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Isopluvial Maps of Kerala using IMD Gridded Rainfall Data

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TABLE OF CONTENTS

	Abstract	3
1.	**Introduction**	4
2.	**Data Used**	5
3.	**Methodology**	5
4.	**Results and Discussion**	
	4.1. Rainfall Climatology	7
	4.2. Isopluvial Maps of Kerala	8
	4.3. Comparison Between Two 60 Year Periods (1901-1960 Vs 1961-2020)	10
5.	**Conclusion**	10
	Fig 1: Daily normal rainfall averaged over Kerala (1901-2022)	12
	Fig 2: Spatial distribution of average annual rainfall over Kerala during 1901-2022.	12
	Fig 3: Isopluvial map of Kerala for 2 years return period using gridded rainfall data	13
	Fig 4: Isopluvial map of Kerala for 5 years return period using gridded rainfall data	14
	Fig 5: Isopluvial map of Kerala for 10 years return period using gridded rainfall data	15
	Fig 6: Isopluvial map of Kerala for 25 years return period using gridded rainfall data	16
	Fig 7: Isopluvial map of Kerala for 50 years return period using gridded rainfall data	17
	Fig 8: Isopluvial map of Kerala for 100 years return period using gridded rainfall data	18
	Fig 9: The spatial plot of anomalies for 2, 5, 10 ,25 ,50 and 60 years return period	19
	References	20

ABSTRACT

Rainfall characteristics are an essential input for the design of water management infrastructures such as dams, reservoirs, culverts, drains, etc. Engineers often make use of isopluvial maps to estimate design floods for the planning and design of such hydraulic structures. However, intensification of the hydrologic cycle in changing climate has perturbed the frequency and intensity of rainfall events, and are expected to increase in the future. The recent occurrence of frequent extreme rainfall events (EREs) in changing climate have hampered the stability of hydraulic structures, warranting a timely review of the rainfall characteristics considered in hydraulic designs. An overestimated/ underestimated design flood will lead to uneconomical or unsafe designs. The Indian Meteorological Department (IMD) provides the isopluvial maps of Kerala using station rainfall data, but the latest report was released in 2009. Although the probability for the occurrence of EREs over Kerala is very low, the recent years (2018, 2019, and 2020) witnessed the occurrence of multiple EREs across Kerala. In this context, the present study aims to prepare isopluvial maps of Kerala, and evaluate its evolution under the influence of the recent EREs. Isopluvial maps of return periods of 2, 5, 10, 25, 50, and 100 years are developed using 122 years of IMD gridded rainfall data (1901 – 2022) at a spatial resolution of 0.25°. The results show an increase in rainfall for all the return periods except 2 years. This is a typical characteristic of the impact of climate change, whereby an increase in rainfall intensity is observed with a decrease in rainy days. In other words, rainfall events of larger return periods are more intense.

Keywords: climate change; isopluvial map; extreme rainfall events

1. INTRODUCTION

Water is the most valuable and limited natural resource for humans, with rainfall being the major source (Venkata et al. 2018). However, rainfall is not distributed evenly; while certain areas receive abundant rainfall, other areas experience a shortage. Water must be distributed consistently to multiple demand sites, which requires the construction of man-made structures. In order to hold excess water during the rainy season, barriers like dams are placed across the river on the upstream side and are cautiously withdrawn during the dry season to various demand sites located in the downstream side. Rainfall is a key component in the construction of many engineering projects, like dams, aqueducts, canals, sewers, and drainage systems (Arvind et al., 2017, Powell et al, 2006). In recent decades, climate change has altered every phase of the global water cycle. Numerous records from meteorological stations, satellites, and radar amply demonstrate that global precipitation patterns have changed (IPCC AR6 WG 2, 2021). Because of global warming, South Asia is already experiencing danger of an increased flood and drought events which are expected to increase further (Mishra et al. 2020).

One of the most significant effects of climate change is the intensification of the hydrological cycle. At both global and local level, this intensification increases the intensity and frequency of precipitation (Sarkar et al., 2020, Mukherjee et al.2018, Pai et al. 2015), which results in flash floods, landslides and will have a negative impact on society, economy and environment (Mishra et al. 2018, Mukherjee et al. 2018, Goswami et al. 2006). In the month of August 2018, Kerala witnessed some of the worst extreme rainfall events (EREs) leading to widespread flooding and associated landslides in majority of the state's districts, seriously harming both the built environment and the natural ecosystem (Kieran et al. 2020). The prolonged rainfall episodes and the EREs occurring throughout the Indian Summer Monsoon Rainfall season were the main causes of flooding in Kerala during 2018 (KSCSTE Report, 2019).

Since rainfall characteristics are often used to design water management infrastructures, reviewing and updating rainfall characteristics is necessary for future designs of structures, as unexpected climate change have hampered the stability of hydraulic structures. An overestimated or underestimated design flood will lead to uneconomical and unsafe designs. Therefore, utmost care needs to be taken to estimate the design rainfall. The knowledge about the frequency and magnitude of EREs is important for adapting to the extreme weather, designing engineering structures, managing reservoirs etc. Engineers requires design rainfalls in order to design stable hydraulic structures (Johnson et al. 2019). Though probability distribution models are appropriate, they are rigorous. In comparison, the isopluvial maps are often used as a quick tool to estimate the rainfall intensity at any place with fairly good accuracy (Parvez et al. 2019). Isopluvial are lines on a map connecting points

having the same amount of rainfall for a return period. The return period is a statistical parameter used in frequency analysis and is a measure of the probable time interval between the occurrence of a given event and that of an equal or greater event (SOP for Hydromet services, 2021)

India Meteorological Department (IMD) has prepared the isopluvial maps of Kerala using station rainfall data. But the latest report was released in 2009. Although the probability for the occurrence of EREs over Kerala is low, the recent years (2018, 2019, and 2020) have witnessed the occurrence of multiple EREs across Kerala. In this context, the present study aims to prepare isopluvial maps of Kerala, and evaluate its evolution in view of sudden increase in the EREs in recent years. Isopluvial maps of return periods of 2, 5, 10, 25, 50, and 100 years are developed using 122 years of IMD gridded rainfall data (1901 – 2022) at a spatial resolution of 0.25°.

2. DATA USED

IMD gridded rainfall data with a spatial resolution of 0.25° × 0.25° was utilized for a period of 122 years (1901-2022). This dataset was prepared using the observed rainfall records from 6955 rain gauging stations across the country. The gridded data proves to be better in model evaluation and such studies, since station data may have some missing data or may get biased due to improper methodologies etc. such issues are resolved in the gridded dataset by removing those errors and by providing regular space time grid data which is useful to many studies (Pai et al. 2014).

