Original Research article

A GIS-based Approach to Spatially Explicit Mean Monthly Areal Rainfall Estimation of Krishna District

Abstract

Rainfall analysis is pivotal for understanding hydrological systems, crucial for effective water resource management. In this study spatial rainfall analysis is carried out for Krishna District of Andhra Pradesh using ArcGIS software. Rainfall data for a period of 30 years(1992-2021) was collected from the Directorate of Economics and Statistics, Vijayawada, Andhra Pradesh. Utilizing the spatial interpolation techniques in Geographic Information System(GIS) software, mean monthly areal rainfall was found using the three methods viz., Arithmetic mean, Thiessen's polygon and isohyet method. This study utilized Geographic Information Systems (GIS) to visualize spatial patterns of rainfall across Krishna district. To account for missing data in the rainfall record, the normal ratio method was implemented. Spatial maps were generated to depict mean monthly areal rainfall variations. The analysis yielded mean monthly areal rainfall for Krishna district as 84.72 mm, 85.22 mm and 83.97 mm using the arithmetic mean, Thiessen polygon and Isohyet methods, respectively.Isohyet method is considered to be more accurate and rainfall is the basic data required for all hydrological analysis as an input layer for runoff generation, water resources planning, evapotranspiration studies, crop planning, flood estimation and water budget estimations etc.

Keywords: Areal Rainfall, spatial interpolation, thiessen polygon, isohyet

1. Introduction:

Rainfall serves as a critical dataset, essential for water resource management, hydrological and ecological modelling, recharge assessment and irrigation scheduling. It constitutes a fundamental aspect of the hydrological cycle, with its variability and analysis holding significant importance for various hydrological models (Cheng et al., 2012).For studies such as rainfall-runoff models, accurate estimate of areal rainfall is required and to improve hydrograph prediction results a dense network of rainfall stations covering the basin is preferred. However many constraints, such as topographic variations, budget limitations, inaccessible areas etc., limit the rainfall gauging stations. In all such conditions spatial interpolation of precipitation is required for all the hydrological studies.

Spatial interpolation of rainfall data using Geographic Information Systems (GIS) has been extensively explored in hydrological research, agriculture, urban planning, environmental management and water resource management.Cai*et al.* (2024) studied the impacts of temporal/spatial rainfall heterogeneities on peak runoff distribution for a river basin of South China.Pan *et al.* (2024) investigated the impact of temporal and spatial resolution of rainfall data on watershed flood simulation performance.

Researchers have investigated various interpolation techniques within GIS platforms to accurately estimate rainfall distribution across landscapes by averaging rainfall depths recorded at ground stations. GIS had been used effectively worldwide for spatial mapping(Al-ozeer, 2020 and Anand, B. and Karunanidhi, D., 2020).Hari, D.S. and Reddy, K.R. (2022) analysed the annual and seasonal rainfall patterns with over 30 years rainfall data for Hyderabad city by using statistical tools and GIS interpolation techniques. Abhijeet*et al.*, (2023) analysed the 21 years annual rainfall data of Satara district, Maharashtra and studied spatial distribution of annual rainfall utilizing interpolation techniques in the ArcGIS software.

Conventional methods such as the isohyetal and thiessen polygon techniques are commonly utilized for this purpose, particularly to estimate the areal rainfall across entire basins. (Tabios and Salas, 1985). The choice of interpolation method varies based on the characteristics of the watershed. In many studies, spatial interpolation is typically applied using monthly or annual time intervals for precipitation mapping. (Ly *et al.* 2013). Thiessen polygons are a simple but effective method for areal interpolation of rainfall data. Research conducted by Javadian*et al.* (2018) evaluated the performance of thiessen polygons in estimating rainfall distribution and found it to be suitable for applications requiring quick and straightforward interpolation.The arithmetic average and isohyets methods excel in accurately calculating average rainfall in hilly terrain, whereas the Thiessen polygon method is better suited for computing rainfall in flat or less rugged areas (Chowdary*et al*., 2016).This study aims at calculating the mean monthly areal rainfall of Krishna District, Andhra Pradesh using three different methods viz., Arithmetic mean, Thiessen Polygon and Isohyet methods.

2. Material and Methods:

2.1. Study Area:

Rainfall analysis is carried out for Krishna District of Andhra Pradesh. It consists of about 25 mandals with a total geographical area of 3679 sq. km. It is located between longitude $80^{0}71'$ and $81^{0}54'$ Eand latitude $15^{0}71'$ and $16^{0}47'$ N. It has a tropical climate with hot summers having its peak in May. South west monsoon yields most of the rainfall received in the district and is followed by North East monsoon. Majorly grown agriculture crops are paddy, cotton, sugarcane, maize, groundnut and pulses. Black cotton soils covers the highest proportion of study area.

