interpolation methods was evaluated using the metrics given in Table 5.

Table 5. Performance metrics

Determination Coefficient (R^2)	$R^2 = \frac{\left[\sum_{i=1}^{n}(Z_{g_i} - \overline{Z_g})(Z_{m_i} - \overline{Z_m})\right]^2}{\sum_{i=1}^{n}(Z_{g_i} - \overline{Z_g})^2 \sum_{i=1}^{n}(Z_{m_i} - \overline{Z_m})^2}$
Nash-Sutcliffe Efficiency Coefficient (NSE)	$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Z_{g_i} - Z_{m_i})^2}{\sum_{i=1}^{n}(Z_{g_i} - \overline{Z_g})^2}\right]$
Mean Absolute Error (MAE)	$MAE = \frac{1}{n}\sum_{i=1}^{n}\lvert Z_m - Z_g\rvert$
Root Mean Squared Error (RMSE)	$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Z_m - Z_g)^2}$

In the equations given in Table 5, Z_g is the measurement data, Z_m is the data generated by the model, and n is the data number. In addition, $\overline{Z_g}$ and $\overline{Z_m}$ are the average of measurement data and model data, respectively. According to the NSE metric, model performance levels are evaluated as "very good" for $0.75 < NSE \le 1$, "good" for $0.65 < NSE \le 0.75$, "satisfactory" for $0.50 < NSE \le 0.65$, and "unsatisfactory" for $NSE \le 0.5$ [45].

4. RESULTS and DISCUSSION

In this study, the usability of different interpolation techniques in the spatial distributions of monthly total precipitation data in KCB were investigated. Two different time periods, long (1971-2019) and short (2014-2019), were considered in the spatial distribution of precipitation. Precipitation data from 11 and 34 stations were used in the long and short periods, respectively. Thus, it was aimed to evaluate the effect of the number of stations, i.e., density, on the estimation success of interpolation methods by using fewer stations in the long period and more stations in the short period.

4.1. Spatial Interpolation Results of Monthly Total Precipitation for Long Period (1971-2019)

The results obtained by applying the interpolation methods for the KCB's monthly total precipitation data between 1971 and 2019 are given in Table 6. The maximum NSE value was considered in determining the most successful interpolation method and is shown in bold in Table 6.

Table 6. The long period (1971-2019) **p**erformance values of interpolation methods

Station Name	Model Name	R^2	NSE	Performance	MAE (mm)	RMSE (mm)
17898 Seydişehir	IDW	0.781	0.503	Satisfactory	28.87	45.28
	Sp-R	**0.762**	**0.561**	**Satisfactory**	**27.78**	**42.55**
	Sp-T	0.783	0.556	Satisfactory	27.73	42.84
	UK	0.604	0.137	Unsatisfactory	36.77	59.66
	OK-C	0.761	0.409	Unsatisfactory	31.36	49.41
	OK-E	0.715	0.404	Unsatisfactory	31.63	49.61
	OK-G	0.734	0.370	Unsatisfactory	32.31	50.99
	OK-S	0.755	0.413	Unsatisfactory	31.34	49.25
17191 Cihanbeyli	IDW	0.747	0.719	Good	9.23	12.45
	Sp-R	0.686	0.659	Good	10.09	13.73
	Sp-T	**0.741**	**0.721**	**Good**	**9.11**	**12.42**
	UK	0.654	0.644	Satisfactory	9.76	13.99
	OK-C	0.654	0.605	Satisfactory	9.80	14.74
	OK-E	0.494	0.294	Unsatisfactory	10.91	19.72
	OK-G	0.724	0.710	Good	9.08	12.65
	OK-S	0.627	0.566	Satisfactory	9.96	15.47
17902 Karapınar	IDW	0.730	0.686	Good	8.89	11.94
	Sp-R	0.648	0.612	Satisfactory	9.37	13.25
	Sp-T	0.708	0.683	Good	8.73	11.98
	UK	0.577	0.513	Satisfactory	10.08	14.89
	OK-C	0.684	0.648	Satisfactory	8.81	12.88
	OK-E	0.499	0.319	Unsatisfactory	9.82	17.55
	OK-G	**0.725**	**0.704**	**Good**	**8.24**	**11.55**
	OK-S	0.652	0.601	Satisfactory	8.88	13.45

At Seydişehir station, the IDW, Sp-R, and Sp-T models showed "satisfactory" level prediction success with NSE values of 0.503, 0.561, and 0.556, respectively, while the other 5 models showed "unsatisfactory" level prediction success. At this station, the most successful interpolation method in monthly total precipitation prediction was obtained as the Sp-R method (NSE=0.561). Other metric values of the Sp-R model were R^2=0.762, MAE=27.78 mm, and RMSE=42.55 mm. At Seydişehir station, the performance metric values of the Sp-R and IDW interpolation methods were also close to the Sp-T model's. The OK models using the four semivariograms performed close to each other, and the OK-S model with an NSE value of 0.413 was the most successful OK model. The interpolation method with the lowest prediction success was the UK method with NSE=0.137. According to the results obtained, it can be said that deterministic interpolation methods are generally more successful at Seydişehir station.