3. METHODOLOGY

It is difficult to forecast many of the extreme events in hydrology using deterministic approaches (Adlouni et al.2010). Thus, we rely on probabilistic approaches to take decisions and the most commonly adopted method is rainfall frequency analysis, it consists of estimating the peak quantity for a set of non-exceedance (N. Bhagat et al. 2017). Rainfall frequency analysis helps to find the rainfall depth for a specific return period and is performed using historical rainfall data. It is assumed that the future time series will have a similar distribution as that of the observed one. Frequency analysis is performed by fitting the theoretical frequency distribution with the annual maximum rainfall series, and it is highly recommended to use at least thirty years of rainfall data for such statistical methods as short series data does not give accurate results. Commonly used probability distributions for hydrologic variables were normal distribution, log normal distribution, exponential distribution, gamma distribution, Pearson Type III distribution, Log-Pearson Type III distribution and extreme value distribution. Extreme value distribution is further subdivided into three form - EVI (Gumbel distribution), EVII (Frechet distribution) and EVIII (Weibull distribution) (S. Syafalni et al., 2015). The Gumbel distribution is a common frequency technique used to analyse hydrological phenomena like floods, rainfall, temperature, evaporation, etc. to clearly express information about

the pattern of rainfall (A.K.Das et al. 2022). The Standard Operating Procedure (SOP for Hydromet services, 2021) for storm analysis also suggest use of Gumbel's Extreme value distribution for fitting rainfall data. To assume the probabilistic future prediction the Gumbel's distribution method of frequency analysis requires minimum ten years annual maximum historical data (M. K Kumar et al. 2021). The parameters in the Gumbel distribution can be calculated using any of the two methods, namely method of moments and method of least squares.

For the development of isopluvial map, the procedure used by the Indian Meteorological Department (IMD) is followed (SOP for Hydromet Services, 2021). The annual maximum rainfall for 122 years was considered for all the grid points covering the state and performed frequency analysis using Gumbel extreme value distribution. If X is a hydro meteorological variable, then according to Gumbel, the cumulative probability that any extreme value of a variable X will be equal to or less than x for Gumbel distribution is given by eqn 1,

$$P(X \leq x) = \exp[-\exp\{-\alpha(x-u)\}] \qquad \text{..... (1)}$$

Let

$$y = \alpha(x-u)$$

Then,

$$X = u + \frac{1}{\alpha}Y \qquad \text{..... (2)}$$

By definition,

$$T = \frac{1}{1-P(X \leq x)}$$

$$T = \frac{1}{1-e^{-e^{-y}}}$$

$$y = -log_e log_e \frac{T}{T-1} \qquad \text{..... (3)}$$

The parameters in the Gumbel distribution can be calculated using either method of moments or method of least square. In this study we follow method of moments.

Method of moments:

The u in the distribution is defined as,

$$u = \overline{X} - \frac{c}{\alpha}$$

where,

$\overline{X}$: Mean of extreme(X) series

c : Euler's constant ≈ 0.58

and,

$$\frac{1}{\alpha} = \frac{\sqrt{6}}{\pi} s \approx 0.78 \times s$$

where s is the standard deviation of the extreme series.

$$\frac{c}{\alpha} = 0.58 \times (0.78 \times s) \approx 0.45 \times s$$

Equation 2 can be written as

$$X_T = \overline{X} - 0.45s + 0.78sY_T \quad \text{..... (4)}$$

where,

$\overline{X}$ and s are the mean and the standard deviation of annual maximum rainfall series of data and T is the return period, then parameters α (scale parameter) and u (location parameter) can be obtained. The rainfall estimates corresponding to various return periods were calculated using equation 4. The return periods considered in this study are 2 years, 5 years, 10 years, 25 years, 50 years and 100 years

To find the variability of rainfall in the study region coefficient of variation was utilized. The coefficient of variation quantifies the variability of rainfall in the study area. Greater rainfall variability is indicated by a higher value of CV. CV can be calculated using equation 5.

$$CV = \frac{\sigma}{\mu} \times 100 \quad \text{..... (5)}$$

where,

σ: standard deviation

μ : mean rainfall

The degree of variability of rainfall is divided into three categories using CV, i.e. low (CV<20), moderate (20<CV<30) and high (CV>30).

4. RESULTS AND DISCUSSION

4.1. Rainfall climatology

This study made use of IMD gridded rainfall data of Kerala for the last 122 years (1901-2022). The Annual rainfall cycle over Kerala is influenced by the monsoon phenomena. Most of the mean annual rainfall occurs during the Indian summer monsoon and post-monsoon seasons. The onset of the Indian summer monsoon generally commences over Kerala by early June and peaks during June and July months. The retreating monsoon currents cause occasional showers during the post-monsoon season and can be perceived as minor peak in the bimodal annual rainfall cycle. Daily normal rainfall averaged over Kerala is shown in figure 1.

The spatial distribution of rainfall over Kerala is influenced by the orographic barriers of the Western Ghats (WG) (Figure 2), and shows a typical characteristic pattern. In general, rainfall is concentrated along the coastal areas and westerly slopes of WG, whereas rainfall decreases along the leeward slopes of the WG and rain shadow regions. Lower rainfall is also a characteristic of the Palakkad Gap. The northern and central parts of Kerala receive more rainfall compared to the southern region. From the annual average rainfall for the period 1901-2022 a grid point in Pathanamthitta which contributes 28.67 % of the district(Fig 2, grid 2) show the least value (885 mm), and a grid point in Kasaragod which contributes 37.96% of the district (Fig 2, grid1) shows the highest value (4801 mm) which are highlighted in figure 2.

4.2. Isopluvial Maps for Kerala

The isopluvial maps of Kerala for 2 years, 5 years, 10 years, 25 years, 50 years and 100 years return period are shown in figure 3 to 8. In all return periods the northern and central districts experience higher amount of rainfall, with Kasaragod and Kannur in Kerala receiving the most and Palakkad receiving the least. The southern part of Kerala receives comparatively less rainfall except some regions of Kottayam showing heavy rainfall. The maximum estimated rainfall for any return periods is in the range of 380.91-165.59mm over the northern region, in the range of 295.28-136.36mm over the centre region and in the range of 295.86-131.76mm over the southern region. The minimum rainfall for any return periods is in the range of 160.75-60.85mm in the northern region, 129.2-55.36mm in the central region, and 133.40-56.37mm in the southern region. Table- 1 shows the statistical features for each return period. The coefficient of variation (CV) for various return periods show moderate variation of rainfall in all the return periods as CV lies in between 20 and 30%.

Table 1: Mean, standard deviation, maximum and minimum and CV of rainfall over Kerala for various return periods.