2.2. Rainfall Data and software: Daily rainfall data for 30 years period from 1992-2021 was collected for all the mandals in the Krishna District from the Department of Economics and Statistics, Vijayawada, Andhra Pradesh. Table 1. Shows the details of rain stations with in the study area for which the data was procured. From the collected rainfall record, monthly averages were calculated for all the 25 stations in the study area (Table.1). It was found that certain data was missing especially in the period of 1992-2000 for certain stations. Normal ratio method was used to find out the missing rainfall data because for selective missing stations the coefficient of variation was found to be >10%. Monthly average of precipitation for the mandals in the Krishna district was calculated. Finally an excel sheet was prepared with mandal name, longitude, latitude and mean monthly rainfall in mm and is saved in .csv format to be imported into GIS software from which a point shape file was generated.

Spatial maps were generated to conclude the final mean areal rainfall using AcGIS10.3 software. This interface was used to generate polygons around the rain stations, calculation of polygon areas and also for generation of isohyet maps. Spatial Interpolation of mean monthly rainfall data of Krishna District is carried out using thiessen polygon and Isohyet methods from which the areal rainfall is calculated following the procedures described in the sub sequent sections. With all the procedures, the final results are obtained from the maps generated in the UTM coordinate system.

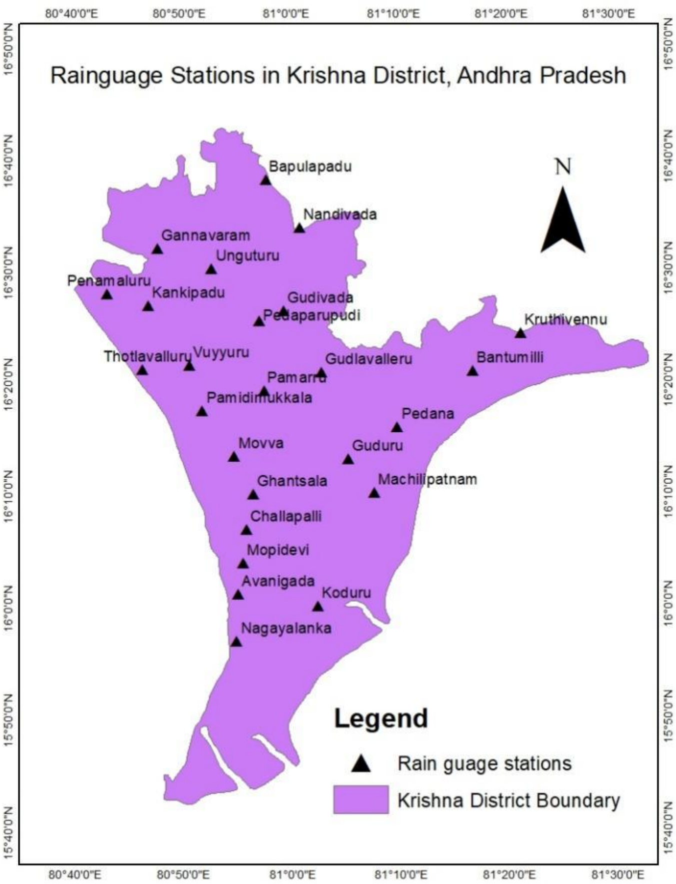

Fig. 1. Study Area with point rainfall stations

Table 1: Details of rain stations in the Krishna District

Sl.No.	Mandals	Longitude	Latitude	Elevation, m
1	Bantumilli	81.2833	16.35	4
2	Bapulapadu	80.9661	16.6363	19
3	Gannavaram	80.7987	16.5357	23
4	Gudivada	80.9926	16.4410	9
5	Gudlavalleru	81.05	16.35	8
6	Kruthivennu	81.3577	16.4058	3
7	Unguturu	80.8816	16.505	9
8	Pedaparupudi	80.9548	16.426	9
9	Nandivada	81.0183	16.565	4
10	Vuyyuru	80.8461	16.3602	13
11	Pamidimukkala	80.8661	16.2925	11
12	Kankipadu	80.7833	16.4500	14
13	Pamarru	80.9612	16.3229	8
14	Challapalli	80.9333	16.1167	8
15	Ghantsala	80.9442	16.1693	9
16	Mopidevi	80.9276	16.0667	7
17	Movva	80.915	16.225	8
18	Koduru	81.0416	16.0022	3
19	Avanigada	80.92	16.0197	10
20	Guduru	81.09	16.22	5
21	Nagayalanka	80.9167	15.95	6
22	Machilipatnam	81.13	16.17	9
23	Pedana	81.1667	16.2667	7
24	Penamaluru	80.7194	16.4680	21
25	Thotlavalluru	80.7741	16.355	12