In precipitation estimation at Cihanbeyli station, NSE values for the IDW, Sp-R, Sp-T, and OK-G models were obtained as 0.719, 0.659, 0.721, and 0.710, respectively, and according to these NSE values there is a "good" level of prediction success. The OK-E model shows "unsatisfactory" prediction success with NSE=0.294. The NSE values in other models vary between 0.50 and 0.65, and "satisfactory" prediction success was obtained. The most successful interpolation model at Cihanbeyli station was the Sp-T model with NSE=0.721. In this model, R^2=0.741, MAE=9.11 mm, and RMSE=12.42 mm were obtained.

The OK-G model, which had a maximum NSE value of 0.704, was the best-performing interpolation method for the Karapınar station. The OK-G model showed a "good" level of prediction success. Other metric values for this model were R^2=0.725, MAE=8.24 mm, and RMSE=11.55 mm. IDW and Sp-T models also showed "good" prediction performance with NSE=0.686 and NSE=0.683, respectively. Sp-R, UK, OK-C, and OK-S methods showed "adequate" prediction performance with NSE values of 0.612, 0.513, 0.648 and 0.601, respectively. The lowest prediction success in precipitation prediction at Karapınar station was obtained in the OK-E model with NSE=0.319, which is at the "unsatisfactory" level.

The time series and scatter diagrams of the interpolation techniques that had the best prediction success for the long period are presented in Figure 3.

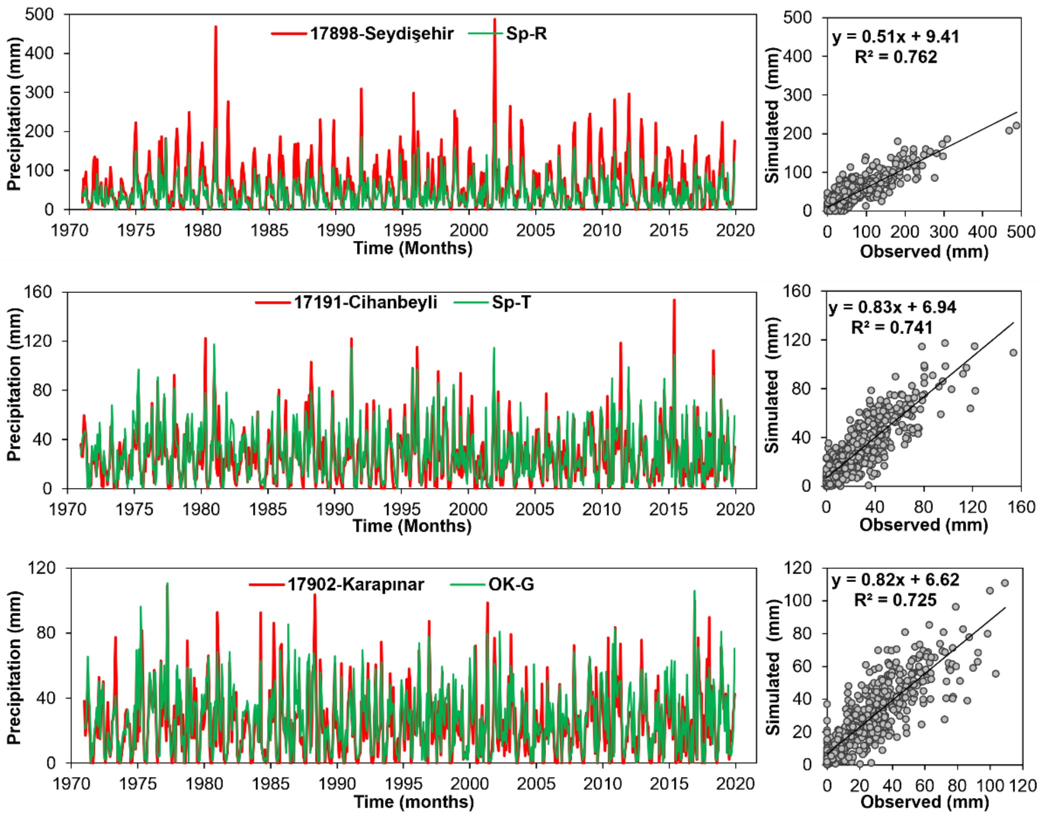


Figure 3. Monthly total precipitation time series and scatter diagrams for the period 1971-2019

As can be seen from the time series given in Figure 3 for the Seydişehir station, the monthly total precipitation data obtained by the Sp-R method generally successfully represent the behavior of the measured precipitation data. However, at this station, the Sp-R method underestimated the precipitation data compared to the observation data. When the time series of the Cihanbeyli station is examined, it is seen that Sp-T forecasts represent the behavior of the measured precipitation more successfully than other stations. The scatter diagram of the Cihanbeyli station also shows that the interpolation method has a higher prediction success at this station. The time series and scatter diagram given for Karapınar station in Figure 3 also show that the success of the OK-G method at this station is similar to Cihanbeyli station.

Monthly total precipitation maps of the interpolation methods applied in KCB for the period 1971-2019 are given in Figure 4. For this period, the locations of the stations used in the spatial distribution of monthly total precipitation are illustrated as red dots on the IDW map in Figure 4, and the locations of the stations used as test stations are shown as black dots.