	2 years	5 years	10 years	25 years	50 years	100 years
Average	104.55	140.82	164.83	195.17	217.68	240.02
SD	28.56	33.55	37.35	42.5	46.52	50.63
Max	165.59	223.2	261.37	309.61	345.39	380.91
Min	55.37	75.26	88.32	104.82	117.06	129.21
CV	27.31	23.83	22.66	21.78	21.37	21.1

Table 2 shows the statistical features like mean, standard deviation, maximum, minimum and CV for all the districts of Kerala corresponding to various return periods. Coefficient of variation of each districts show that all districts had low variation (CV < 20%) in rainfall in all the return periods considered, except Palakkad and Idukki, which experienced a moderate variation (20<CV<30%). In

addition, Pathanamthitta experienced moderate variation in 5-year return period and Kollam district experienced moderate variation in 2-year return period.

Table 2: Mean, standard deviation, maximum and minimum and CV of rainfall over the districts of Kerala for various return periods.

	2 year Return Period					5 year Return Period					10 year Return Period				
District	Mean	SD	Max	Min	CV	Mean	SD	Max	Min	CV	Mean	SD	Max	Min	CV
Kasaragod	151.08	9.59	165.59	135.62	6.35	189.76	16.51	214.24	165.5	8.7	215.37	21.24	246.45	185.29	9.87
Kannur	132.09	25	165.54	90.82	18.93	175.78	30.04	223.2	126.9	17.09	204.7	33.92	261.37	150.79	16.58
Wayanad	73.72	14.12	93.83	60.86	19.15	109.33	21.21	138.28	87.6	19.4	132.91	25.98	167.71	105.31	19.55
Kozhikode	136.7	7.93	144.75	123.6	5.81	177.69	11.84	194.07	161.63	6.67	204.82	14.79	226.73	186.81	7.22
Malappuram	108.49	17.05	125.68	82.79	15.72	148.37	19.96	171.43	115.76	13.45	174.77	22.47	205.76	137.59	12.86
Palakkad	79.17	18.35	106.52	55.37	23.18	111.5	27.45	146.7	75.26	24.62	132.9	33.94	182.66	88.32	25.54
Thrissur	117.12	9.01	125.89	104.79	7.7	153.32	13.43	166.09	135.34	8.76	177.29	16.38	192.71	155.58	9.24
Ernakulam	109.07	3.13	112.96	106.02	2.87	148.77	5.65	156.6	143.11	3.8	175.06	7.52	185.49	167.67	4.3
Idukki	77.36	17.3	108.3	56.38	22.36	111.51	26.23	152.67	77.6	23.52	134.12	32.4	182.05	91.11	24.16
Kottayam	112.65	17.31	131.76	98.03	15.37	149.52	22.85	175.7	133.61	15.28	173.94	26.75	204.79	157.17	15.38
Alappuzha	106.22	12.6	129.17	94.51	11.86	135.83	14.82	162.82	121.24	10.91	155.44	16.42	185.1	138.95	10.56
Pathanamthitta	78.56	19.84	100.69	62.37	25.26	108.61	22.11	133.16	90.31	20.36	128.5	23.61	154.66	108.8	18.37
Kollam	96.5	19.46	111.79	68.18	20.16	131.58	22.81	146.76	99.13	17.33	154.8	25.38	169.91	119.63	16.4
Trivandrum	87.52	10.62	105.12	78.62	12.13	121.74	11.44	141.5	106.39	9.4	144.4	13.27	165.58	123.67	9.19

	25 year Return Period					50 year Return Period					100 year Return Period				
District	Mean	SD	Max	Min	CV	Mean	SD	Max	Min	CV	Mean	SD	Max	Min	CV
Kasaragod	247.73	27.28	287.15	210.28	11.02	271.73	31.78	317.52	228.83	11.7	295.56	36.26	348.41	247.24	12.27
Kannur	241.24	39.23	309.61	180.98	16.27	268.35	43.37	345.39	203.37	16.17	295.26	47.6	380.91	225.6	16.12
Wayanad	162.69	32.06	204.89	127.68	19.71	184.79	36.58	232.47	144.28	19.8	206.72	41.08	259.86	160.76	19.88
Kozhikode	239.11	18.68	267.99	218.63	7.82	264.54	21.64	298.6	242.23	8.18	289.79	24.6	328.98	265.66	8.49
Malappuram	208.13	26.09	249.12	165.17	12.54	232.88	28.98	281.29	185.63	12.45	257.44	31.99	313.23	205.95	12.43
Palakkad	159.95	42.37	228.11	104.82	26.49	180.01	48.72	261.82	117.06	27.07	199.93	55.07	295.29	129.21	27.55
Thrissur	207.57	20.14	226.34	181.14	9.71	230.03	22.94	251.28	200.11	9.97	252.33	25.71	276.05	218.93	10.19
Ernakulam	208.27	9.95	221.99	198.71	4.78	232.91	11.78	249.07	221.73	5.06	257.36	13.61	275.95	244.58	5.29
Idukki	162.69	40.32	219.17	108.18	24.78	183.88	46.24	246.71	120.84	25.15	204.91	52.15	274.04	133.41	25.45
Kottayam	204.79	31.84	241.54	185.88	15.55	227.67	35.68	268.8	205.18	15.67	250.39	39.53	295.87	224.35	15.79
Alappuzha	180.22	18.54	213.25	161.31	10.29	198.6	20.17	234.14	177.91	10.16	216.84	21.82	254.87	194.38	10.06
Pathanamthitta	153.63	25.51	181.83	132.17	16.61	172.28	26.92	201.98	149.51	15.63	190.79	28.32	221.98	166.72	14.85
Kollam	184.14	28.89	199.16	145.52	15.69	205.9	31.64	220.86	164.73	15.37	227.51	34.46	242.4	183.8	15.15
Trivandrum	173.02	16.45	196.01	145.5	9.51	194.25	19.18	218.59	161.69	9.88	215.33	22.07	241	177.77	10.25

4.3. Comparison between Two 60 Year Periods (1901-1960 Vs 1961-2020)

A comparison study was conducted to evaluate the changes in rainfall with return periods in the recent sixty years (1961-2020) compared to the previous one (1901-1960) by dividing the rainfall data into two periods, 1901 to 1960 and 1961 to 2020. Rainfall depth was estimated for both periods for various return periods. The difference in rainfall depth between the two periods was examined. In Idukki and Ernakulum districts, it was found that there had been a significant increase in the rainfall in recent sixty years; this increase is almost 2.1 times that of the amount of average rainfall that Kerala received over the winter. The districts of Kasaragod, Wayanad, and Kozhikode exhibit a significant decline; in fact, the drop was 2.5 times the amount of average rainfall that Kerala received during the winter. Figure 9 shows the spatial plot of anomalies for 2, 5, 10, 25, 50 and 60 year return period. The figure clearly shows that rainfall in Kerala's southern region show significant increase with increase in return period, with a particularly notable increase in the districts of Idukki, Ernakulum, and Thiruvananthapuram. In the northern portion of Kerala in the recent sixty years, there has been a noticeable fall of approximately 50mm over a two-year return period. Table 3 displays the percentage deviation from the prior sixty years. The estimate of recent sixty years rainfall increases in all the return periods, with an average increase of about 4.5%, except a decrease in the two-year return period and the five-year return period, respectively, by 5.39% and 0.14%.

