Spatial variability and rainfall characteristics of Kerala

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Geographical regions of covariability in precipitation over the Kerala state are exposed using factor analysis. The results suggest that Kerala can be divided into three unique rainfall regions, each region having a similar covariance structure of annual rainfall. Stations north of 10°N (north Kerala) fall into one group and they receive more rainfall than stations south of 10°N (south Kerala). Group I stations receive more than 65% of the annual rainfall during the south-west monsoon period, whereas stations falling in Group II receive 25–30% of annual rainfall during the pre-monsoon and the north-east monsoon periods. The meteorology of Kerala is profoundly influenced by its orographical features, however it is difficult to make out a direct relationship between elevation and rainfall. Local features of the state as reflected in the rainfall distribution are also clearly brought out by the study.

1. Introduction

Kerala is an elongated coastal state situated in the south-west tip of peninsular India between latitudes 8° 15′N and 12° 50′N and longitudes 74° 50′E and 77° 30′E. Although only 38863 sq.km in area, Kerala is topographically diverse. From the lowlands adjoining the sea on the west, the landscape ascends steadily towards the east to the midlands and further on to the highlands sloping from the Western Ghats, (figure 1). The mountain ranges form a natural wall separating Kerala from the adjoining states and have an average elevation of 1 km, with peaks rising to over 2 km. The highest of these peaks is Anamudi (2695 m) at the crest of Anamalai in Devikulam of Idukki district. A southern off-shoot from Anamalai are the Cardamom hills of south Kerala where the hill station Peerumade (1067 m) is located. To the north of Anamalai are the Nilgiris, whose highest peak is Doda Betta (2640 m). The Ghats are divided into two by the Palghat gap, which is about 24 kms in length. The south-west monsoon current, which brings in most of the annual rainfall, gets a forced ascent at the Ghats and the windward slopes experience very heavy rainfall. However, rainfall is not uniformly distributed on the windward slopes and there are pockets of very heavy rainfall and relatively less rainfall. The coastal region of the state also receives abundant rainfall. The western windward slopes of the hills and mountains receive copious rainfall during the monsoon months, and form the watershed for a large number of rivers.

The principal rain-giving seasons in Kerala are the south-west monsoon (June – September) and north-east monsoon (October – November). The pre-monsoon months (March – May) account for the major thunderstorm activity in the state and the winter months (December – February) are characterized by minimum clouding and rainfall (Ananthakrishnan *et al* 1979). Even though the state does not suffer from large interannual variations in the total seasonal rainfall amount, there is large spatial variation in the rainfall distribution. An earlier study on coherent rainfall patterns over India had grouped Kerala as a whole as one cluster as far as south-west monsoon rainfall is concerned (Gadgil *et al* 1993). In the present paper, an attempt is made to identify homogeneous regions of rainfall in Kerala for targeting particular areas

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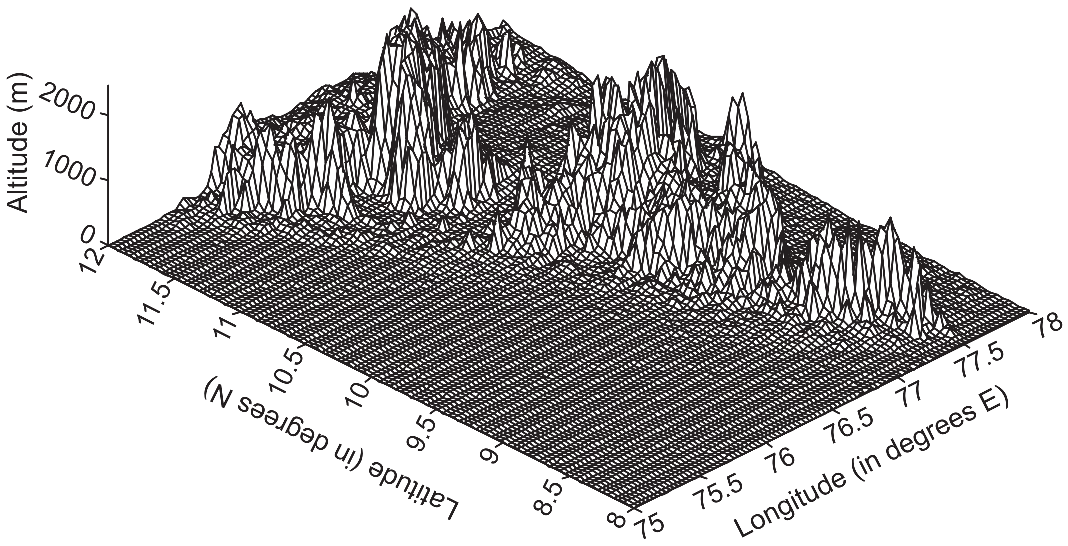

Figure 1. Terrain of Kerala state as obtained from ETOPO 30 sec. data.

for prediction. The study is expected to delineate and emphasize the various boundaries and areas of transition and bring out the regional characteristics of rainfall distribution in Kerala state.

