COMPARISON OF SPATIAL INTERPOLATION METHODS FOR RAINFALL DATA OVER SRI LANKA

A L K Wijemannage[1], Manjula Ranagalage[2], E N C Perera[3]

[1]Department of Meteorology, Bauddhaloka Mawatha, Colombo 07, Sri Lanka.
Email: ajithlkw@gmail.com
[2]Department of Environmental Management, Rajarata University of Sri Lanka
Email: manjularanagalage@gmail.com
[3]Institute of Human Resources Advancement, University of Colombo, Sri Lanka
Email: chinssu@gmail.com

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Spatial variation of rainfall over Sri Lanka is not uniform due to topography and terrain. Higher resolution measurements of rainfall data are available only confined to the southwest quarter while over other parts these are of coarse resolution. Nevertheless, incomplete rainfall records due to either missing data, or un-even and insufficient spatial variability of station network is added to the complexity of estimating rainfall of the country. A good knowledge of rainfall distribution is very useful in water resource management, as well as planning for the future in many socio-economic activities and also in almost all research work. Therefore the necessity to have good interpolation techniques. Spatial interpolation method is one of the most common techniques frequently used to estimate values of meteorological parameters. In this study, five common interpolation techniques such as Inverse Distance Weighting (IDW), Ordinary Kriging (OK), Universal Kriging (UK), Spline (S) and Topo to Raster (TR) were compared and assessed against monthly total rainfall and annual total rainfall of about 300 rain gauge stations over Sri Lanka. ArcGIS software was used to generate the rainfall for unknown points and for missing areas. The accuracy of each method was assessed by the Mean Absolute Error (MAE), Standardized Root Mean Square Error (SRMSE) and Goodness of Prediction Measure (G). Quantitative assessment was done and there were considerable differences among the five interpolation methods. Kriging interpolation methods out of five methods performed better than the other three methods. However, the extreme values were underestimated in Kriging while those values from other three methods are quite better. In error matrices, minimum MAE and SRMSE values were obtained from OK and UK techniques. According to the MAE, SRMSE and G values, the OK and UK techniques are the most suitable for spatial interpolation methods of rainfall data over Sri Lanka.

1 INTRODUCTION

Rainfall is a very crucial meteorological parameter which is frequently required for the economic development, disaster management, water resource management, hydrologic and ecologic modeling, recharge assessment, and irrigation scheduling for the country. In Sri Lanka, rainfall plays an important role in agriculture as any shortages or excesses of rainfall gives way to a reduction in yields. Detailed knowledge of variations in rainfall is essential for proper water management practices. Thus, understanding the variations in rainfall both spatial and temporal and improving the ability of forecasting rainfall may help in planning crop cultivation as well as in designing water storages, planning drainage channels for flood mitigation etc. The last two decades frequencies and intensities of extreme rainfall were rapidly increased and it was caused soil erosion, landslides, flash flooding, changes in transportation systems and infrastructures. Changes in rainfall variability extent also affect agriculture, forestry and ecosystems, hydrology and water resources, human health, tourism and energy supplies.

There are 23 meteorological stations and more than 500 rain gauge stations, scattered throughout the country, maintained by the Department of Meteorology (DOM). These rain gauge stations are established in collaboration with agencies such as Department of Agriculture, Department of Irrigation, etc. The hardware required for the stations are supplied by the Department of Meteorology while daily measurements are performed by the personnel of collaborating agency. Some of the stations in this network operate uninterrupted for over 150 years. The daily observed rainfall information is communicated on near real time basis to the head-quarters of the Department of Meteorology where they are quality controlled and archived. At the same time they are also used in day-to-day weather services. Archived rainfall data are used by local as well as overseas researchers and other scientific personnel involved in climatological research. Furthermore, this data is also used for climatological purposes related to national development activities.

Measurements of rainfall data at higher resolution are confined only in southwest quarter of Sri Lanka while coarse resolution rainfall data over the other parts of the country **(Figure 1)**. However, rainfall records are often incomplete because of missing rainfall data in the measured period due to malfunctioning of rain gauge for specific time periods or insufficient stations in the country. So, if we have a technique to calculate missing values for the any given location rainfall which is very much benefited to water resource management as well as planning for the future. For almost all the research work, it is extremely important to have higher spatial resolution rainfall data all over the country. This problem can be overcome some extent by applying interpolation techniques.