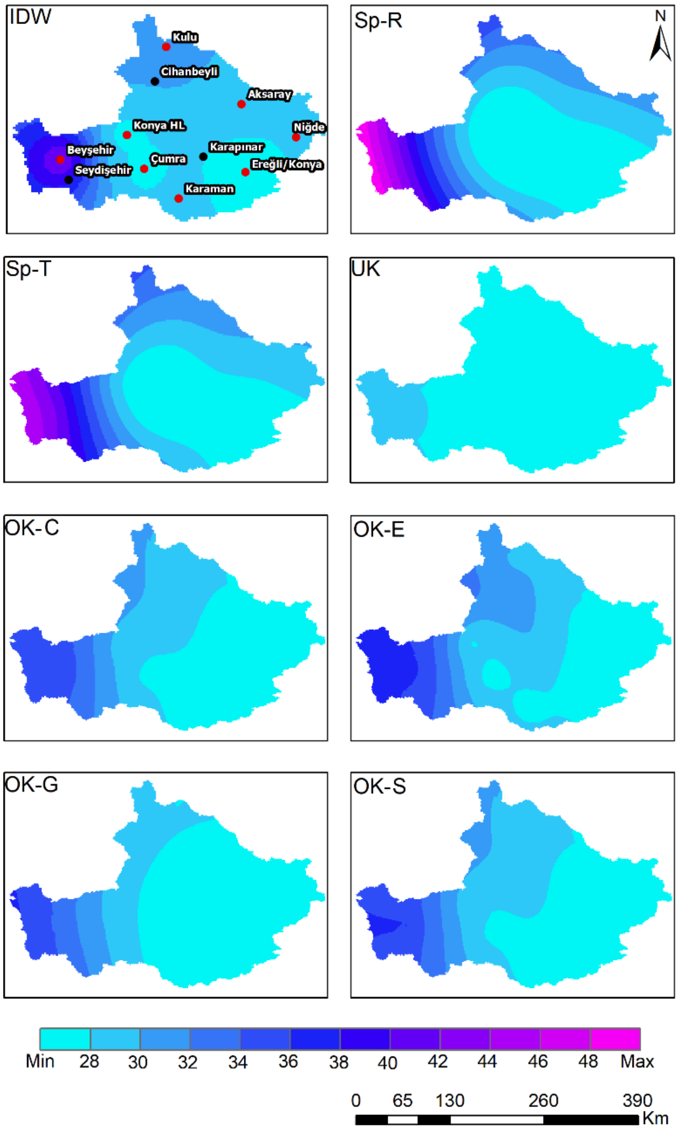


Figure 4. Spatial distribution of monthly total precipitation in KCB for the period 1971-2019

When the precipitation distribution maps are analyzed, it is seen that the monthly total precipitation amount varies between 26 and 41 mm in the IDW method. In the IDW method, it is seen that the maximum precipitation is around Beyşehir and Seydişehir, and the minimum precipitation is around Konya, Çumra, and Ereğli. In the Sp-R method, total monthly precipitation varies between 25 and 51 mm. In the Sp-T method, it varies between 26 and 46 mm. In the Sp-R and Sp-T methods, the maximum precipitation falls around Beyşehir and Seydişehir, while the minimum precipitation falls around Konya, Çumra, Karapınar, and Ereğli. In the UK method, total monthly precipitation is distributed between 25 and 36 mm. While the maximum precipitation falls around Beyşehir and Seydişehir, the rest of the basin is dominated by minimum precipitation. There is not a clear pattern in the UK method. In the OK methods, total monthly precipitation varies between 25 and 37 mm. It is observed that the maximum precipitation in OK methods is around Beyşehir and Seydişehir. Minimum precipitation falls around Çumra, Karapınar, Karaman, Ereğli, Niğde, and Aksaray.

4.2. Spatial Interpolation Results of Monthly Total Precipitation for Short Period (2014-2019)

The performance of the interpolation methods applied to monthly total precipitation data for the short period (multi-station) between 2014 and 2019 is given in Table 7.

Table 7. The short period (2014-2019) performance values of interpolation methods