2. Data and analysis

The rain gauge network of Kerala, whose data for 1950–1990 was used in this study, is shown in figure 2. There are 77 well distributed stations over Kerala. The dividing line between south and north Kerala is about 10°N. South Kerala has 38 rain gauge stations and north Kerala has 39 rainfall stations. The details of the stations are given in table 1.

The technique of factor analysis is employed here. Factor analysis is a statistical technique concerned with the reduction of a set of observable variables in terms of a small number of latent factors (Carter and Elsner 1996). The underlying assumption of factor analysis is that there exist a number of unobserved latent variables (or "factors") that account for the correlations among observed variables, such that if the latent variables are held constant, the partial correlations among observed variables all become zero. In other words, the latent factors determine the values of the observed variables. Factor analysis decomposes the variance of a single variable into common variance that is shared by other variables included in the model, and unique variance that is unique to a particular variable and includes the error component. Common factor analysis (CFA) analyzes the *common* variance of the observed variables whereas principal component analysis considers the *total* variance and makes no distinction between common and unique variance.

The "eigenvalues greater than one" rule has been used to select the number of significant factors (Kaiser-Guttman rule). It states that the number of factors to be extracted should be equal to the number of factors having an eigenvalue (variance) greater than 1.0, the rationale for this being that a factor must have variance at least as large as that of a single standardized original variable.

3. Results and discussion

The rainfall stations over Kerala can be grouped into three clusters (3 eigenvalues greater than 1) according to the annual rainfall distribution:

(a) Group I, stations with Ist factor as the primary loading, i.e., Ist factor greater than IInd and IIIrd factors (table 2);
(b) Group II, stations with IInd factor as the primary loading, i.e., IInd factor greater than Ist and IIIrd factors (table 3); and
(c) Group III, stations with IIIrd factor as the primary loading, i.e., IIIrd factor greater than Ist and IInd factor (table 4), The classification of Kerala according to the important factors is given in figure 2.

There are 28 rainfall stations in Group I, which can be again classified into 2 according to the contribution of south-west monsoon rainfall (see regions Ia and Ib in figure 2): Stations receiving more than 75% of the annual rainfall during the south-west monsoon, and stations receiving 65–75% of the annual rainfall during the south-west monsoon season. All these stations are situated north of 10°N (north Kerala) and receive more rainfall than stations south of 10°N (south Kerala). This division into north and south Kerala