Many studies have been dedicated to the comparison and evaluation of different spatial interpolation methods at various spatial scales all over the world (Yang et al., 2015). There are many varieties of spatial interpolation techniques and they can be classified into a few categories based on interpolation methods. To create a surface grid in ArcGIS, the Spatial Analyst extension employs one of several interpolation tools. Interpolation is a procedure used to predict the values of cells at locations that lack sampled points. It is based on the principle of spatial autocorrelation or spatial dependence, which measures degree of relationship/dependence between near and distant objects (Childs, 2011). ArcGIS Spatial Analyst offers several interpolation tools for generating surface grids from point data. These methods are Natural Neighbor, Thiessen polygons, Spline, Topo to Raster and various forms of Kriging and Inverse Distance Weighting (IDW) which are frequently used in interpolating rainfall data from rain gauge stations. It was revealed that, IDW is the most adequate rainfall interpolation method for coastal city of Annaba located in eastern Algeria, by using three interpolation techniques such as IDW, spline and ordinary kriging (Keblouti et al., 2012). The rainfall location network density is low in that city and there were significant differences between deterministic and stochastic interpolation methods. Assessment of four spatial interpolation methods of daily rainfall over Greater Sydney Region, reveal that similar patterns across the area, while kriging produced slightly different seasonal patterns (Yang et al., 2015). Although, it was not significant, IDW was slightly superior to the other methods. Spatial interpolation methods of quality control meteorological data over Taiwan, were evaluated and it was found that residual kriging was the best out of six different kriging based spatial interpolation methods, for temperature. Interpolation of precipitation spatial patterns was more complex than the temperature and there were no statistically significant difference among those six interpolation methods (Chiu et al., 2009). Rainfall interpolation over the Zambezi area in Southern Africa, the Multiple Realization Ordinary Kriging model (MROK), has proven to be particularly suitable for the weekly and monthly time steps and under relatively high spatial data availability (Matos et al., 2013). Ordinary Kriging and the Universal Kriging are the most optimal methods for interpolation mean monthly air temperature in Western Saudi Arabia (Eldrandaly and Abu-Zaid, 2011). In this study it was used six interpolation methods and OK and UK had the smallest errors compared with other four methods. Four interpolation methods, IDW, OK, UK and Spline were selected to generate the precipitation data for missing areas in South Korea, and the most accurate value was found with the OK, while IDW also generate values to the closest range (D. W. Jang et al., 2015). Another study, evaluated rainfall data from agro-ecological monitoring network for producing maps of total monthly rainfall in Sri Lanka (Plouffe et al., 2015). They compared four spatial interpolation techniques: IDW, thin-plate splines, ordinary kriging and Bayesian kriging. Bayesian kriging and splines performed best in low and high rainfall, respectively.

Optimization of different settings of the various interpolation methods has been carried out using a subset of the available rainfall dataset (modeling set) while the remaining subset (validation set) has been used to compare the results obtained by the different algorithms. The ordinary kriging of residuals from linear regression between precipitation and elevation, which has provided the best performance at annual and monthly scale, has been used to complete the precipitation monthly time series in Sicily, Italy (di Piazza et al., 2011). Using the geostatistical tools from ArcGIS, it was interpolated the data and filled in the areas with missing values by applying the future regional climate change results. The results have shown that Ordinary Kriging is the best methods for the reduction of the error from original climate change data for South Korea coastal (D. Jang et al., 2015). In this study, it was tried to develop a system to find rainfall in any location all over the Sri Lanka with closer to real value.

The knowledge of the rainfall distribution patterns is very important to achieve sustainability in agricultural production as well as water resource management and future planning. Rainfall data are generally recorded at point locations and the spatial distribution is un-even all over the country. Spatial variability of the rain gauge stations are not even and the complexity of the rainfall distribution is combined with the measurement difficulties. It is needed to have good interpolation techniques to overcome this problem and using spatial interpolation technique it can be estimated the values of unknown points with the help of known sample points. Also, it is extremely important to have higher spatial resolution rainfall data for the entire country in almost all the research work. Therefore, in this study it can be generated finer resolution gridded rainfall data for Sri Lanka and it will be more useful for future planning in various field of industry as well as further research studies.

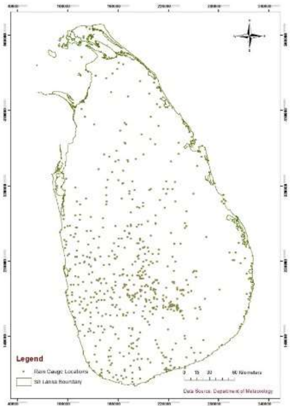

Figure 1 *Rain gauge locations over Sri Lanka*

1.1 Objectives

The major objective of this study is to analyze different interpolation methods with regard to their suitability to produce spatial rainfall estimates for the monthly total and the annual total rainfall. The specific objectives of the study are as follows:

- To identify the differences among each interpolation techniques over Sri Lanka.
- To find out the most suitable interpolation method for rainfall interpolation over Sri Lanka.