Station Name	Model Name	R^2	NSE	Performance	MAE (mm)	RMSE (mm)
17898 Seydişehir	**IDW**	**0.848**	**0.843**	**Very Good**	**15.29**	**22.52**
	Sp-R	0.610	0.397	Unsatisfactory	28.66	44.15
	Sp-T	0.681	0.557	Satisfactory	25.14	37.94
	UK	0.782	0.627	Satisfactory	23.19	34.61
	OK-C	0.695	0.665	Good	22.47	32.91
	OK-E	0.553	0.536	Satisfactory	24.93	38.69
	OK-G	0.764	0.701	Good	21.10	31.02
	OK-S	0.643	0.622	Satisfactory	23.20	34.92
17191 Cihanbeyli	IDW	0.733	0.722	Good	10.34	14.43
	Sp-R	0.725	0.676	Good	11.86	15.69
	Sp-T	**0.760**	**0.739**	**Good**	**10.52**	**14.00**
	UK	0.673	0.666	Good	11.07	15.86
	OK-C	0.001	-20.252	Unsatisfactory	26.01	126.31
	OK-E	0.094	-1.762	Unsatisfactory	16.46	45.18
	OK-G	0.000	-31.908	Unsatisfactory	29.19	155.65
	OK-S	0.002	-15.837	Unsatisfactory	24.16	111.33
17902 Karapınar	**IDW**	**0.746**	**0.720**	**Good**	**8.48**	**11.71**
	Sp-R	0.589	0.203	Unsatisfactory	13.49	19.74
	Sp-T	0.714	0.685	Good	8.30	12.44
	UK	0.705	0.681	Good	8.32	12.45
	OK-C	0.698	0.672	Good	8.38	12.76
	OK-E	0.696	0.662	Good	8.71	13.54
	OK-G	0.705	0.678	Good	8.39	12.60
	OK-S	0.683	0.647	Satisfactory	8.71	13.22
18489 Bozkır	**IDW**	**0.849**	**0.822**	**Very Good**	**11.88**	**17.14**
	Sp-R	0.546	0.286	Unsatisfactory	24.33	34.50
	Sp-T	0.605	0.387	Unsatisfactory	21.71	31.88
	UK	0.814	0.778	Very Good	12.18	19.13
	OK-C	0.271	-0.689	Unsatisfactory	18.80	52.98
	OK-E	0.587	0.490	Unsatisfactory	15.78	29.16
	OK-G	0.811	0.795	Very Good	11.96	18.48
	OK-S	0.411	0.018	Unsatisfactory	17.22	40.46
18484 Kazımkarabekir	**IDW**	**0.837**	**0.836**	**Very Good**	**8.39**	**13.09**
	Sp-R	0.784	0.757	Very Good	10.63	15.89
	Sp-T	0.800	0.786	Very Good	9.60	14.92
	UK	0.784	0.709	Good	11.16	17.30
	OK-C	0.779	0.757	Very Good	10.23	15.82
	OK-E	0.781	0.765	Very Good	10.10	15.65
	OK-G	0.801	0.776	Very Good	9.62	15.20
	OK-S	0.778	0.759	Very Good	10.10	15.79
18496 Halkapınar/İvriz	IDW	0.725	0.710	Good	9.19	14.42
	Sp-R	0.505	0.378	Unsatisfactory	14.32	21.16
	Sp-T	0.613	0.558	Satisfactory	11.64	17.79
	UK	0.751	0.712	Good	9.17	14.39
	OK-C	**0.742**	**0.716**	**Good**	**9.46**	**14.28**
	OK-E	0.730	0.708	Good	9.40	14.47
	OK-G	0.744	0.714	Good	9.37	14.31
	OK-S	0.727	0.705	Good	9.51	14.54
18213 Karatay(TAGEM)	IDW	0.777	0.530	Satisfactory	10.69	14.72
	Sp-R	**0.777**	**0.663**	**Good**	**8.10**	**12.43**
	Sp-T	0.785	0.646	Satisfactory	8.42	12.75
	UK	0.662	0.453	Unsatisfactory	12.01	15.89
	OK-C	0.719	0.521	Satisfactory	11.25	14.89
	OK-E	0.727	0.521	Satisfactory	11.29	14.89
	OK-G	0.707	0.485	Unsatisfactory	11.75	15.46
	OK-S	0.716	0.517	Satisfactory	11.26	14.91

Table 7. The short period (2014-2019) performance values of interpolation methods (continued)

Station Name	Model Name	R^2	NSE	Performance	MAE (mm)	RMSE (mm)
18117 Sultanhanı	IDW	0.569	0.528	Satisfactory	10.26	15.64
	Sp-R	0.478	0.371	Unsatisfactory	11.75	18.14
	Sp-T	0.508	0.458	Unsatisfactory	10.33	16.80
	UK	0.569	0.527	Satisfactory	9.59	15.71
	OK-C	0.574	0.528	Satisfactory	9.50	15.70
	OK-E	0.552	0.496	Unsatisfactory	10.12	16.25
	OK-G	**0.576**	**0.533**	**Satisfactory**	**9.30**	**15.61**
	OK-S	0.564	0.515	Satisfactory	9.70	15.93
18502 Bor	IDW	0.764	0.721	Good	8.26	11.70
	Sp-R	0.729	0.681	Good	8.58	12.52
	Sp-T	0.750	0.714	Good	7.99	11.83
	UK	0.762	0.718	Good	8.63	11.84
	OK-C	0.754	0.726	Good	8.39	11.63
	OK-E	**0.754**	**0.731**	**Good**	**8.32**	**11.56**
	OK-G	0.761	0.728	Good	8.36	11.59
	OK-S	0.749	0.721	Good	8.46	11.68
18482 Gülağaç	IDW	0.721	0.441	Unsatisfactory	10.92	16.03
	Sp-R	0.293	-1.044	Unsatisfactory	19.51	30.62
	Sp-T	0.486	-0.247	Unsatisfactory	14.56	23.87
	UK	**0.777**	**0.740**	**Good**	**7.37**	**10.82**
	OK-C	0.714	0.632	Satisfactory	8.38	12.94
	OK-E	0.665	0.562	Satisfactory	9.41	14.17
	OK-G	0.724	0.636	Satisfactory	8.28	12.93
	OK-S	0.702	0.614	Satisfactory	8.68	13.32