2.3.Data Analysis Techniques

A. Normal Ratio Method:

This method is used if any particular stationhad the normal annual precipitation exceeding 10% of the considered station. This weighs the effect of each surrounding station (Singh, 1994). The missing data are estimated by,

$$P_x = \frac{1}{m}\sum_{i=1}^{m}\frac{N_x}{N_i}P_i$$

Where, P_x = Estimate for the missedstation

P_i = Rainfall values of rain gauges used for estimation

N_x = Normal annual precipitation of X station

N_i = Normal annual precipitation of surrounding stations

m = No. of surrounding stations

B. Arithmetic mean method:

The arithmetic average method operates under the assumption that rain gauge records are independent and that rainfall across the entire catchment is uniform (Tao Zhang, 2016). This technique computes the mean monthly areal rainfall (MMAR) by taking the unweighted average of rainfall values from all stations within the designated area. It is suitable when rain gauges are evenly distributed across a relatively small area. The MMAR is calculated by summing the average rainfall observed at each station within the catchment and dividing it by the total number of stations, as illustrated by the equation below (Al-ozeer, 2020 and Anand and Karunanidhi, 2020).

$$P_{avg} = \frac{1}{n}\sum_{i=1}^{i=n} P_i$$

Where, P_{avg} =MMAR according to this method

P_i= Rain recorded at the station

n=Total number of stations.

C. Thiessen's Polygon Method:

The thiessen polygon method relies on spatial interpolation through proximal mapping (Malik et al., 2019). This technique assigns a constant weight for mean monthly areal rainfall (MMAR) based on proximity to the nearest rain station, assuming uniform rainfall distribution across all stations. This assumption holds true when rainfall coverage is extensive, homogeneous and over flat terrain (Tao Zhang, 2016). The formula for calculating the MMARusing this method is given below in the equation (Al-ozeer, 2020)

$$P_{avg} = \frac{A_1P_1 + A_2P_2 + \cdots + A_nP_n}{\sum_{i=1}^{n} A_i}$$

Where P_{avg}=Mean Monthly Areal Rainfall according to this method,

A= Polygon's area,

n= number of used polygons,

P= Mean monthly precipitation of the rain station.

In Arctool box, "Create Thiessen Polygons" tool under Proximity of Analyst tools was used to create polygons from the point shape confined to the Krishna district boundary. The created polygons were clipped to the administrative boundary and then projected to UTM coordinate system, where in the linear distances are defined in meters. In the attribute table, polygon area was calculated in square kilometres by adding new field. Finally the attribute table is then exported for calculation of mean monthly areal rainfall as per equation above.

D. Isohyet method:

Isohyet involves delineating equal rainfall contours across the catchment's map (Limin et al., 2015). These contours are then divided into marked sections, with rain gauge station values assigned within each section, including those from neighbouring stations outside the catchment boundary. The mean monthly areal rainfall (MMAR) values are calculated for the inter-isohyet areas represented by P_1, P_2, and P_n (isohyets), and A_1, A_2,..., A_{n-1} (inter-isohyet areas), as shown in the equation below (Manning, 2016):

$$P_{avg} = \frac{A_1(\frac{P_1+P_2}{2}) + A_2(\frac{P_2+P_3}{2}) + \cdots + A_{n-1}(\frac{P_{n-1}+P_n}{2})}{\sum_{i=1}^{n} A_i}$$

Where P_{avg}= Mean Monthly Areal Rainfall according to this method,

A= Area enclosed between each series of contour lines,

n= number of contour lines,

P= precipitation at the contour lines

Before generating the isohyet map, raster interpolation under 3D Analyst tools in the ArcGIS software was performed for the point shape file. Then "Contour" tool under the Raster Surface of 3D Analyst tools was used for generating isohyets. Number of contours to be generated depends on the defined contour interval. Finally, the isohyet map was clipped to the area of interest that is the Krishna District administrative boundary. Interpolated raster map is also visualized for the study area using the "Extract by Mask" tool in the Spatial Analyst tools and then finally the mean monthly areal rainfall was calculated.