1.2 Study Area

The study area of this research is whole the country of Sri Lanka situated south of Indian sub-continent and having the area of 65,610 square kilometer **(Figure 1)**. Due to its location within the tropics between 5^o 55' to 9^o 51' North latitude and between 79^o 42' to 81^o 53' East longitude, and in the Asiatic monsoon region, the climate of the island could be characterized as both tropical as well as monsoonal. Topographical features influence strongly on spatial variation of climate in the island. The mean annual rainfall varies from under 1000mm in the southeastern and northwestern parts to over 5000mm in the western slopes of the central highlands. The mean annual temperature varies from 27^0C in the coastal lowlands to 16^0C at Nuwara Eliya, in the central highlands (1900m above mean sea level). The highlands, mostly above 300 meters, occupy the south central part of Sri Lanka with numerous peaks (Pidurutalagala -2524 m, Kirigalpotte - 2396 m), high plateaus and basins are surrounded by an extensive lowland area. This relatively unique feature manifesting as sunny beaches to rain forests inland is a tourist attraction. The island is seasonally affected by two regional scale wind regimes. The Southwest monsoon is from May to September and the Northeast monsoon from December to February. The inter-monsoon periods, the transition periods between the two monsoons are, from March to April and from October to November. The rainfall during these inter-monsoon periods is mainly due to convective thunderstorm activity. It is characteristic to have long spells of dry days over most parts of the country except in the north and east during January and February, with ground frost appearing in the central hills where vegetables are grown.

2 MATERIALS AND METHODS

In recent years, some researchers developed many modified interpolation methods (Chai et al., 2011). Several interpolation methods were used in the climate mapping: global interpolators (trend surfaces and regression models), local interpolators (Thiessen polygons, inverse distance weighting, splines), geostatistical methods (simple kriging, ordinary kriging, block kriging, directional kriging, universal kriging and co-kriging) and mixed methods (combined global, local and geostatistical methods) (Vicente-Serrano et al., 2003).

In this study, about ~350 rain gauges were spatially interpolated using five different interpolation methods such as Inverse Distance Weighting (IDW), Ordinary Kriging (OK), Universal Kriging (UK), Spline (S) and Topo to Raster (TR) and they were compared and assessed against monthly total rainfall and annual total rainfall data over Sri Lanka.

2.1 Materials

This research used *ESRI ArcGIS* to produce the precipitation data by applying the spatial interpolation method to missing area, where the rainfall data is not provided and also the area where the observations were not carried out and achieved the mentioned objectives. All five different interpolation methods mentioned above were tested for the whole country. Two types of rainfall data from about 350 rain gauge stations were used in this study and those were collected from Sri Lanka Department of Meteorology for four years such as 2000, 2005, 2008 and 2010. These were the monthly total rainfall data for months January, April, July and November in year 2005 and 2010 and annual total rainfall data for year 2000, 2005, 2008 and 2010. Months selected from different seasons such as, January from northeast monsoon, April from first inter-monsoon, July from southwest monsoon and November from second inter-monsoon. Before use the data for the experiment, all the data were quality controlled.

2.2 Methods

2.2.1 Spatial Distribution of rain gauge locations

Data for ~400 rain gauge stations were collected initially. The stations which are having missing rainfall records for some periods, having outliers and missing Meta data were removed. Besides, wrong coordinates, or the use of different units, there were some of these errors caused by extreme monthly total as well as extreme annual totals values. After data quality gap analysis, remove some stations with errors, and finally, the database of rainfall records consisted ~350 locations **(Figure 2)**. The geographical distribution of locations is not random and more stations are in southwest quarter of the country as well as a few stations are distributed in other areas. The higher density locations are mostly hilly areas in the country and it was helped to improve the interpolation techniques over central hills of the country.