In Table 7, IDW models showed the highest prediction success with NSE= 0.843 (very good), NSE= 0.720 (good), NSE= 0.822 (very good), and NSE= 0.836 (very good) for Seydişehir, Karapınar, Bozkır, and Kazımkarabekir stations, respectively. For the Karatay (TAGEM) station, the Sp-R model showed the best performance with NSE=0.663 and achieved "good" prediction success. The best-performing interpolation method for Cihanbeyli was Sp-T, which showed a "good" prediction success with NSE=0.739. For Sultanhanı station, the highest NSE value was obtained for the OK-G model, and "satisfactory" prediction success was obtained with NSE=0.533. At Gülağaç station, the UK method showed the highest prediction success with NSE= 0.740 (good). For Halkapınar/İvriz, the OK-C model showed the best performance with a value of NSE=0.716 (good). At this station, the OK-G method also performed very close to the OK-C method. The model with the best performance for Bor station was the OK-E model with NSE=0.731, which is at a "good" level.

Figure 5 shows the time series and scatter diagrams of the methods with the highest success in the test stations for the period 2014-2019. The IDW model was the most successful interpolation model at Seydişehir and Kazımkarabekir stations. It is seen that the precipitation estimates obtained with IDW represent the behavior of the observed precipitation at these stations quite consistently. Sultanhanı was the station with the least agreement between the observation and simulation (model) data. However, this station achieved a "satisfactory" success level in the OK-G model with the value of NSE = 0.533.

Monthly total precipitation maps of the interpolation methods applied for the short period between 2014 and 2019 are given in Figure 6. In this period, the stations used in the spatial distribution are shown on the IDW map using the station codes specified in Table 1, and the test stations are shown on the IDW map using their names. When the precipitation distribution maps are examined, it is seen that the monthly average precipitation in the IDW method varies between 25 and 96 mm. In the IDW method, it is seen that the maximum precipitation is around Seydişehir/Alacabel (S9) and Derebucak (S16), and the minimum precipitation is around Eskil (S21). In the Sp-R method, the monthly average precipitation varies between 0 and 107 mm, and in the Sp-T method, it varies between 17 and 101 mm. According to the Sp-R and Sp-T methods, maximum precipitation falls around Seydişehir/Alacabel (S9), Derebucak (S16), and Seydişehir. In the Sp-R method, minimum precipitation is seen in an area starting from Eskil (S21) and

Halkapınar/İvriz (S30) station to the borders of the Eastern Mediterranean and Seyhan Basins. In the Sp-T method, the minimum area in the Sp-R method narrowed, and Halkapınar/İvriz station remained outside the minimum area.