Table 3: Percentage deviation of rainfall in the recent sixty years

Return period	1901-1960	1961-2020	% deviation
2	107.54	101.76	-5.39
5	140.28	140.09	-0.14
10	161.96	165.47	2.18
25	189.34	197.54	4.34
50	209.66	221.33	5.57
60	214.97	227.56	5.86

5. CONCLUSIONS

In this study the rainfall characteristics of Kerala was analysed using the last 122 years' IMD gridded rainfall data having a resolution of 0.25^0 and found that the annual average rainfall received by a grid point in the Pathanamthitta district which covers 28.67% of the district is least and a grid point in Kasaragod which covers 37.96% received the highest rainfall. Since isopluvial is crucial for the purpose of planning & designing water resources-related projects, such as the construction of dams, aqueducts, canals, sewers, and drainage systems, this study will be very helpful for design engineers, hydrologists, and hydraulic-consultants. The isopluvial maps of Kerala, which are crucial for the design

of hydraulic structures were prepared for return periods of 2, 5, 10, 25, 50, and 100 years, the result shows that in all return periods Kasaragod and Kannur districts in Kerala receive the most rainfall, while Palakkad receive the least. Kerala's southern portion receives relatively less rain except for some areas of Kottayam that receives considerable rainfall. The coefficient of variation (CV) for various return period reveals that rainfall in Kerala varies only moderately. Considering the district wise variation, with the exception of Palakkad and Idukki, which show a moderate variation in rainfall during all return periods and rainfall in all other districts shows low variation. Pathanamthitta and Kollam district both experience moderate variation during 5-year return period and 2-year return period, respectively. There has been a considerable increase in rainfall in the recent 60 years in the districts of Idukki and Ernakulum and this increase is over 2.1 times that of Kerala's average winter rainfall and Kasaragod, Wayanad, and Kozhikode districts show a considerable dip; in fact, the reduction was 2.5 times more than Kerala's average winter rainfall. Rainfall in Kerala's southern region increases significantly when return periods rise, with a particularly notable increase in the districts of Idukki, Ernakulum, and Thiruvananthapuram. In the northern portion of Kerala in the recent sixty years, there has been a noticeable fall in two-year return period.

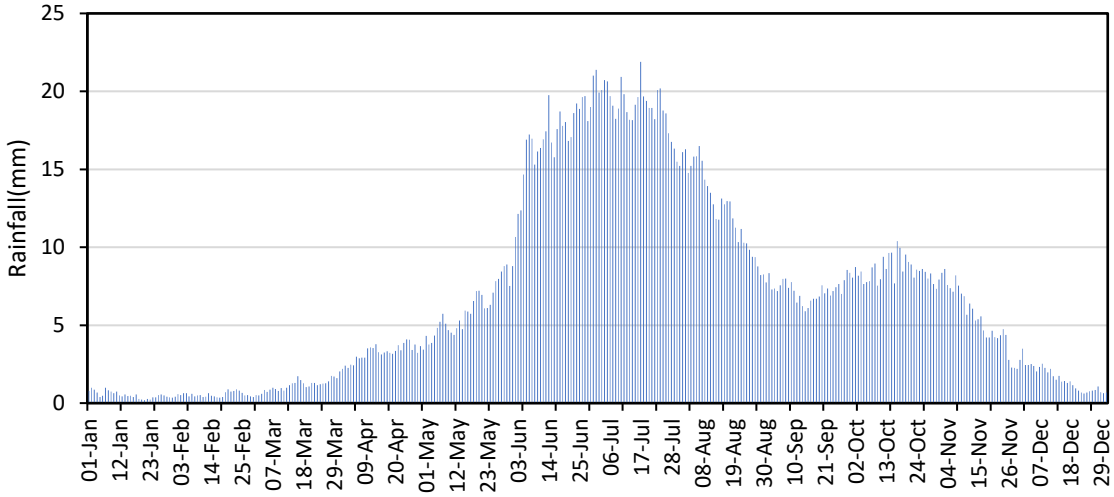


Figure 1: Daily normal rainfall averaged over Kerala (1901-2022)

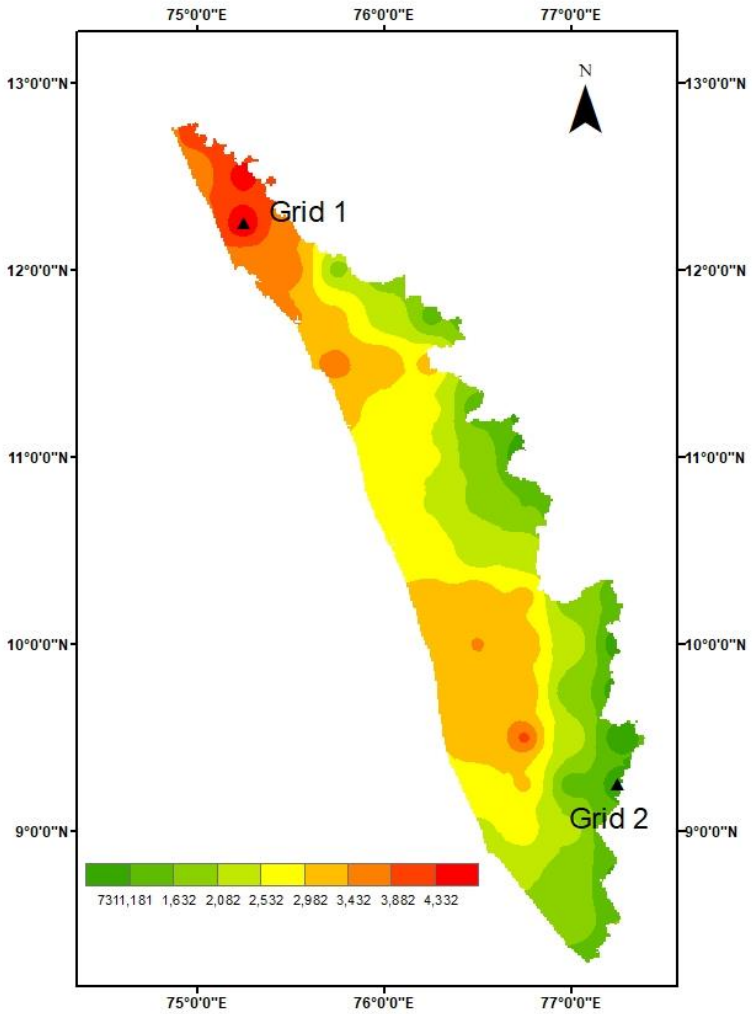


Figure 2: Spatial distribution of average annual rainfall over Kerala during 1901-2022.