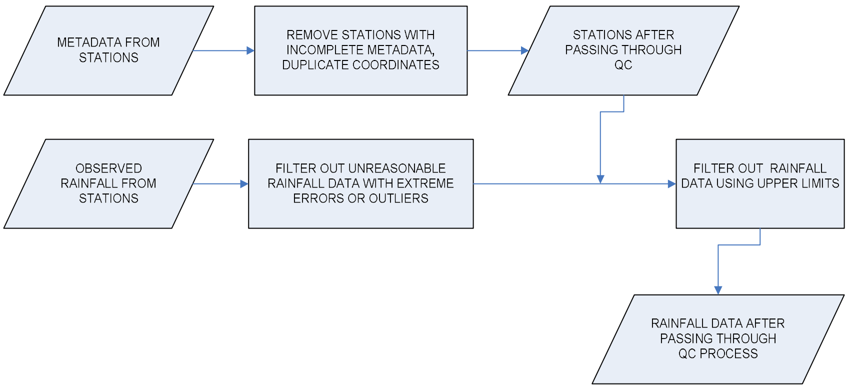

Figure 2 *Flow chart of selecting rainfall stations and getting the data sample for study*

At the beginning, these ~350 locations were split into two groups and they were the group of locations for interpolation procedure and the group of locations for verification of interpolated data. The small group contained 25 different locations from the all over the Sri Lanka. This small group represents the locations such as high dense as well as the low dense locations area. The bigger group used for the model interpolation while the small group for the cross validation. The coordinates of the locations were rounded up to one decimal place of degree and it lead to a little shift from correct location.

2.2.2 Accuracy Assessment

To select the most suitable interpolation method out of above mentioned five different interpolation techniques, the output values and actual ones were quantitatively compared by excluding the values of certain points in the data series. Mean Absolute Error (MAE) **(equation 1)**, Standardized Root Mean Squared Error (SRMSE) **(equation 2)** and Goodness of prediction measure (G) **(equation 3)** analysis were conducted to evaluate the spatial interpolation method, and the optimum spatial interpolation method were determined by minimizing those errors.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i| \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(1)}$$

$$SRMSE = \frac{\sqrt{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}}{\frac{1}{n}\sum_{i=1}^{n} y_i} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(2)}$$

$$G = \left(1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}\right) \times 100 \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(3)}$$

Where, y_i is a value observed from position *i* and $\hat{y}_i$ is a value estimated for position *i,* n is number of data points and $\bar{y}$ is the research average. The estimated value is more accurate, when the calculation value of MAE and SRMSE are smaller. Besides, if G value is '100' it is a perfect estimation but if it is a negative value, it is less reliable than the predictor is used as an average of data values (D. W. Jang et al., 2015).

3 RESULTS AND DISCUSSION

Cross validation is used to compare observed values with interpolated values using only the available data in the sample data set. The observed values at particular points were temporarily discarded from the sample data set, and the value at the same locations were estimated using the remaining sample data. Monthly total rainfall for four selected months (January, April, July and November) in year 2005 and 2010 and annual total rainfall for year 2000, 2005, 2008 and 2010 were interpolated using five Geographic GIS based interpolation techniques (IDW, OK,UK, S and TR). For this, ~350 rain gauge stations data were used to interpolation and verification the outputs using 25 stations sample which stations were not used to interpolation methods.

The interpolation methods can be divided into two major groups: deterministic and geostatistical (Keblouti et al., 2012). The deterministic interpolation methods assign values to locations based on the surrounding measured values and on specified mathematical formulas that determine the smoothness of the resulting surface. The deterministic methods include IDW, Natural Neighbor, Trend, and Spline. The geostatistical methods (is also called stochastic methods) are based on statistical models that include autocorrelation (the statistical relationship among the measured points). Because of this, geostatistical techniques not only have the capability of producing a prediction surface but also provide some measure of the certainty or accuracy of the predictions. Kriging is a geostatistical method of interpolation. The remaining interpolation tools, Topo to Raster and Topo to Raster by File, use an interpolation method specifically designed for creating continuous surfaces from contour lines, and the methods also contain properties favorable for creating surfaces for hydrologic analysis.

It is important to consider the spatial distribution of the rainfall over Sri Lanka using the spatial pattern and the spatial structure of the interpolation data in order to carryout accuracy assessment. To compare the spatial pattern of the interpolation methods, it is needed to have correct spatial distribution of rainfall for the relevant period. In this study, only spatial structures were assessed as it was difficult to prepare the perfect rainfall map for Sri Lanka using those coarse resolution point observations. The interpolation rainfall maps were prepared in monthly and annual time scales at a ground resolution of 100 m for the whole country, and the spatial structures were assessed using a few statistical methods.

3.1 Evaluation of the accuracy of spatial interpolation techniques

Spatially interpolated data was generated and estimated precipitation value was filled the missing areas by using spatial analyst tools from ArcGIS. Spatial maps of monthly total rainfall distribution were prepared from each interpolation methods for January, April, July and November in year 2005 and 2010 were displayed **(Figures 3 & 4)**. The annual total rainfall distribution maps of each interpolation methods for year 2000, 2005, 2008 and 2010 were prepared and displayed in **Figures 5**. Among the all spatial maps of rainfall distribution, there is clear difference in each method. On examining the interpolation maps of monthly total rainfalls, it was clear that the highest spatial rainfall was received majority of the country in November in year 2005 and 2010, while annual total rainfall visualized the same pattern in year 2010. It showed in each spatial maps and it was clear that, highest amount of rainfall always received southwest quarter of Sri Lanka.