3. Results and Discussions:

3.1. Arithmetic mean method:

For all the mandals in the Krishna District, the mean monthlyrainfall is calculated and is shown is Appendix A. Using Arithmetic mean method the mean monthly areal rainfall for the Krishna District is found to be 84.72 mm. For the considered study period 1992-2021, highest mean monthly rainfall was generated at the Avanigadda station with 109.3 mm and lowest mean monthly rainfall was recorded at the Ghantasala station with the rainfall amount of 70.8 mm (Table 2).

3.2. Thiessen polygon method:

The thiessen polygon map was generated in Arcmap and is shown in Fig.2. A total of 25 polygons were generated corresponding to the point rain guage stations. Polygon area was computed in the attribute table and is found to range from 387.64 km^2 for the point rain gauge station of Nagayalanka to 53.97 km^2 for the point rain guage station of Avanigadda. Total area covered by polygons is 3678.87 km^2. The attribute table is exported to excel sheet for further calculation of mean monthly areal rainfall by computing weighted area and weighted precipitation. Table2 below shows the calculation of mean monthly areal rainfall using the thiessen polygon method. Weighted precipitation of polygons was found to range from 1.42 to 9.97 mm, lowest corresponding to Thotlavalluru and the highest corresponding to Nagayalanka.Mean monthly areal rainfall of Krishna district, according to the thiessen polygon method is found to be 85.22 mm (Table 2).

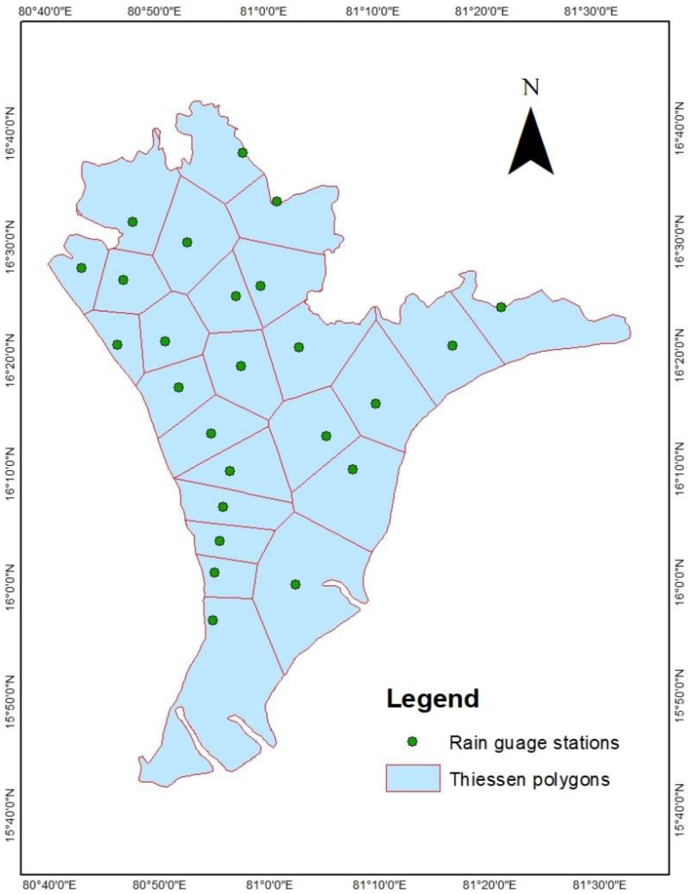

Fig.2: Thiessen Polygon method for the Krishna District

Table 2: Mean monthly areal rainfall calculation using Thiessen polygon method

FID	Mandals	Mean monthly rainfall (mm)	Polygon Area (Sq. Km)	weighted area (=polygon area/total area)	weighted precipitation (=weighted area x rainfall)
0	Mopidevi	89.18	66.970	0.0182	1.62
1	Machilipatnam	91.78	207.661	0.0564	5.18
2	Kruthivennu	80.33	191.476	0.0520	4.18
3	Gudlavalleru	83.05	166.436	0.0452	3.76
4	Vuyyuru	75.53	104.450	0.0283	2.14
5	Bapulapadu	79.83	132.906	0.0361	2.88
6	Nandivada	84.02	153.259	0.0416	3.50
7	Nagayalanka	94.66	387.641	0.1053	9.97
8	Avanigada	109.29	53.979	0.0146	1.60
9	Movva	83.89	119.510	0.0324	2.73
10	Ghantsala	70.79	114.972	0.0312	2.21
11	Challapalli	95.06	97.800	0.0265	2.53