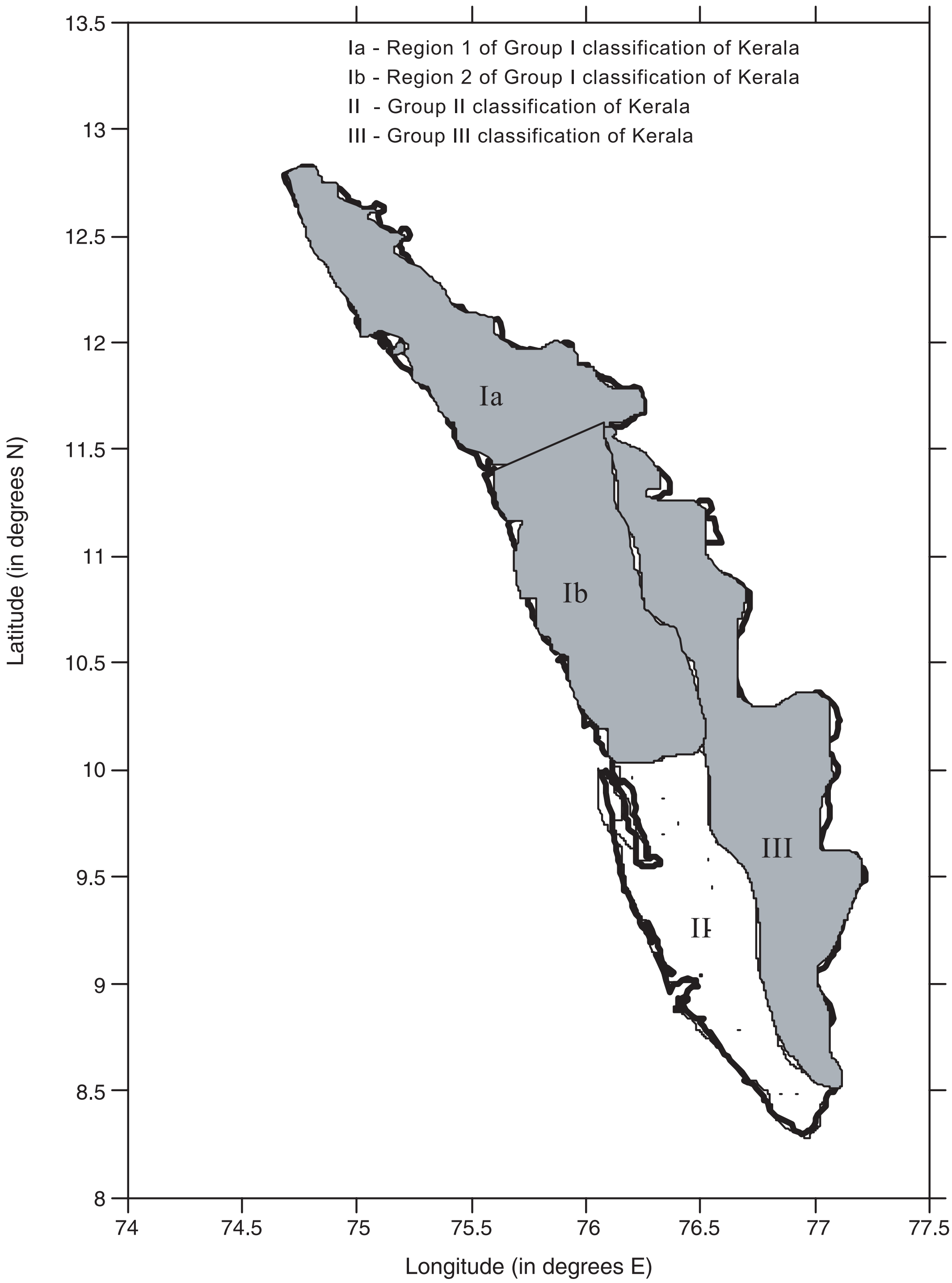

Figure 2. Grouping of rainfall stations into three categories according to factor analysis. Group I can be further subdivided into 2 sub-groups.

arises from the fact that monsoon rainfall progresses from south to north along the west coast of India and there are differences in the rainfall characteristics between the southern and northern parts of the state (Ananthakrishnan and Soman 1988). South-west monsoon (June – September) is the primary rain-giving season and during active spells of the south-west monsoon season, north Kerala is in the cyclonic shear area of the Low level Jet (LLJ) and south Kerala is in the anticyclonic shear zone. Dynamically the areas to the north of the LLJ axis, which have cyclonic vorticity in the boundary layer, can sustain convection forced by the boundary layer friction (Krishnamurthi 1985).

An examination of the monthly rainfall pattern shows that rainfall is highest in June south of 10°N while north Kerala experiences the highest rainfall