When compare the interpolation maps, variation of estimate values were less in OK and UK methods, while other three methods were having more extreme estimate values and the variation also considerably high. Each interpolation method produced similar spatial patterns of monthly and annual rainfall distribution in eastern and northern areas of the country. The reason of the similar pattern might be sparse locations of observations. The spatial pattern of northwestern and southeastern areas were slightly different. The other areas especially, southwest quarter of Sri Lanka, central hills and inland areas showed different spatial pattern for each method. The reason of considerable difference for each model is that high spatial resolution of rain gauge locations in southwest quarter of the country.

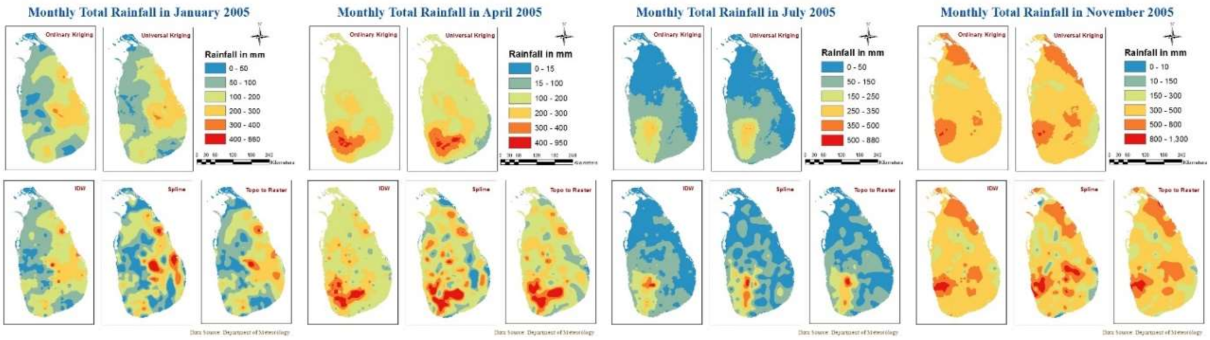

Figure 3 *Spatial interpolation distribution of all interpolation methods for January, April, July and November monthly total rainfall in year 2005.*

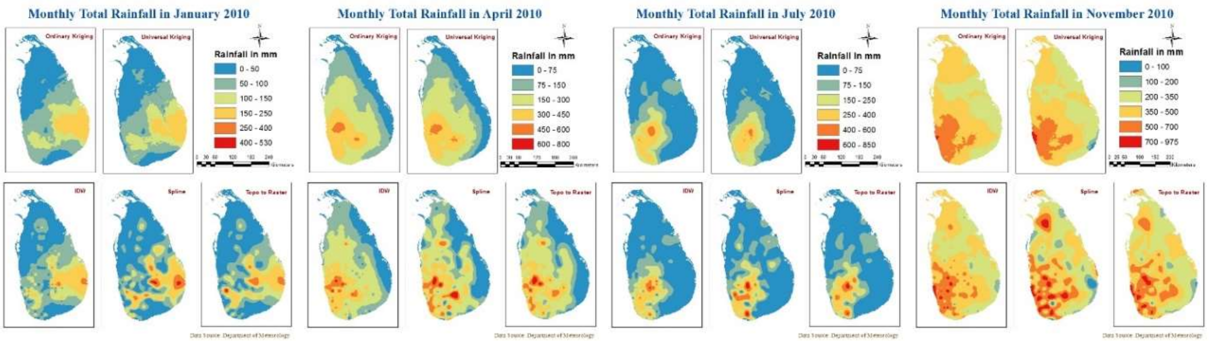

Figure 4 *Spatial interpolation distribution of all interpolation methods for January, April, July and November monthly total rainfall in year 2010*