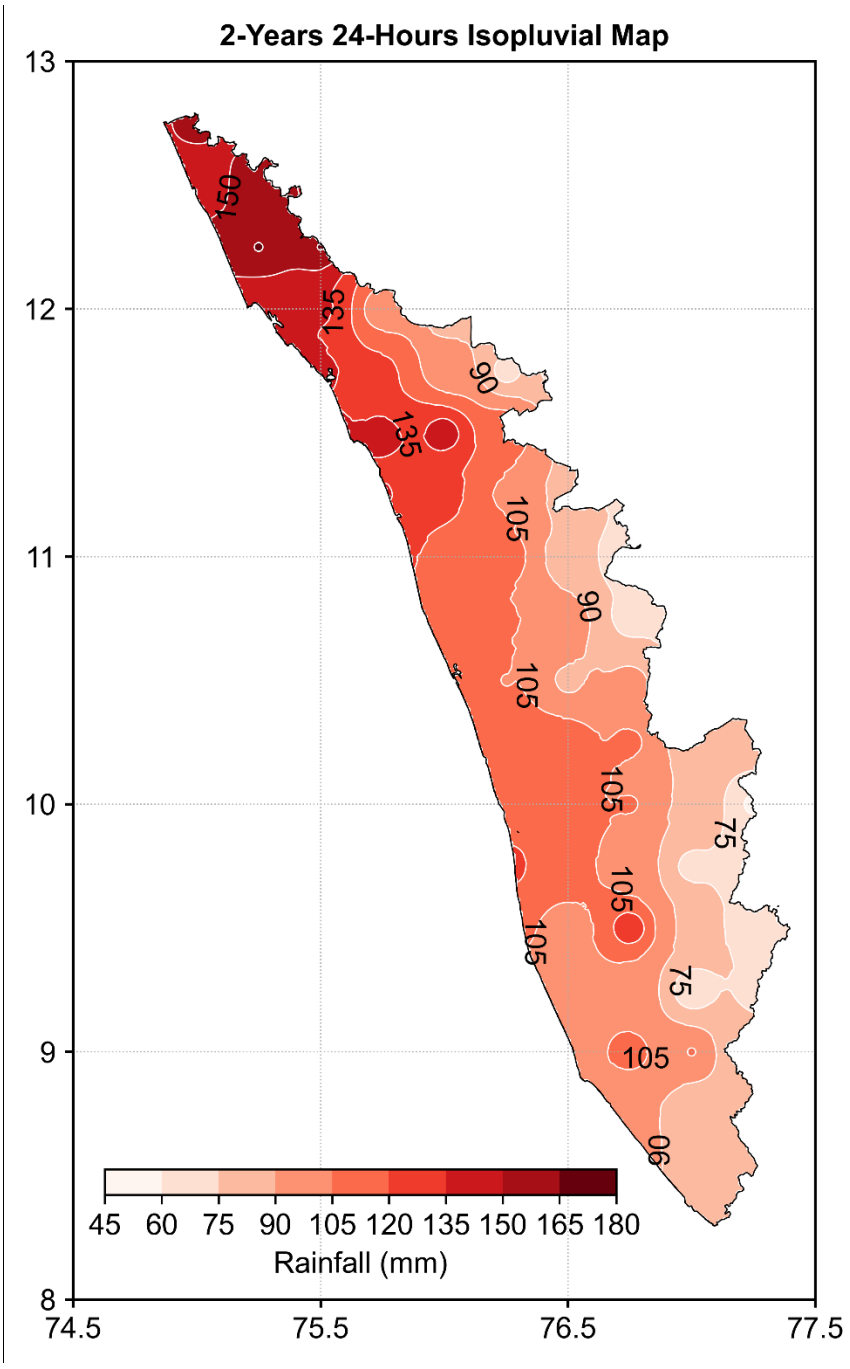


Figure 3: Isopluvial map of Kerala for 2 years return period using gridded rainfall data

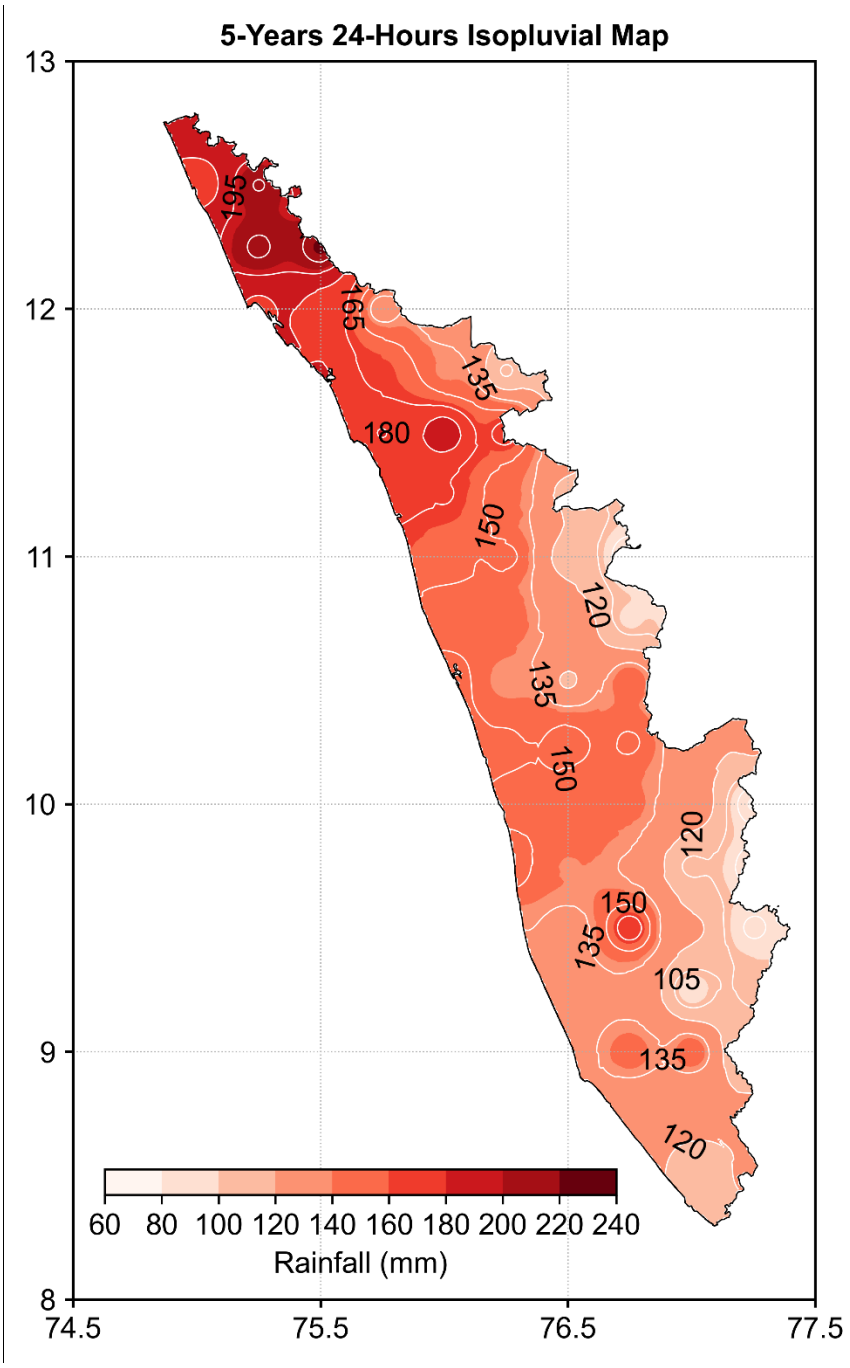


Figure 4: Isopluvial map of Kerala for 5 years return period using gridded rainfall data