Table 1. *List of stations as indicated in figure 2.*

Station no.	Station name	Latitude	Longitude	Altitude
1.	Parasala	8° 20′	77° 09′	65
2.	Neyyattinkara	8° 23′	77° 05′	50
3.	Trivandrum	8° 29′	76° 57′	64
4.	Nedumangadu	8° 36′	77° 01′	100
5.	Attingal	8° 42′	76° 49′	75
6.	Varkala	8° 43′	76° 42′	75
7.	Ponmudi	8° 55′	76° 31′	973
8.	Paravur	8° 47′	76° 40′	40
9.	Nilamel	8° 34′	76° 57′	10
10.	Quilon	8° 53′	76° 36′	8
11.	Aryankavu	8° 59′	76° 10′	240
12.	Punalur	9° 00′	77° 17′	45
13.	Kottarakara	9 01′	76° 46′	18
14.	Karunagappily	9 04′	76° 32′	18
15.	Adoor	9° 09′	76° 44′	121
16.	Kayamkulam	9° 11′	76° 30′	5
17.	Konni	9° 13′	76° 51′	175
18.	Mavelikara	9° 15′	76° 32′	10
19.	Haripad	9° 17′	76° 27′	12
20.	Chengannur	9° 19′	76° 37′	45
21.	Ambalapuzha	9° 23′	76° 22′	16
22.	Thiruvalla	9° 23′	76° 33′	50
23.	Changanassery	9° 27′	76° 33′	45
24.	Chinnar	9 52′	77° 06′	50
25.	Alapuzha	9 33′	76° 25′	2
26.	Velloor	9° 32′	76° 58′	870
27.	Pirmedu	9° 34′	76° 59′	950
28	Kottayam	9° 35′	76° 32′	30
29.	Kumali	9° 35′	77° 10′	1100
30.	Palai	9° 36′	77° 09′	274
31.	Ettumanur	9° 40′	76° 34′	823
32.	Cherthala	9° 42′	76° 20′	10
33.	Vandanmettu	9° 43′	77° 08′	900
34.	Vaikom	9° 45′	76° 24′	2
35.	Karikode	9° 50′	76° 40′	160
36.	Arukutti	9° 52′	76° 20′	35
37.	Fort Cochin	9 58′	76° 14′	3
38.	Muvattupuzha	9° 58′	76° 35′	40
39.	Neriyanmanglam	10° 03′	76° 43′	45

Table 1. *(Continued).*

Station no.	Station name	Latitude	Longitude	Altitude
40.	Devikulam	10° 04′	77° 06′	1650
41.	Marayur	10° 06′	77° 09′	870
42.	Munnar	10° 07′	76° 21′	1150
43.	Aluva	10° 07′	76° 21′	10
44.	Perumbavur	10° 07′	76° 29′	48
45.	Malayattur	10° 12′	76° 31′	40
46.	Cranganore	10° 13′	76° 12′	175
47.	Parur	10° 09′	76° 13′	45
48.	Mukundapuram	10° 15′	76° 10′	39
49.	Chalakudi	10° 15′	76° 01′	14
50.	Thalappily	10° 04′	76° 15′	20
51.	Parli	10° 48′	76° 33′	76
52.	Thrissur	10° 31′	76° 13′	102
53.	Alathur	10° 38′	76° 33′	65
54.	Chittur	10° 42′	76° 44′	300
55.	Ottapalam	10° 47′	76° 23′	34
56.	Palaghat	10° 47′	76° 39′	95
57.	Ponani	10° 47′	75° 55′	20
58.	Cherplasseri	10° 52′	76° 19′	35
59.	Perinthalmana	10° 58′	76° 14	192
60	Mannarkad	10° 59′	76° 28′	120
61.	Thiruvangadi	11° 03′	75° 55′	43
62.	Mancheri	11° 07′	76° 08′	106
63.	Kozhikode	11° 15′	75° 47′	8
64.	Nilambur	11° 17′	76° 14′	88
65.	Quilandy	11° 27′	75° 42′	58
66.	Vythiri	11° 33′	76° 02′	945
67.	Badagara	11° 36′	76° 35′	45
68.	Kuttiyadi	11° 40′	75° 45′	20
69.	Mahe	11° 37′	75° 47′	8
70.	Thalassery	11° 45′	75° 30′	100
71.	Manathavady	11° 46′	76° 01′	900
72.	Cannanore	11° 52′	75° 22′	18
73.	Irikkur	11° 58′	75° 33′	156
74.	Thaliparambu	12° 03′	75° 21′	110
75.	Payyannur	12° 06′	75° 12′	120
76.	Hosdurg	12° 18′	75° 06′	55
77.	Kasargod	12° 31′	74° 59′	85

Table 2. *Stations with Ist factor as primary loading.*

Station no.*	Station name	Annual rainfall (cm)	SW rainfall (cm)	% SW
68	Kutiyadi	416.61	308.41	74.03
66	Vythiri	395.53	317.15	80.18
65	Quilandi	379.04	289.76	76.45
77	Kasargod	354.81	296.12	83.46
76	Hosdurg	350.99	287.90	82.03
73	Irikkur	344.49	272.80	79.19
69	Mahe	334.84	267.92	80.01
72	Cannanore	333.50	274.10	82.19
70	Thalassery	328.84	257.35	78.26
75	Payyanur	328.38	265.19	80.76
67	Badagara	326.81	258.03	78.96
74	Taliparambu	324.30	264.60	81.59
49	Chalakudi	319.51	230.18	72.04
48	Mukundapuram	313.28	222.37	70.98
52	Thrissur	312.90	226.70	72.45
63	Kozhikode	307.77	229.53	74.58
46	Cranganore	299.76	204.46	68.21
47	Parur	295.48	199.38	67.48
61	Thiruvangadi	295.37	212.85	72.06
57	Ponani	294.35	200.07	67.97
62	Manjeri	290.34	214.21	73.78
44	Perumbavur	284.15	197.22	69.41
40	Devikulam	278.35	197.61	71.00
50	Thalappily	275.08	200.82	73.01
71	Manathavady	255.42	205.80	80.57
58	Cherplassery	253.53	176.18	69.49
55	Ottapalam	250.33	176.07	70.34
43	Aluva	209.64	144.96	69.15