12	Guduru	83.98	147.613	0.0401	3.37
13	Koduru	86.99	299.291	0.0813	7.08
14	Pedana	79.95	193.070	0.0524	4.20
15	Bantumilli	88.84	198.476	0.0539	4.79
16	Thotlavalluru	83.8	62.459	0.0170	1.42
17	Penamaluru	80.41	75.198	0.0204	1.64
18	Pamarru	85.71	130.712	0.0355	3.05
19	Kankipadu	81.87	94.855	0.0258	2.11
20	Pamidimukkala	77.13	99.202	0.0270	2.08
21	Pedaparupudi	79.55	96.179	0.0261	2.08
22	Unguturu	77.59	161.448	0.0439	3.41
23	Gudivada	87	133.284	0.0362	3.15
24	Gannavaram	87.8	190.026	0.0516	4.54
		Total	3678.874		**85.22**

3.3. Isohyet method:

Interpolation method is found to range from 68.92 to 110.18 mm and is divided into five classes using the Reclassify tool. Isohyet map was generated with a contour interval of 10 and the resultant map was shown in Fig. 3 below. The map depicts that about 67% of the total area was covered within the rainfall zone having mean monthly rainfall of 80-90 mm. Rainfall categories ranging from 60-70 mm and 100-110 mm collectively represent the smallest portion of the area, accounting for approximately 1.41% of the total. Mostly in the southern part, the mean monthly rainfall of 90-100mm class was found covering an area 9.35%. Rainfall class with mean monthly rainfall of 70-80 mm was found to cover an area of about 21.62% of the total study area. Using the isohyet method, the areal precipitation is calculated and is shown in table below. The mean monthly areal rainfall of the Krishna District as calculated using the Isohyet method is found to be 83.97mm.

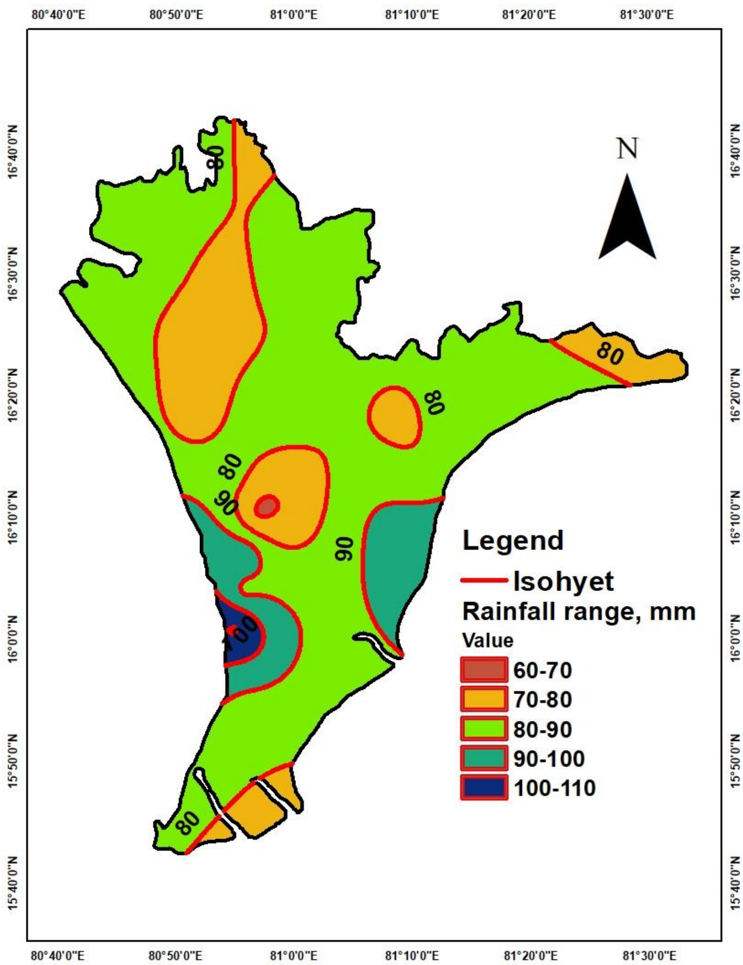

Fig. 3: Isohyet map of Krishna District

Table 3: Mean monthly areal rainfall calculation using Isohyet method

Contour range	Mean monthly rainfall, mm	Area, Sq km	weighted area	Average weighted rainfall, mm	% area
60-70	65	7.96	0.002	0.14	0.22
70-80	75	795.00	0.216	16.22	21.62
80-90	85	2485.97	0.676	57.47	67.61
90-100	95	343.85	0.094	8.88	9.35
100-110	105	43.92	0.012	1.25	1.19
	Total	3676.69		83.97	100

Mean monthly areal rainfall in the all the three methods is more or less closer to each other. In thiessen polygon method an average rainfall is indicated for the entire polygon area by giving rational weightage to the rain guage stations.The accuracy of isohyetal method depends on the number of gauges used for the study and it allows the better understanding of rainfall patterns under GIS environment (Al-Hallaq and Elaish, 2008). As per the literature, isohyetal method is the best and the results can be used for further hydrological studies.