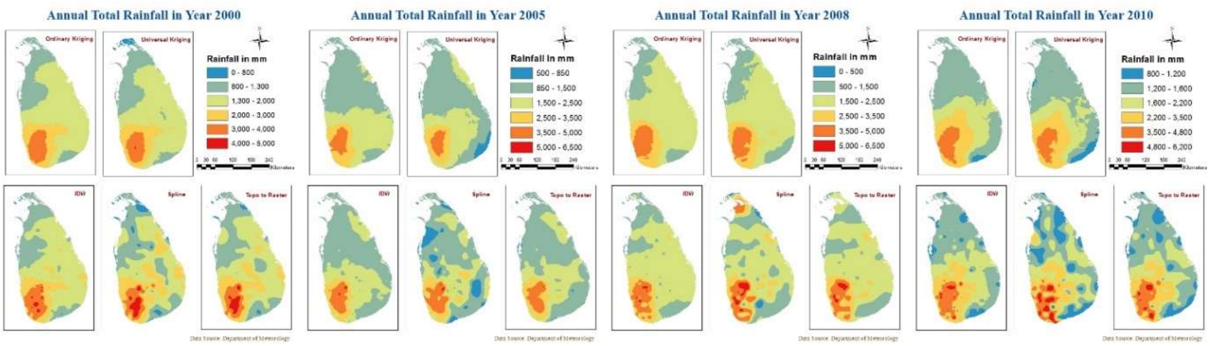

Figure 5 *Spatial interpolation distribution of all interpolation methods for year 2000, 2005, 2008 and 2010 annual total rainfall.*

The cross validation technique was achieved by removing data from 25 locations, taken all of the available data from other locations and then estimating the value of the removed locations data using those remaining data. This validation test was given the evaluation about how well neighboring stations estimate the unknown value using previously described interpolation methods. Before evaluate the interpolating techniques using error measuring statistics, it is important to compare about maximum, minimum, average and standard deviation between the observation and interpolation data. The comparisons between the observation rainfall and the rainfall values derived from the interpolated maps were carried out for 25 locations which were not used to estimating procedures for the years 2000, 2005, 2008 and 2010 and January, April, July and November in 2005 & 2010 **(Tables 1 & 2)**.

Table 1 *Maximum (Max), Minimum (Min), Average, and Standard Deviation (Std. Dev.) of monthly total rainfall in millimeter of the observation and estimation results of the spatial interpolation methods for January, April, July and November in year 2005 & 2010*

Period	Comparison Factor	Rainfall Observation	Interpolation Results IDW	OK	UK	S	TR
January 2005	Max	535.0	535.0	349.4	310.0	534.5	531.2
	Min	0.0	0.0	0.0	0.0	-9.3	0.0
	Average	111.6	105.1	108.9	110.9	106.3	108.4
	Std. Dev.	81.8	90.7	62.9	57.5	83.9	78.0
April 2005	Max	1081.0	718.9	426.2	448.5	707.9	708.5
	Min	3.5	0.0	0.0	0.0	0.0	0.0
	Average	224.1	208.5	213.6	209.7	206.6	217.2
	Std. Dev.	133.0	126.1	84.8	89.9	125.4	125.8
July 2005	Max	1169.5	884.0	341.0	343.6	617.2	711.1
	Min	0.0	0.0	0.0	-4.2	-26.2	0.0
	Average	130.0	130.0	124.8	117.1	122.1	125.9
	Std. Dev.	133.5	154.2	86.7	87.1	118.7	125.3
November 2005	Max	1054.0	1054.0	819.7	818.1	1053.9	1054.0
	Min	0.0	0.0	0.0	0.0	0.0	0.0
	Average	447.8	423.2	425.1	426.8	425.7	430.4
	Std. Dev.	188.0	212.6	152.5	156.6	205.0	195.6
January 2010	Max	783.0	366.2	228.2	227.2	366.6	538.0
	Min	0.0	0.0	10.3	3.7	-0.4	0.0
	Average	87.6	85.0	83.6	83.2	82.3	88.1
	Std. Dev.	89.9	75.4	45.8	46.8	75.1	77.1
April 2010	Max	836.2	712.4	529.0	528.1	793.1	706.0
	Min	0.0	0.0	14.5	-25.1	-0.2	0.0
	Average	275.4	263.2	272.2	268.6	272.4	272.9
	Std. Dev.	162.8	158.1	114.2	118.4	161.0	149.5
July 2010	Max	920.5	687.2	556.3	428.6	836.6	693.3
	Min	0.0	0.0	3.6	0.9	-0.1	0.0
	Average	176.1	170.2	165.9	159.8	168.8	175.7
	Std. Dev.	169.5	162.2	124.0	112.0	156.1	160.8
November 2010	Max	996.1	971.5	798.6	813.8	970.1	856.3
	Min	61.9	61.9	220.5	197.0	63.7	62.7
	Average	458.9	455.2	456.7	455.6	456.8	456.0
	Std. Dev.	160.8	160.8	112.2	102.5	156.7	143.4

Table 2 *Maximum (Max), Minimum (Min), Average, and Standard Deviation (Std. Dev.) of Annual total rainfall in millimeter of the observation and estimation results of the spatial interpolation methods for year 2000, 2005, 2008 and, 2010.*