SW rainfall – South-west monsoon rainfall.
% SW – Percentage of south-west monsoon rainfall to the annual total.
*Station no. as from table 1.

in July. With each surge in the monsoon current, rainfall is more in north Kerala than in the south and the frequency of surges is higher in July than in June. The active spells of monsoon are also more in July and August. Further, under weak monsoon conditions there is divergence over south Kerala causing little or no rain, while there is convergence resulting in rain over north Kerala on many occasions.

South Kerala stations have the second factor as the primary factor and there are 26 stations in Group II. All these stations receive 25–30% of the annual rainfall during the pre-monsoon and north-east monsoon season. Precipitation during pre-monsoon is mainly from thundershowers and there is an increased thunderstorm activity in the southern tip of Kerala state from March onwards increasing progressively with the advance of the season. May makes the maximum contribution to the rainfall of the pre-monsoon period (March – May). The south-west monsoon advances over south Kerala between 11th and 31st May in nearly 50% of the

Table 3. *Stations with IInd factor as primary loading.*

Station no.*	Station name	Annual rainfall (cm)	SW (cm)	% SW	NE (cm)	% NE	Pre (cm)	% Pre
2	Neyyattinkara	160.01	73.40	45.87	46.20	28.87	36.23	22.64
1	Parasala	138.28	61.27	44.31	41.39	29.94	32.08	23.20
3	Trivandrum	168.84	80.81	47.86	47.86	28.34	35.17	20.83
4	Nedumangad	173.67	80.12	46.13	49.86	28.71	40.08	23.08
5	Attingal	174.87	92.17	52.71	42.52	24.32	37.12	21.23
10	Quilon	249.09	130.33	52.32	53.71	21.56	59.30	23.81
9	Nilamel	278.90	145.33	52.11	65.19	23.37	63.80	22.88
6	Varkala	214.44	117.06	54.59	49.81	23.23	45.40	21.17
8	Paravur	174.11	100.03	57.45	35.71	20.51	36.53	20.98
14	Karunagapilly	249.09	146.68	58.89	50.64	20.33	48.11	19.31
13	Kottarakara	230.65	131.86	57.17	50.73	22.00	44.72	19.39
16	Kayamkulam	229.80	138.76	60.39	47.12	20.50	40.16	17.47
21	Ambalapuzha	287.92	172.86	60.04	58.13	20.19	51.37	17.84
19	Haripad	305.21	186.11	60.98	59.63	19.54	54.65	17.90
25	Alapuzha	300.42	181.94	60.56	58.96	19.63	53.45	17.79
15	Adoor	241.79	140.50	58.11	49.62	20.52	46.53	19.24
20	Chengannur	316.40	192.97	60.99	59.14	18.69	59.01	18.65
18	Mavelikara	285.39	173.27	60.71	55.09	19.30	52.40	18.36
36	Arukutti	317.01	201.89	63.69	51.53	16.25	60.53	19.09
32	Cherthala	286.88	180.98	63.08	55.65	19.40	46.05	16.05
22	Thiruvalla	279.04	176.91	63.40	50.78	18.20	47.11	16.88
28	Kottayam	306.87	191.31	62.34	57.10	18.61	54.10	17.63
23	Changanssery	274.66	176.30	64.19	50.70	18.46	44.11	16.06
31	Ettumanur	171.80	107.71	62.69	31.47	18.32	31.04	18.07
37	Fort Cochin	318.18	209.67	65.90	49.49	15.55	52.91	16.63

SW – South-west monsoon rainfall (cm).
% SW – Percentage of south-west monsoon rainfall to the annual total.
NE – North-east monsoon rainfall (cm).
% NE – Percentage of north-east monsoon rainfall to the annual total.
Pre – Pre monsoon rainfall (cm)
% Pre – Percentage of pre-monsoon rainfall to the annual total.
*Station no. as from table 1.

years, and this is a contributory factor for the pronounced rainfall maximum over south Kerala during this season (Ananthakrishnan *et al* 1979).