4. Conclusions:

The mean monthly areal rainfall of the Krishna District in the Andhra Pradesh region is calculated using ArcGIS 10.3 software. Normal rainfall method was used for filling out the missing data. Arithmetic mean method resulted a mean monthly areal rainfall of 84.72 mm. Thiessen polygons were constructed using proximity tools and this method resulted mean monthly areal rainfall of 85.22 mm. Isohyetal map was generated in Arcmap and then using the isohyet method, mean monthly areal rainfall was computed and is found to be 83.97 mm. The outcomes are similar across all three methods of estimating areal rainfall. Under GIS environment isohyet method gives more information on the mean monthly areal rainfall and the rainfall patterns can also be comprehended, making it most used for the hydrological studies. Such spatial interpolation techniques support decision-making processes related to water allocation, flood risk assessment, crop yield prediction, and infrastructure planning.

References:

Cai, Y., Yang, Y., Tan, Q., Dai, C., Zhu, Z. and Zhang, X. 2024. Impacts of temporal/spatial rainfall heterogeneities on peak runoff distribution and intensities for an urban river basin of south China. *River*. 3(1):24-37.

Pan, X., Hou, J., Wang, T., Li. X., Jing. J., Chen, G.,Qiao, J. and Guo, Q. 2024 Study on the Influence of Temporal and Spatial Resolution of Rainfall Data on Watershed Flood Simulation Performance. *Water Resources Manage*ment. https://doi.org/10.1007/s11269-023-03661-3

Abhijeet A. D., Prakash S. S., Vinayak H. M. J. 2023. Spatial analysis of rainfall data using geospatial technology in Satara District, Maharashtra. *International Journal of Advance and Applied Research*. 4(1):29-38.

Hari, D.S., Reddy, K.R. 2022. Spatial Analysis of Rainfall Using GIS Techniques. *International Journal for Research Trends and Innovation*. 7(6):1215-1223.

Al-ozeer, A., Abdaki, M.A., Al-Iraqi, A., Al-Samman, S. and Al-Hammadi, N. 2020. Estimation of mean areal rainfall and missing data by using gis in nineveh, Northern Iraq. *The Iraqi Geological Journal*. 53(1E): 93-103.

Anand, B. and Karunanidhi, D. 2020. Long term spatial and temporal rainfall trend analysis using GIS and statistical methods in Lower Bhavani basin, Tamil Nadu, India.*Indian Journal of Geo-Marine Sciences*. 49(3): 419-427.

Malik, A., Kumar, A., Guhathakurta, P. and Kisi, O. 2019. Spatial-temporal trend analysis of seasonal and annual rainfall (1966-2015) using innovative trend analysis method with significance test. *Arabian Journal of Geosciences*, 12.

Chowdhury, M.A.I., Kabir, M.M., Sayed, A.F. and Hossain, S. 2016. Estimation of rainfall patterns in Bangladesh using different computational methods (arithmetic average, thiessen polygon and isohyet). *Journal of Biodiversity and Environmental Sciences. 8*(1):43-51.

Limin, S. G., Oue, H., and Takase, K., 2015. Estimation of areal average rainfall in the Mountainous Kamo River watershed,*Journal of Agricultural Meteorology*. 71:90-97.

Ly, S., Charles, C.; Degre, A. 2013.Different methods for spatial interpolation of rainfall data for operational hydrology and hydrological modeling at watershed scale. A review.*Biotechnology, Agronomy and Society and Environment*. 17(2): 392–406.

Cheng, C. D., Cheng, S. J., Wen, J.C. and Lee, J. H. 2012. Effects of rain gauge distribution on estimation accuracy of areal rainfall. *Water Resource Manage Water Resources Management: An International Journal – Published for The European Water Resources Association (Ewra).* 26:1-20.

Al-Hallaq, A.H. and Elaish, B.S.A. 2008. Determination of mean areal rainfall in the Gaza Strip using geographic information system (GIS) technique. *University of Sharjah Journal of Pure and Applied Sciences*, *5*(2):105-126.

De Silva, R.P., Dayawansa, N.D.K. and Ratnasiri, M.D. 2007. A comparison of methods used in estimating missing rainfall data. *Journal of Agricultural Sciences*. *3*(2):101-108.

Manning, J. C. 2016. Applied Principles of Hydrology.