Period	Comparison Factor	Rainfall Observation	Interpolation Results IDW	OK	UK	S	TR
2000	Max	4949.2	4420.8	3855.1	3866.3	4944.3	4624.5
	Min	748.0	748.0	894.1	675.8	748.3	748.0
	Average	2135.9	2143.9	2149.6	2113.0	2142.6	2146.4
	Std. Dev.	865.5	855.0	675.4	671.0	887.7	839.2
2005	Max	6581.9	6581.8	4290.4	4188.3	5052.5	5092.4
	Min	816.0	888.0	1062.5	906.2	816.6	887.9
	Average	2224.2	2328.6	2209.9	2165.7	2170.0	2229.1
	Std. Dev.	1044.4	1116.7	873.6	819.9	1031.9	992.2
2008	Max	7159.1	5814.4	4733.8	4690.3	6151.1	5808.6
	Min	855.7	855.8	1217.3	1105.9	943.2	943.7
	Average	2570.2	2464.9	2556.8	2531.8	2586.6	2562.7
	Std. Dev.	1184.5	1130.4	870.2	861.9	1136.8	1099.2
2010	Max	6952.8	6173.8	4370.9	4285.3	6178.4	6173.5
	Min	830.1	830.4	1042.5	915.6	839.4	840.3
	Average	2639.7	2649.3	2558.9	2516.0	2585.5	2619.0
	Std. Dev.	1244.5	1261.3	869.4	853.0	1171.9	1155.8

The month of January had the lowest rainfall in both year 2005 and 2010. The monthly total maximum rainfall was obtained in July 2005 while the lowest monthly total from January 2005. The maximum values were always considerably underestimated, when used ordinary kriging and universal kriging while other three methods were estimated a bit closer values. The minimum values were overestimated mostly when used the ordinary kriging and universal kriging except a few cases in July 2005, April 2010 and year 2000 which were underestimated. The average rainfall for each interpolation method was very closer to the real value of average. Standard deviations were also underestimated when used ordinary kriging and universal kriging but the other three methods were estimated to closer of real values **(Tables 1 & 2)**. Therefore the variation of estimated values of both kriging methods were low when compare with the other three methods.

The monthly and annual total rainfall values from the five interpolation methods were used in the assessment and evaluation. In this study, MAE, SRMSE and G were compared from the five interpolation methods and the results are presented in **Tables 3 and 4**. The MAE values of monthly total rainfall were similar for ordinary kriging and universal kriging and most of the times lower than other three methods and only a bit higher to the IDW and the topo to raster methods in April 2005 and November 2010 (the range of difference values was from 0.7 to 4.4 mm). The lowest MAE values for OK and UK are 32.1 and 31.4 respectively **(Table 3)**. Therefore the MAE values were lowest for OK and UK six times out of eight. The MAE values for annual total rainfall also nearly similar for both OK and UK methods and lowest three times out of four. Only year 2000, MAE values were lower in IDW and TR methods and difference with OK and UK were considerably low. According to this MAE analysis, OK and UK are the most optimum interpolation methods out of these five methods.

Table 3 *Mean Absolute Error (MAE) and Standardized Root Mean Squared Error (SRMSE) between observed rainfall (monthly total & annual total in mm) and interpolations of testing stations sample for given months and years*

Period	MAE				
	IDW	OK	UK	S	TR
Jan - 2005	47.1	32.1	31.4	42.1	37.4
Apr - 2005	49.5	52.5	53.9	69.7	51.8
Jul - 2005	77.4	45.0	47.8	55.3	53.6
Nov - 2005	113.6	76.7	71.3	126.4	89.3
Jan – 2010	54.9	39.9	42.4	45.8	42.3
Apr – 2010	89.6	65.6	72.9	108.6	105.4
Jul – 2010	85.7	62.7	66.2	73.0	85.4
Nov - 2010	75.8	77.2	80.1	92.9	76.5
2000	302.3	368.7	356.9	445.0	311.6
2005	338.8	286.9	299.6	408.8	355.4
2008	413.4	370.3	403.2	467.1	381.4
2010	581.0	439.8	461.5	537.8	549.5
Period	**SRMSE**				
	IDW	**OK**	**UK**	**S**	**TR**
Jan - 2005	0.814	0.419	0.392	0.575	0.537
Apr - 2005	0.333	0.288	0.321	0.435	0.333
Jul - 2005	0.022	0.034	0.041	0.022	0.026
Nov - 2005	0.025	0.019	0.016	0.019	0.020
Jan – 2010	0.872	0.712	0.714	0.759	0.765
Apr – 2010	0.471	0.297	0.326	0.491	0.484
Jul – 2010	0.019	0.020	0.022	0.022	0.025
Nov - 2010	0.006	0.013	0.011	0.006	0.006
2000	0.187	0.207	0.201	0.261	0.179
2005	0.181	0.164	0.168	0.233	0.194
2008	0.003	0.002	0.003	0.002	0.003
2010	0.005	0.004	0.004	0.003	0.004