Most of the rainfall during north-east monsoon is closely associated with the westward passage of storms and depressions, which are remnants of low pressure systems that move into the Bay of Bengal (Das 1995). The tapering shape of the peninsula and the lower elevation of the Western Ghats in the south are the main reasons for rainfall during this season in south Kerala.

The meteorology of Kerala is profoundly influenced by its orography. This is reflected as the third factor in the factor analysis. Of the 77 stations, 23 have this factor as the primary loading. Even though these stations have the third factor as their primary loading, all these stations do not have the same rainfall pattern and can be classified into three groups. There are 8 stations that receive very heavy annual rainfall (> than 336 cm) and are located on the windward slope of the Ghats. On the windward side of mountains,

Table 4. *Stations with IIIrd factor as primary loading.*

Station no.*	Station	Ht. of station (m)	Annual rainfall (cm)	Remarks
39	Neriamangalam	45	450.62	Slope of Western Ghats
27	Peermade	950	391.47	Slope of Western Ghats
7	Ponmudi	1090	391.06	Hill station of Western Ghats
35	Karikode	160	349.65	Slope of Western Ghats
42	Munnar	1150	346.30	Slope of Western Ghats
26	Vellor	870	345.98	Slope of Western Ghats
38	Muvattupuzha	40	339.47	Localised terrain
30	Pala	274	338.82	Slope of WG & elevated
45	Malayattur	40	313.77	Localised terrain
17	Konni	175	312.36	Slope of Western Ghats
60	Mannarghat	120	280.35	Ghat Valley
59	Perinthalmana	192	278.79	Localised terrain
64	Nilambur	88	275.28	Localised terrain
12	Punalur	91	261.29	Slope of Western Ghats
51	Parli	78	234.43	Palghat Gap
11	Aryankavu	240	231.58	Lee slope of ghats
53	Alathur	65	209.64	Palghat Gap
56	Palghat	95	207.59	Palghat Gap
33	Vandanmettu	900	202.79	Ghat Valley
29	Kumily	1100	161.77	Ghat Valley
54	Chittur	300	161.52	Palghat Gap
41	Maryaur	870	128.83	Ghat Valley
24	Chinnar	50	46.71	Lee side of Western Ghats

*Station no. as from table 1.

moist air is forced up the slope, where it cools and condenses, leading to precipitation. These peaks also provide convection points of instability. This instability will be triggered when the orographic lifting is strong enough to force air parcels to ascend to their level of free convection (Lin *et al* 2001). Thus, the heavy rainfall over the windward slopes depends not only on the elevation of the station but also on the wind velocity perpendicular to the mountain range and on the moist static stability.

There is a second group of stations that receive normal annual rainfall and has the third factor as their primary loading factor. The local features of the stations are also significant in this factor. For example, Punalur, a station in south Kerala, is surrounded by rocky terrain on its four sides and this station experiences very high thunderstorm activity.

Stations that lie on the leeward slope of the Ghats and stations situated in the Palghat Gap receive very less mean annual rainfall (< than 224 cm) and load primarily on the third factor. Air flowing across a mountain range will be forced upwards, and therefore it cools and produces local precipitation. When the air reaches the other side of the range, it's been effectively "wrung out" and tends to be dry. This produces a "rain shadow" effect on the lee side of mountains (the side away from the wind direction) where it tends to be dry.

The complex relationship between topography and precipitation in mountainous regions is evident in the pattern of rainfall distribution. A frequency table showing the rainfall and elevation is illustrated in table 5. Stations are classified according to their elevation into 5 groups. The normal rainfall of Kerala for the period of study

Table 5. *Frequency table of rainfall and elevation.*

Altitude (m)	Excess rainfall stations (> 336 cm)	Normal rainfall stations (224–336 cm)	Scanty rainfall stations (< 224 cm)
< 200	8	45	10
201–500	1	1	1
500–1000	4	1	3
1001–1500	1	-	1
> 1500	-	1	-
Total	14	48	15