Krishna topographic map, elevation, terrain (topographic-map.com)

Tabios III GQ. and Salas, J.D. 1985. A comparative analysis of techniques for spatial interpolation of precipitation. *JAWRA Journal of the American Water Resources Association.* 21(3):365-380.

Singh V P. 1994. *Elementary Hydrology*. Prentice Hall of India: New Delhi.

Appendix A: Mean Monthly Rainfall of Mandals in Krishna District.

Years	Bantumilli	Bapulapadu	Gannavaram	Gudivada	Gudlavalleru	Kruthivennu	Unguturu	Pedaparupudi	Nandivada	Vuyyuru	Pamidimukkala	Kankipadu	Pamarru	Challapalli	Ghantsala	Mopidevi	Movva	Koduru	Avanigada	Guduru	Nagayalanka	Machilipatnam	Pedana	Penamaluru	Thotlavalluru
1992	77.88	78.78	53.48	65.92	72.86	70.10	57.75	61.86	73.43	51.80	65.81	57.87	60.75	73.32	33.70	65.68	67.63	51.42	62.88	67.90	83.10	85.43	80.43	44.73	51.73
1993	54.60	53.55	54.49	62.68	60.72	57.62	51.17	58.67	63.22	51.88	61.81	63.14	59.08	74.50	51.01	90.64	75.61	54.88	135.20	59.10	88.88	54.57	47.88	71.08	56.79
1994	88.85	74.54	74.69	94.25	111.82	88.47	89.84	103.60	102.03	114.38	105.15	105.50	101.51	103.26	93.26	105.72	107.28	85.46	111.61	115.26	113.00	140.27	109.58	89.48	107.80
1995	118.49	101.7	88.11	125.52	121.10	108.42	64.52	114.44	145.17	150.03	113.36	132.56	101.12	118.12	95.64	97.59	103.33	67.31	97.49	110.28	88.25	109.03	121.15	150.17	123.43
1996	121.50	89.18	91.23	108.87	108.94	132.48	84.33	99.81	125.74	91.46	112.19	69.47	91.98	158.53	125.12	115.53	71.09	107.41	167.72	106.36	112.53	114.99	114.75	74.93	102.30
1997	87.29	66.84	62.85	77.71	84.67	85.08	59.03	81.87	89.62	84.75	98.78	80.32	80.33	82.08	72.46	82.20	47.68	68.37	109.26	69.78	92.88	113.07	90.90	68.30	81.02
1998	111.57	83.98	70.83	96.68	99.67	98.77	80.00	69.55	94.97	58.44	76.28	83.17	69.78	77.16	68.84	73.70	55.43	80.62	99.78	84.74	83.13	73.57	84.85	69.68	87.97
1999	51.51	80.07	66.20	77.31	21.78	39.18	55.81	65.77	74.99	61.04	59.09	63.83	73.30	78.62	36.17	67.34	62.27	90.90	102.13	64.88	75.14	62.49	46.08	62.83	75.63
2000	76.82	93.43	66.13	78.78	81.42	54.80	88.67	59.00	81.83	88.02	85.68	72.42	78.00	88.51	97.97	86.88	101.24	82.07	126.34	93.21	94.40	111.08	83.20	23.18	100.73
2001	56.02	80.43	90.03	89.87	77.77	38.03	74.72	67.75	87.41	81.02	79.55	85.08	80.68	74.03	69.18	87.78	58.82	92.42	91.23	57.58	82.79	76.08	52.35	95.42	79.45
2002	51.23	51.83	53.28	47.08	45.36	69.47	48.60	46.28	45.56	31.61	50.22	52.48	48.97	67.88	41.03	58.43	30.90	53.06	56.83	34.97	50.83	74.42	47.13	55.73	42.05
2003	75.50	87.88	83.36	70.34	58.92	76.48	82.27	71.26	70.34	74.40	73.78	91.02	74.30	83.78	53.75	96.74	52.45	145.57	96.14	43.62	145.73	68.59	58.88	90.38	86.48
2004	64.42	67.25	94.72	58.43	60.17	64.58	94.66	58.46	58.43	44.98	60.08	68.83	66.32	68.97	40.53	68.67	43.74	42.13	46.72	37.32	42.13	56.32	64.54	68.83	58.40
2005	94.87	90.09	91.45	110.55	111.97	87.25	104.94	102.87	90.62	88.48	98.80	90.37	104.55	95.85	58.41	86.81	75.28	89.81	95.33	81.08	83.41	85.38	117.28	88.28	101.43