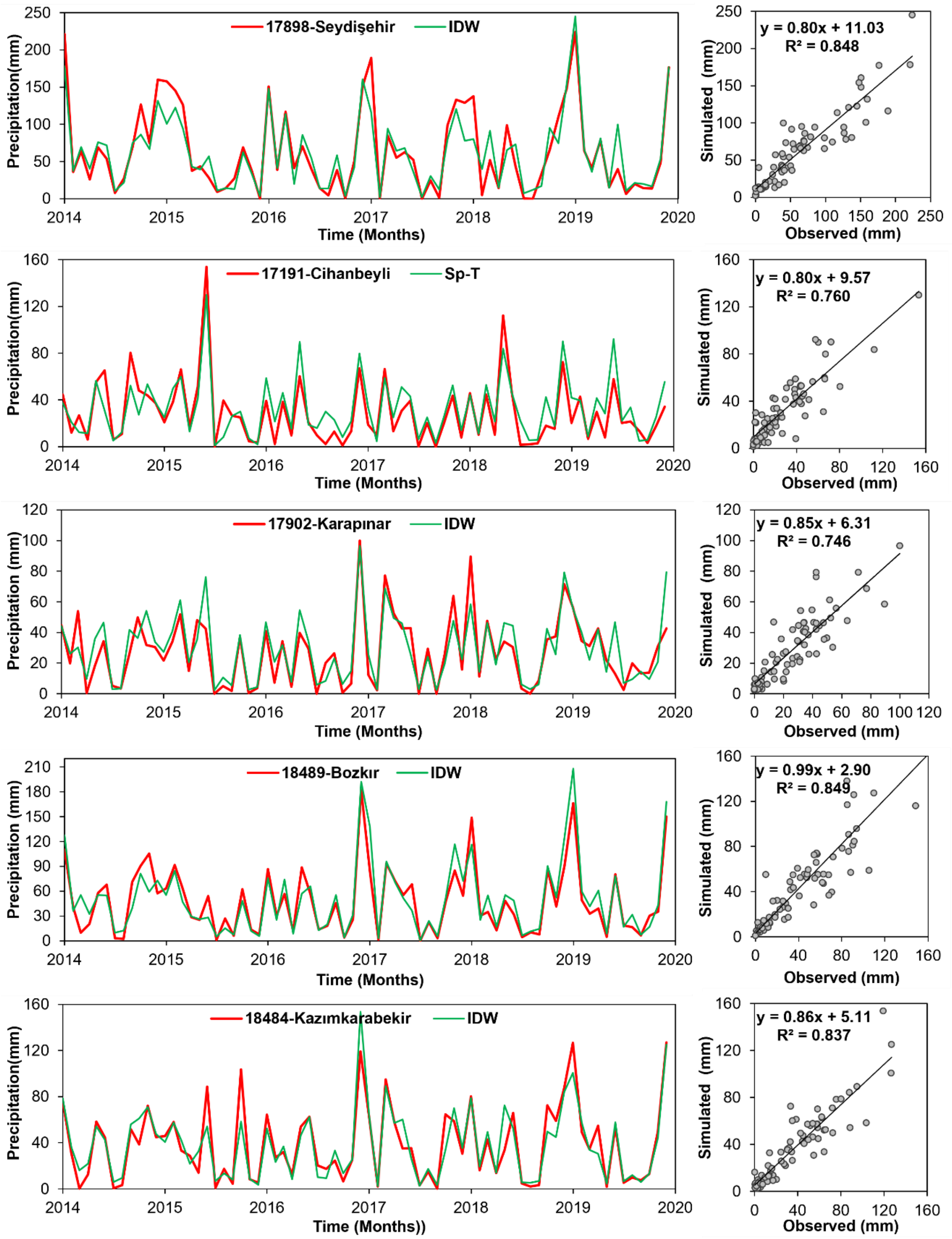


Figure 5. Time series and scatter diagrams for the period 2014-2019

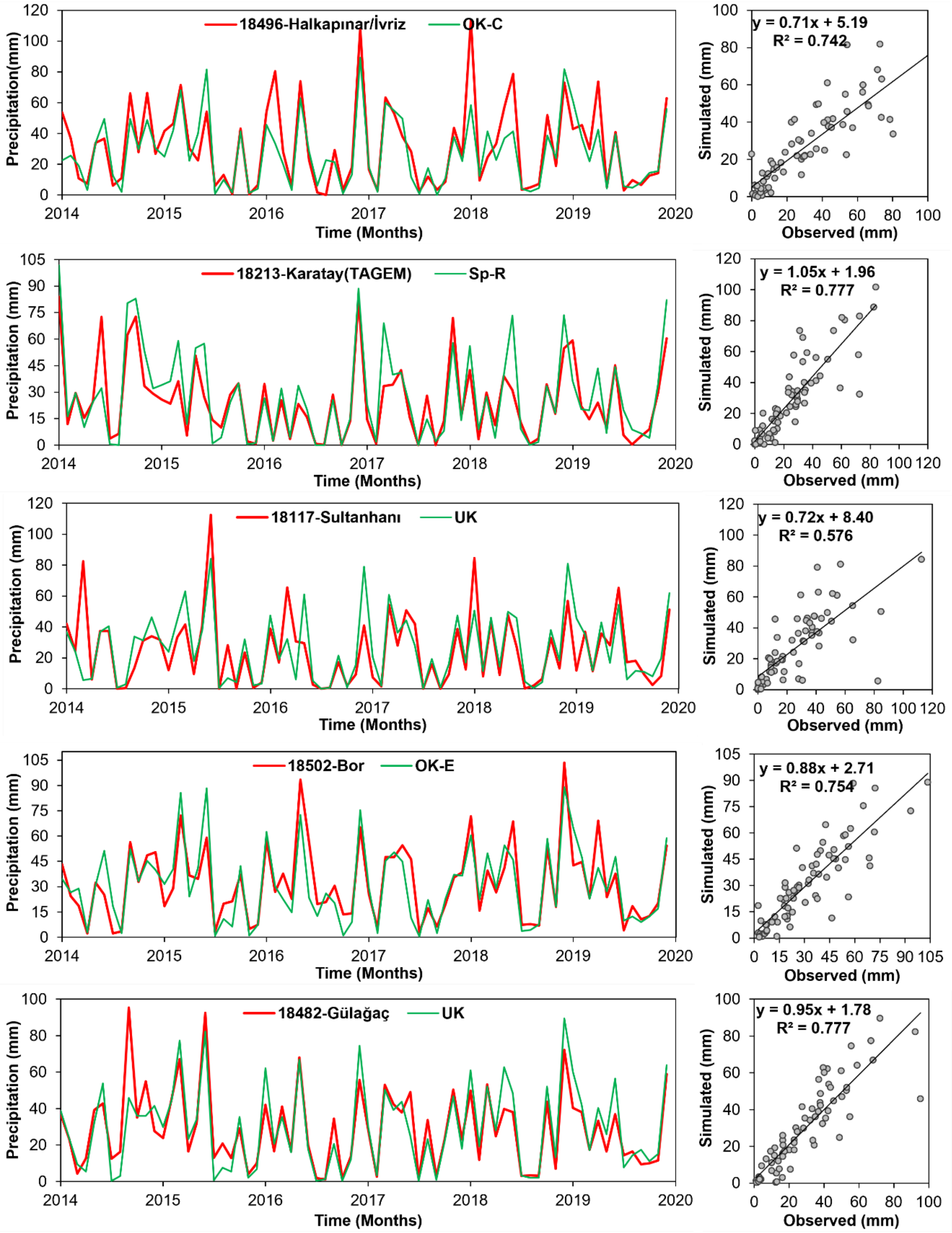


Figure 5. Time series and scatter diagrams for the period 2014-2019 (continued)

In the UK method, the monthly average precipitation is distributed between 26 and 57 mm. The amount of precipitation increases as it approaches the Antalya Basin. It is observed that the color and pattern distribution is less in the UK method compared to the other methods. In the OK methods, the monthly average precipitation amounts start from 25 mm and reach up to 82 mm. The most distinct pattern type is seen in the OK-C method, while the value ranges narrow and the patterns decrease in the OK-S, OK-G, and OK-E methods, respectively. It is seen that the maximum precipitation in the OK methods is around Seydişehir/Alacabel (S9), Derebucak (S16), and Seydişehir. Unlike these, the maximum precipitation is seen around Bozkır station and Cihanbeyli station in the OK-E method.