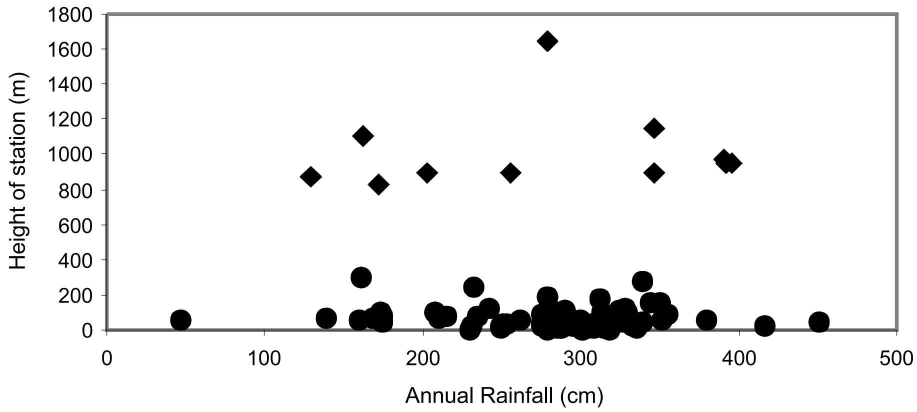

Figure 3. Figure showing the lack of direct relationship between the height of a station and its rainfall.

is 280 cm and stations having rainfall greater than 20% of the state normal (i.e., greater than 336 cm) are classified as excess rainfall stations and those having rainfall less than 20% of the state normal (i.e., less than 224 cm) are grouped as scanty rainfall stations. It can be seen from table 5 that while there are 4 excess rainfall stations with elevation between 500 m and 1000 m 3 stations with the same altitude experiences only scanty rainfall. Figure 3 illustrates the rainfall versus the elevation of each station. It is evident from the figure that it is difficult to make out a direct relationship between elevation and rainfall. There are high altitude stations that receive below normal rainfall. Vythiri (945 m) and Kuttiyadi (20 m) lie on the windward slope of the Western Ghats (figure 4) and receive very heavy rainfall during the south-west monsoon even though both the stations are situated at markedly different elevations. The spatial variability of mean annual precipitation depends upon the topographic factors like exposure of the station to the prevailing wind, elevation, orientation, and slope of the mountain (Basist and Bell 1994). However, Manathavady, a high altitude station (900 m), also situated on the windward slope of the mountains in north Kerala, receives comparatively less rainfall than its neighbouring stations during the monsoon season. Similarly, while Nerimangalam (200 m) receives very heavy rainfall during south-west monsoon, Kumily (1140 m), situated on the windward valley of the Anamalai, receives below normal rainfall during the season (figure 5). Insolation heats the peaks much faster than the valleys below which are shaded by the mountains (Pico 1974). A similar example is of Vandanmettu in Anamalai, a high altitude station (900 m) lying in a valley which receives relatively less of rainfall.

4. Conclusion

Annual rainfall pattern in Kerala may be divided into three unique rainfall regions through factor analysis. Since the leading three eigenvalues are significant with respect to white noise, there exist physical mechanisms underlying these factors. Such a regionalisation will make the description and prediction of rainfall more accurate over the state. Local features of the state as reflected in the rainfall distribution are clearly brought out by the study. The study is, however, limited to the number of rainfall stations available and a better network of stations in the region will reflect more local-scale phenomena. The results are useful for mesoscale and synoptic scale atmospheric modelling.