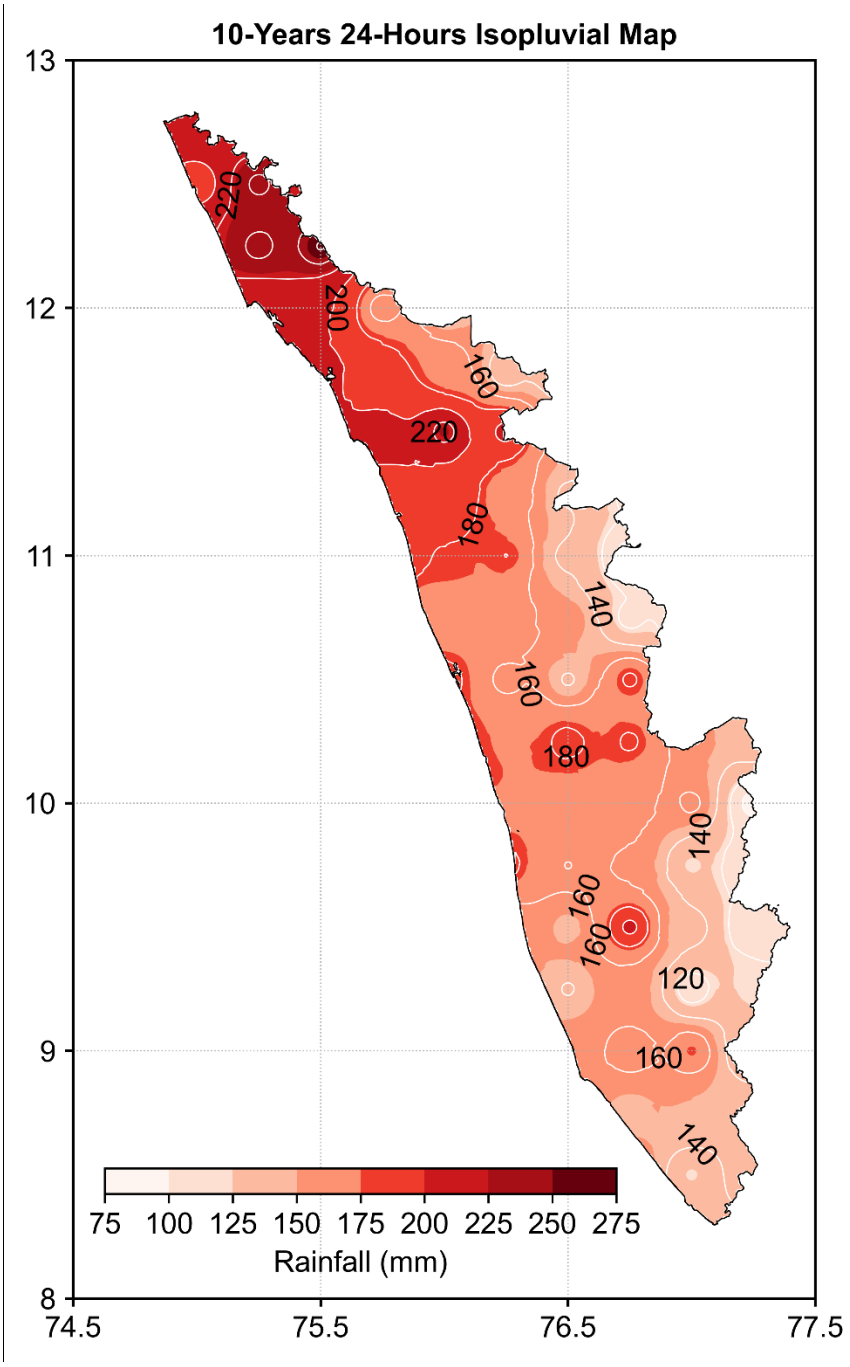


Figure 5: Isopluvial map of Kerala for 10 years return period using gridded rainfall data