Table 4 *Goodness of prediction measure (G) between observed rainfall (monthly total & annual total in mm) and interpolations of testing stations sample for given months and years*

Period	**G**				
	IDW	**OK**	**UK**	**S**	**TR**
Jan - 2005	-175.9	27.0	36.1	-37.7	-20.1
Apr - 2005	20.8	33.3	22.7	-28.7	23.5
Jul - 2005	-70.0	69.9	67.7	56.1	54.3
Nov - 2005	-8.9	51.5	55.4	-77.2	31.1
Jan – 2010	-1.6	32.4	31.9	23.1	21.8
Apr – 2010	-32.3	40.7	30.1	-79.1	-52.2
Jul – 2010	55.1	77.5	72.0	64.0	52.2
Nov - 2010	37.8	41.1	36.6	-10.7	24.1
2000	78.1	73.1	74.6	57.2	80.0
2005	74.9	81.1	81.2	64.4	74.5
2008	70.9	78.4	77.4	68.7	79.4
2010	38.0	73.3	69.9	56.0	51.6

The SRMSE values for annual total rainfall are noticeably lower than the monthly total rainfall values (these values < 0.2) and most of the times these SRMSE values were lowest for OK and UK than the other three interpolation methods. Only a few cases SMRSE of OK and UK were higher than other three methods **(Table 4)**. Therefore, when we consider the SRMSE statistics, the OK and UK interpolation methods are superior to the other three methods. The goodness of prediction measure (G) values of IDW, S and TR were negative several times for both annual and monthly total rainfall, while the G values always positive for both OK and UK methods **(Table 4)**. If G is equal 100 mean, the estimates are perfect. Although, it is difficult to find G value as 100, most of the times G is greater than 50 for OK and UK. The highest G value (81.1) was given for OK method in Jan 2005 (for monthly total rainfall), while the worst G value (-175.9) was given for IDW in year 2005 (for monthly total rainfall). The average values of MAE and SRMSE of all period for monthly total rainfall and annual total rainfall were calculated and the lowest values were given for OK and UK. Both kriging interpolation methods have higher accuracy than the other three interpolation methods. The ordinary and universal kriging methods were generally best for the low rainfall situation while these two methods have failed to produce extreme values. These results were coincided with the previous studies and according to the MAE, SRMSE and G statistics, the most suitable interpolation methods for rainfall data over Sri Lanka are Ordinary Kriging and Universal Kriging (D. Jang et al., 2015), (di Piazza et al., 2011), (D. W. Jang et al., 2015), (Yang et al., 2011).

4 CONCLUSION AND RECOMMENDATION

The two interpolation methods Ordinary Kriging and Universal Kriging performed similarly well. These two methods are the optimum methods for interpolating monthly and annual total rainfall in Sri Lanka while the other three methods are quite better than above two methods when estimating extreme values. However, maximum values are underestimated and minimum values are over estimated when using both kriging methods. Comparisons amongst the three spatial interpolation methods; IDW, spline and topo to raster, showed that the topo to raster method occasionally, performed worst, while IDW and spline performed well, against extreme conditions. The spatial distribution of interpolated monthly total rainfall differed noticeably among the seasons. Certain methods performed better dependent on the month, although they were performed worst in some cases.

The aim of this study, was the comparison of various interpolation techniques and finalized to estimate the missing or not measured data in precipitation observations. From the comparison of those five interpolation methods, it has been observed that the best performances have been obtained with ordinary kriging and universal kriging. These results are in agreement with the results of the previous researches in many countries.

In Sri Lanka the network of the precipitation measuring stations is sparse and available data are insufficient to characterize the highly variable precipitation and its spatial distribution. This study is limited to one monthly total from each climatic season in 2005, 2010 and annual total from year 2000, 2005, 2008 & 2010 due to time limitation. It will have more confident result with more diversified verification by adding utilization and analysis points of different daily, monthly and yearly precipitation data. In this study, it was used five different interpolation techniques only. It is recommended to carry out the researches, using all the interpolation methods, considering more heavy rainfall and low rainfall cases, it must be tested in order to select the best interpolation technique to the country in future.

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