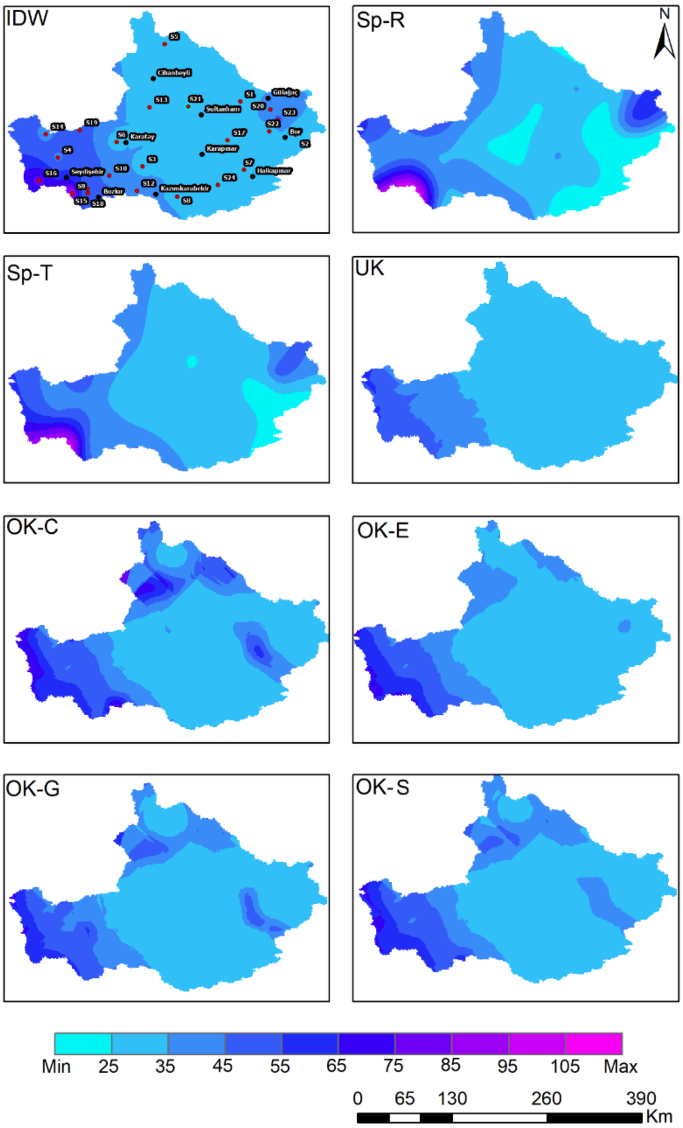


Figure 6. Spatial distribution of monthly total precipitation in KCB (2014-2019)

The model performance of the common test stations, Seydişehir, Cihanbeyli, and Karapınar stations, in the long and short periods was compared according to the NSE metric (Table 8). The most successful interpolation methods obtained in both periods are shown in bold in Table 8.

For monthly total precipitation estimation, the most successful model obtained in the long period at Seydişehir station was Sp-R with a value of NSE=0.561 (satisfactory), while the most successful model in the short period was the IDW method with a value of NSE=0.843 (very good). At Seydişehir station, NSE values always increased in all interpolation methods except Sp-R in the short period compared to the long period, and they exhibited higher success in estimating monthly total precipitation. The only method whose NSE value decreased in the short period compared to the long period was the Sp-R method. While the Sp-R method was the interpolation method that most successfully estimated the monthly total precipitation in Seydişehir in the long period, it was the method with the lowest estimation success in the short period. The NSE value obtained with Sp-R was at the "satisfactory" level with 0.561 in the long period, while it was at the "unsatisfactory" level with 0.397 in the short period.