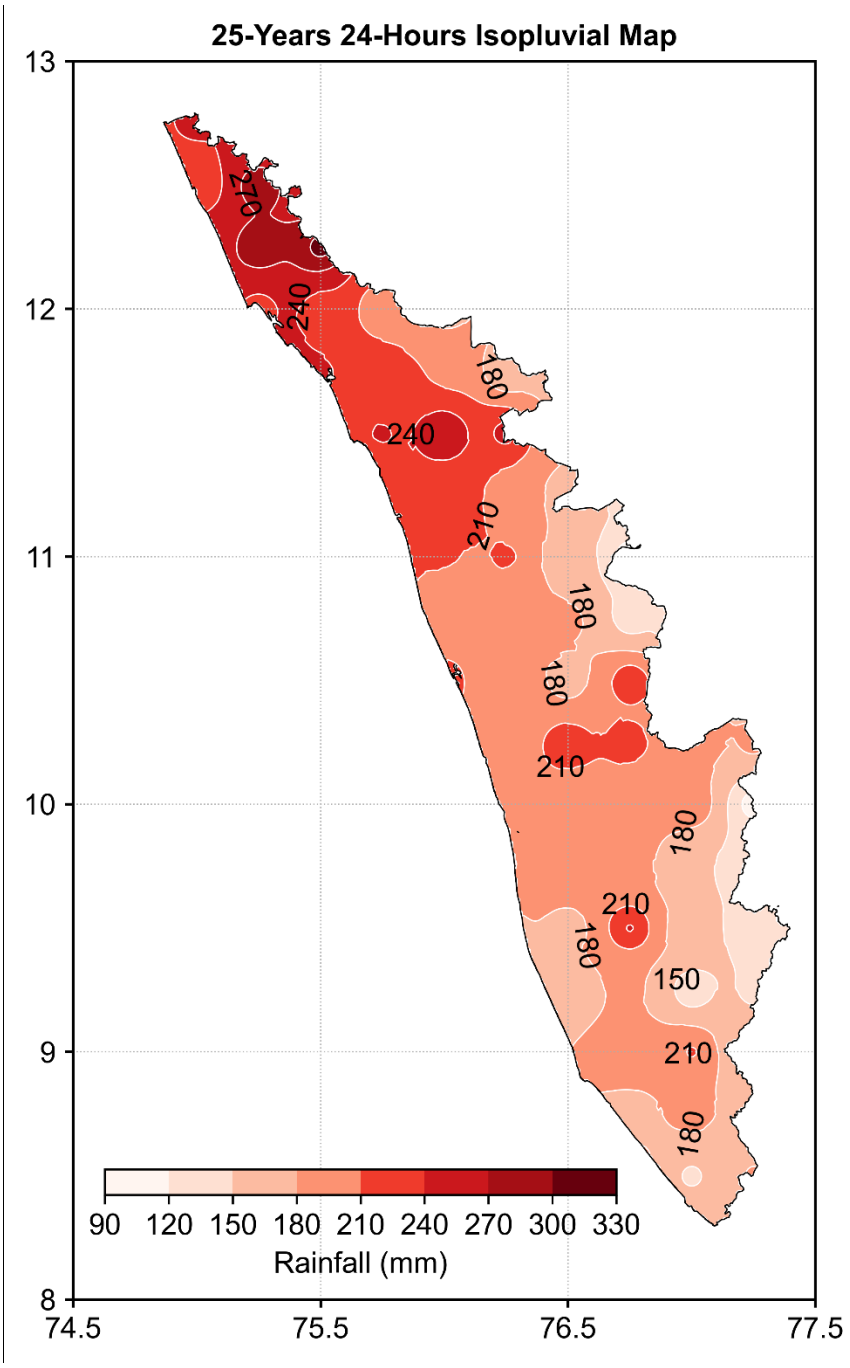


Figure 6: Isopluvial map of Kerala for 25 years return period using gridded rainfall data

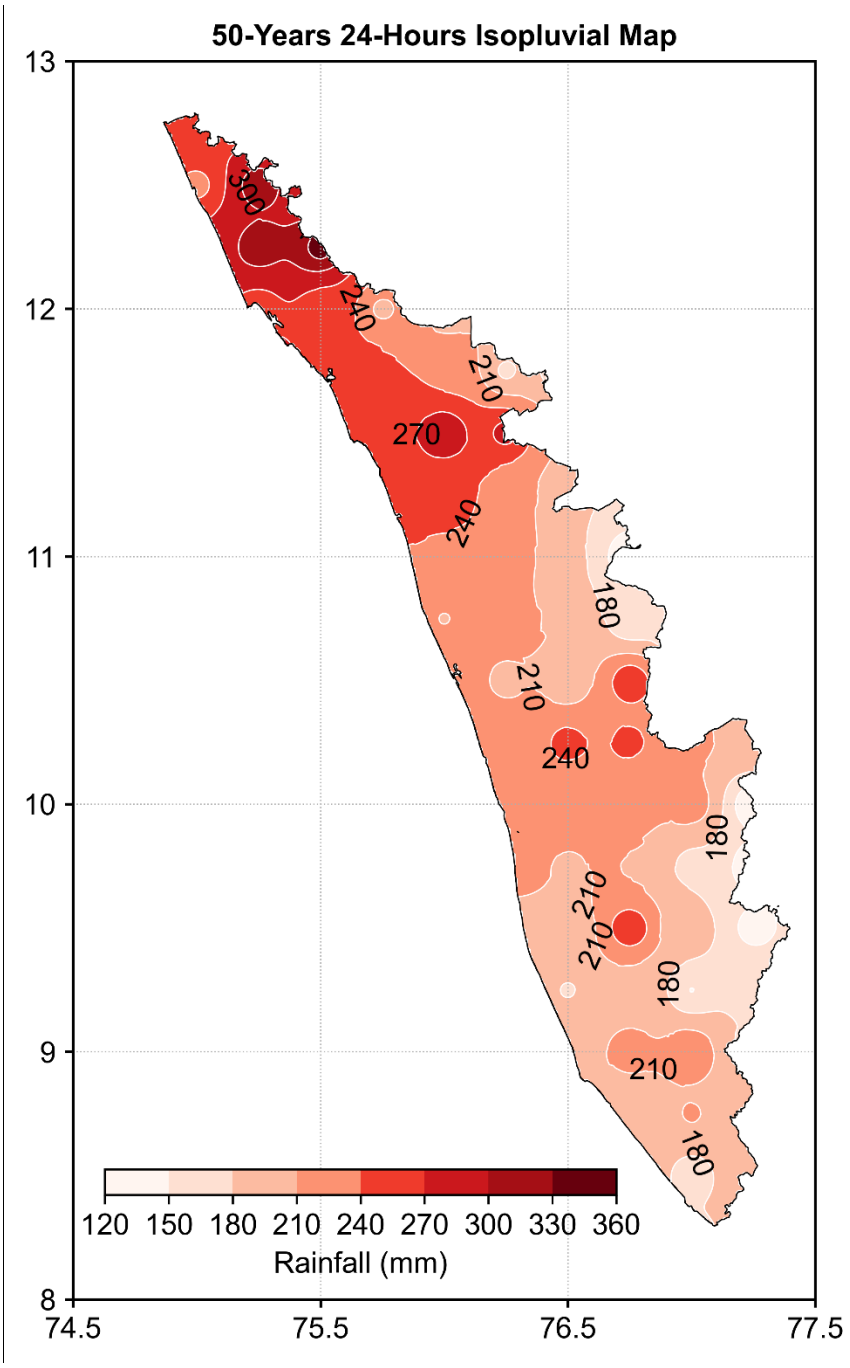


Figure 7: Isopluvial map of Kerala for 50 years return period using gridded rainfall data