2006	102.79	92.00	92.51	132.92	116.88	86.90	96.87	83.68	103.93	105.56	135.47	98.04	133.75	128.53	92.86	133.19	133.32	139.30	150.41	102.13	127.40	140.28	108.50	102.58	118.37
2007	69.43	69.50	92.20	75.77	84.12	59.64	90.49	84.35	86.43	69.97	60.56	68.77	102.68	98.95	76.68	84.13	82.27	129.89	115.28	77.83	112.17	78.10	68.90	77.24	79.28
2008	102.38	99.72	121.35	97.33	97.72	94.00	106.80	89.80	106.45	82.43	69.90	83.65	119.50	129.91	97.37	113.23	106.63	121.35	134.63	129.66	137.82	106.98	97.38	77.10	89.75
2009	66.58	65.86	71.27	51.18	58.50	41.51	50.43	49.83	53.81	56.79	50.80	53.40	75.18	63.74	38.81	48.34	64.49	58.12	85.15	53.37	77.60	63.89	54.68	41.73	44.15
2010	155.48	136.50	173.66	136.18	138.30	135.35	124.93	129.77	135.27	117.17	130.75	160.63	165.68	161.57	130.56	174.75	209.57	168.27	220.42	190.24	183.88	188.63	124.88	125.75	148.90
2011	84.52	74.15	91.90	70.17	69.18	88.98	57.05	66.55	63.72	52.48	64.25	88.91	65.50	84.35	51.08	49.60	72.42	54.57	67.43	77.44	67.77	61.10	68.48	73.53	70.79
2012	131.68	132.55	168.37	126.72	117.75	125.45	114.23	108.60	115.02	102.45	113.25	148.08	149.22	157.60	111.95	127.98	152.05	101.77	147.40	123.74	108.68	117.32	73.38	154.99	157.85
2013	100.88	107.73	155.52	115.62	96.92	109.63	138.67	118.33	120.68	100.78	99.47	126.35	142.60	114.35	95.12	119.96	124.56	101.65	137.73	130.34	102.35	111.61	95.25	148.90	133.45
2014	47.73	44.83	51.08	57.52	58.00	36.58	32.66	46.08	53.74	51.79	52.77	70.73	50.62	62.82	51.24	66.24	52.66	50.08	44.98	73.04	44.64	55.61	44.61	74.33	60.18
2015	111.55	46.40	54.78	95.88	69.92	68.33	62.78	68.30	62.13	51.83	54.45	60.74	69.85	83.44	64.82	112.69	91.88	97.29	113.44	101.73	79.22	85.60	85.89	70.31	75.18
2016	92.90	56.84	76.73	80.53	82.98	56.51	61.85	63.11	61.43	64.94	60.84	62.34	76.66	73.23	63.81	71.07	78.36	72.28	102.13	72.33	85.08	74.33	65.86	74.46	69.23
2017	90.19	54.77	71.05	82.32	57.64	62.24	57.27	65.22	59.79	60.37	45.73	52.35	82.20	65.54	64.68	64.62	80.47	53.31	68.08	53.23	66.13	54.53	57.67	57.45	56.23
2018	74.28	63.08	80.23	79.03	56.19	62.23	61.92	83.36	60.70	50.90	46.13	54.48	59.22	78.38	49.48	56.30	61.23	61.88	79.24	62.52	60.81	74.31	59.02	68.53	53.65
2019	94.32	41.79	86.52	71.06	66.18	90.33	62.78	89.79	73.39	62.09	40.13	58.21	45.13	71.28	53.28	65.83	67.53	88.29	133.18	50.82	95.07	80.56	56.50	57.52	56.04
2020	118.19	112.95	100.88	102.65	106.48	132.57	81.81	105.29	87.23	89.56	74.18	82.03	74.38	118.26	85.17	110.56	93.27	97.41	148.06	98.01	123.48	124.22	117.39	84.45	80.52
2021	91.90	96.59	105.08	71.31	97.52	89.03	91.01	73.29	73.51	74.65	74.57	71.48	68.55	115.25	59.83	93.28	93.17	102.85	132.54	96.81	131.39	111.01	101.08	70.35	65.32
annual average	88.84	79.83	87.80	87.00	83.05	80.33	77.59	79.55	84.02	75.53	77.13	81.87	85.71	95.06	70.79	89.18	83.89	86.99	109.29	83.98	94.66	91.78	79.95	80.41	83.80
Std. deviation	26.01	24.23	31.55	24.34	26.77	28.45	24.73	22.43	25.86	26.03	26.28	28.12	30.44	29.23	26.34	28.44	36.21	31.43	38.47	33.48	31.28	31.52	25.70	30.60	30.04