Table 8. Performance values of interpolation models for long and short period

Station Name	Model Name	1971-2019		2014-2019		Change
		NSE	Performance	NSE	Performance	
17898 Seydişehir	**IDW**	0.503	Satisafactory	**0.843**	**Very Good**	↑
	Sp-R	**0.561**	**Satisfactory**	0.397	Unsatisfactory	↓
	Sp-T	0.556	Satisafactory	0.557	Satisafactory	↑
	UK	0.137	Unsatisfactory	0.627	Satisafactory	↑
	OK-C	0.409	Unsatisfactory	0.665	Good	↑
	OK-E	0.404	Unsatisfactory	0.536	Satisafactory	↑
	OK-G	0.370	Unsatisfactory	0.701	Good	↑
	OK-S	0.413	Unsatisfactory	0.622	Satisafactory	↑
17191 Cihanbeyli	IDW	0.719	Good	0.722	Good	↑
	Sp-R	0.659	Good	0.676	Good	↑
	Sp-T	**0.721**	**Good**	**0.739**	**Good**	↑
	UK	0.644	Satisafactory	0.666	Good	↑
	OK-C	0.605	Satisafactory	-20.252	Unsatisfactory	↓
	OK-E	0.294	Unsatisfactory	-1.762	Unsatisfactory	↓
	OK-G	0.710	Good	-31.908	Unsatisfactory	↓
	OK-S	0.566	Satisafactory	-15.837	Unsatisfactory	↓
17902 Karapınar	**IDW**	0.686	Good	**0.720**	**Good**	↑
	Sp-R	0.612	Satisafactory	0.203	Unsatisfactory	↓
	Sp-T	0.683	Good	0.685	Good	↑
	UK	0.513	Satisafactory	0.681	Good	↑
	OK-C	0.648	Satisafactory	0.672	Good	↑
	OK-E	0.319	Unsatisfactory	0.662	Good	↑
	OK-G	**0.704**	**Good**	0.678	Good	↓
	OK-S	0.601	Satisafactory	0.647	Satisafactory	↑

At Cihanbeyli station, the method with the highest prediction success was the Sp-T method with NSE values of 0.721 and 0.739 in the long and short periods, respectively. In addition, the Sp-T method showed a "good" level of performance. However, the IDW method showed a quite close prediction success to the Sp-T method, with NSE values of 0.719 and 0.733 in both periods. The performance of deterministic methods has increased slightly in the short term compared to the long term. Among the Kriging methods, there was an increase only in the UK in the short period. The performance of OK methods has decreased considerably in the short period and has always at an "unsatisfactory" level.

For Karapınar station, the most successful model in the long period was OK-G with a value of NSE=0.704, while the most successful model in the short period was IDW with a value of NSE=0.720. While NSE values decreased in the short period compared to the long period in OK-G and Sp-R models, higher NSE values were obtained in the remaining methods. The method that obtained the highest increase (decrease) in the NSE value in the short period compared to the long period was the OK-E (Sp-R) method. In 6 of the 8 interpolation methods applied in the short period at Karapınar station, a "good" level of prediction success was achieved with NSE>0.65. In the OK-S method, a "satisfactory" level of prediction success was achieved with NSE=0.647, and success very close to the "good" level was achieved. Only in the Sp-R method, an "unsatisfactory" level of success was achieved with NSE=0.203.

5. CONCLUSION

Interpolation methods are used in hydrological studies to estimate missing data, estimate the data needed at points where observation data is not available, and obtain spatial distribution. In this study, the usability of interpolation methods in estimating monthly total precipitation in KCB was investigated. For this purpose, 8 different interpolation methods were used. While the IDW and Spline methods [Regularized Spline (Sp-R) and Tension Spline (Sp-T)] were used as deterministic methods, OK and UK were used as geostatistical methods, and the estimation performance of all methods was compared. As semivariogram methods, circular (OK-C), exponential (OK-E), gaussian (OK-G), spherical (OK-S) were used for OK, while a Stable semivariogram model was used for the UK. In the study, applications were carried out with few stations in the 1971-2019 period and with many stations in the 2014-2019 period for monthly total precipitation.

In the period 1971-2019, 8 out of 11 stations were used in spatial distribution with interpolation methods, and the monthly total precipitation data for the remaining 3 stations (Seydişehir, Cihanbeyli, and Karapınar) were estimated. When the performance of the 8 different interpolation methods applied was evaluated, the values of 0.561 (satisfactory), 0.721 (good), and 0.704 (good) were obtained in precipitation estimation at Seydişehir, Cihanbeyli, and Karapınar stations according to the NSE metric, respectively. The most successful interpolation methods at Seydişehir, Cihanbeyli, and Karapınar stations were Sp-R, Sp-T, and OK-G, respectively.

In the period 2014-2019, the spatial distribution of monthly total precipitation was carried out using more stations. In this period, 24 of the 34 stations in the basin were used in the spatial distribution, and the monthly total precipitation values of the remaining 10 stations were estimated. In the most successful interpolation methods obtained at 10 test stations with 8 different methods used, NSE values ranging from 0.533 to 0.843 were obtained. While the lowest success with the value of NSE=0.533 was obtained at the "satisfactory" level in the OK-G method at Sultanhanı station, the highest success was obtained with the value of NSE=0.843 and at the "very good" level with the IDW method at Seydişehir station.

When the success of estimating monthly total precipitation values of Seydişehir, Cihanbeyli, and Karapınar stations, which are common test stations used in long and short periods, in both periods was evaluated, it was seen that the success of estimating monthly total precipitation increased in the short period where more stations were used in spatial distribution compared to the long period where fewer stations were used in spatial distribution. Importance should be given to the use of water resources and sustainable basin management policies throughout the country, and action plans that are in practice or will be implemented should be accelerated and finalized. Appropriate databases that are easy to access should be created for use in research.

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DECLARATION OF ETHICAL STANDARDS

Not applicable.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors contributed equally to the study's conception and design.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing interests.

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DATA AVAILABILITY

Not applicable.

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