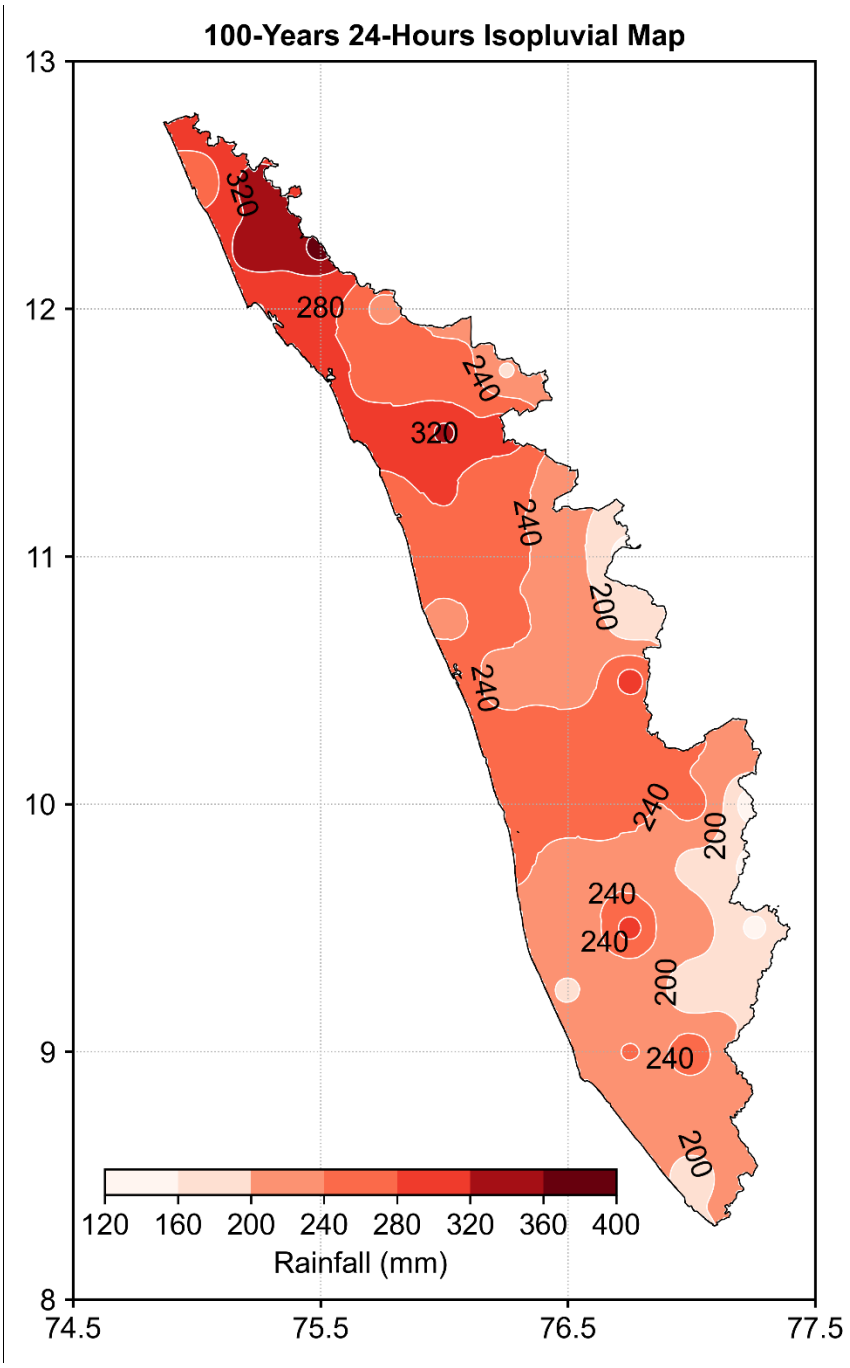
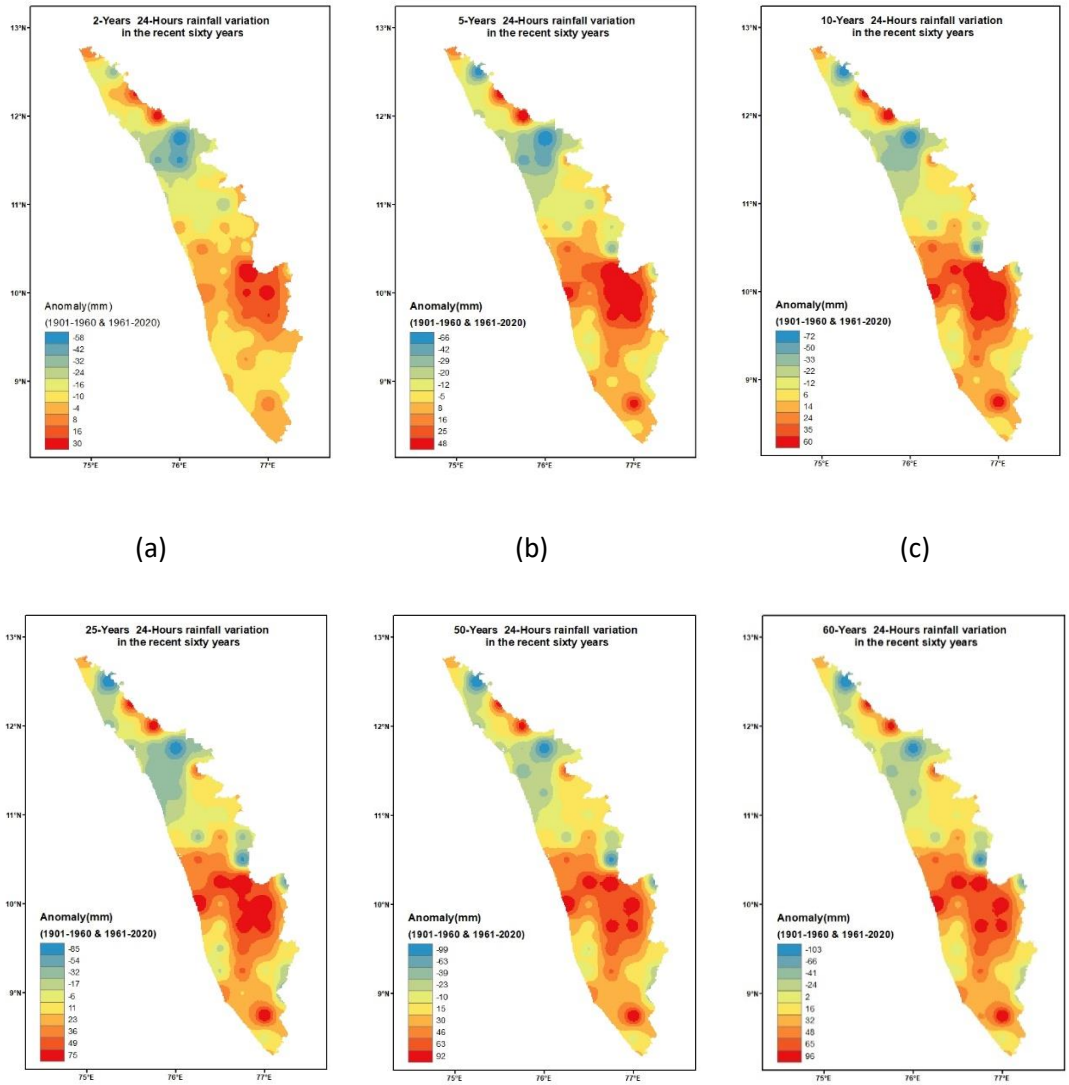


Figure 8: Isopluvial map of Kerala for 100 years return period using gridded rainfall data



(a) (b) (c)

(d) (e) (f)

Figure 9: The spatial plot of anomalies for a) 2-year return period b) 5-year return period c) 10-year return period d) 25-year return period e) 50-year return period f)60-year return period

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