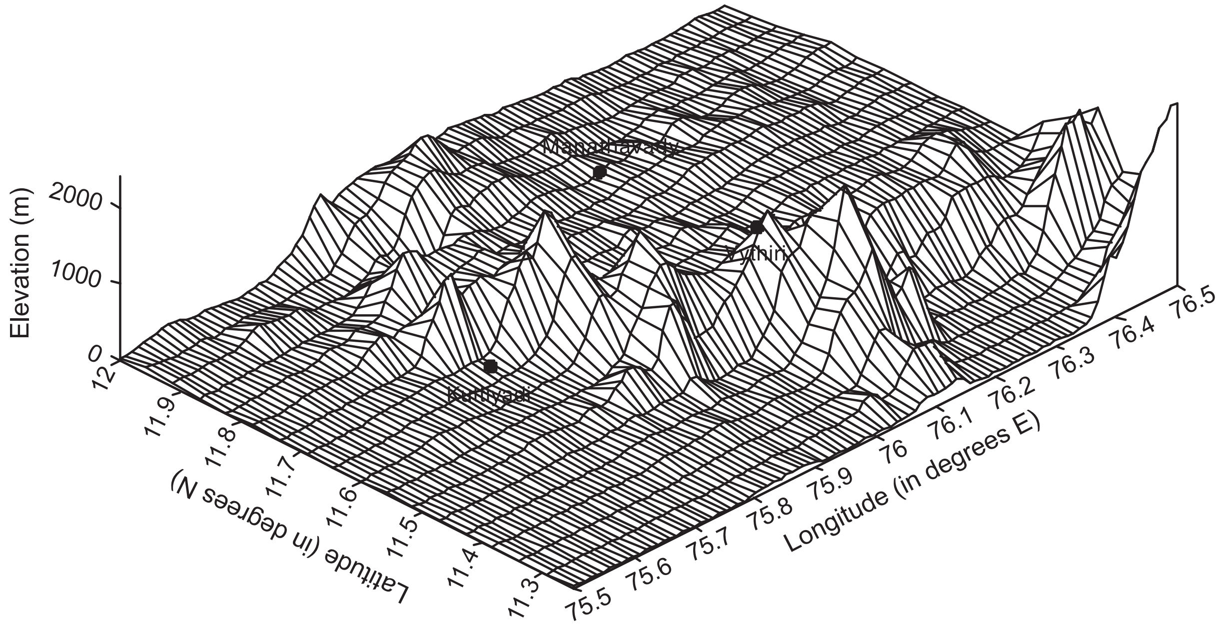

Figure 4. Terrain map of 3 stations north of 10°N, but at different altitudes and receiving varying amounts of rainfall.

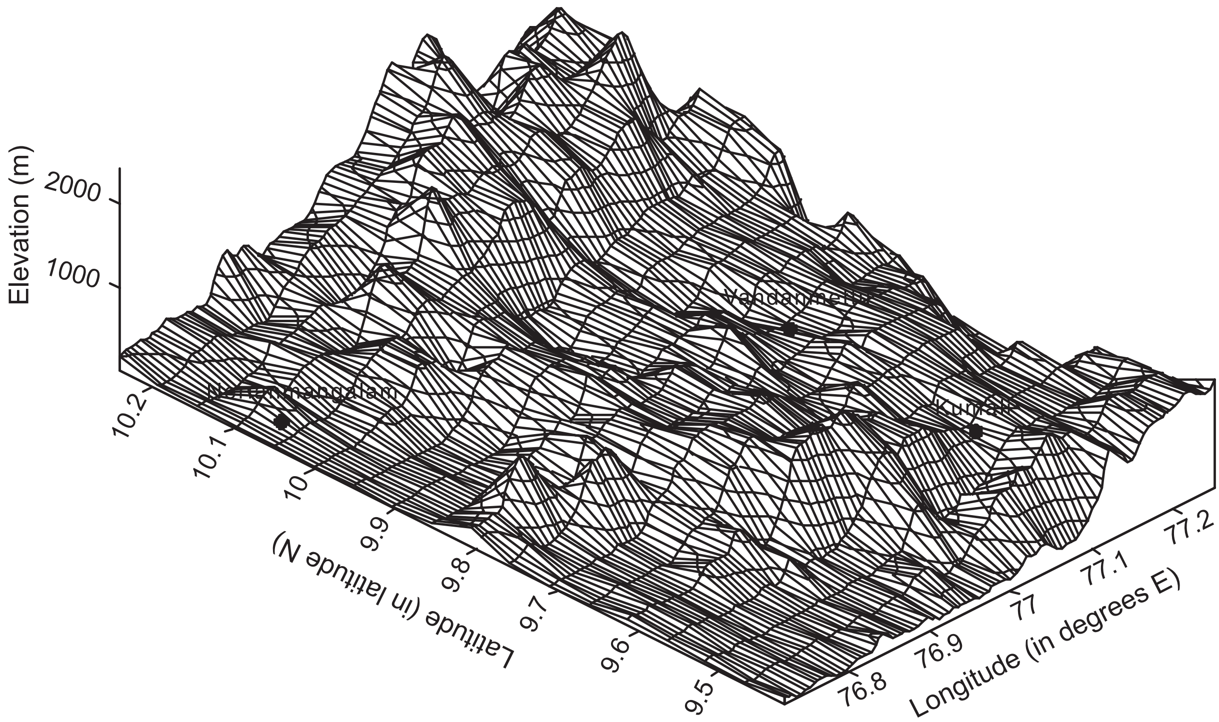

Figure 5. Terrain map of 3 stations south of 10°N, but at different altitudes and receiving varying amounts of rainfall.

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